European Coastal Climate Change Impacts, Vulnerability and Adaptation: A review of evidence

ETC/ACC Technical Paper 2010/7
November 2010

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European Topic Centre
on Air and Climate Change

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Front page picture:
European coastline – top left: bank of Baltic; top-right: Veleka river flowing into Black Sea near Sinemorec, Bulgaria; bottom left: Sussex South Downs way the seven sisters; bottom right: Amalfi coast. Copyright: Shutterstock images

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1. Introduction

1.1. Background to and objectives of the Technical Paper

The purpose of this Technical Paper is to review evidence of the impacts of climate change on Europe's coasts. It focuses on areas that are particularly vulnerable and identifies adaptation policies, measures and actions aimed at increasing their resilience.

The review will contribute to the European Environment Agency's (EEA) forthcoming coastal assessment, which will support the European Commission's (EC) Integrated Coastal Zone Management (ICZM) strategy review. This assessment will take an integrated approach to coastal and maritime space. It will consider development and pollution pressures on coastal and marine areas, particularly ecosystems and their services, and assess their vulnerability to environmental change and the need for adaptation. EEA's 2006 coastal report *The changing faces of Europe's coastal areas* (EEA, 2006) and its 15 priority actions will be used as a baseline for the study. The results will be published in 2012 and information on the state of the environment, policy responses and an overview of best management practices will be provided.

1.2. Policy setting

In Europe, the impacts of climate change in coastal areas and adaptation to associated risks is a key component of the EC's work on ICZM. Since 1996, the EC has been working to identify and promote measures to remedy problems of environmental, socio-economic and cultural deterioration facing many European coasts. From 1996 to 1999, the EC ran an ICZM demonstration programme - an approach to achieving sustainable coastal development in which all policies, sectors and interests are properly addressed through information and communication systems, planning and land management instruments, and institutional coordination mechanisms. The programme led to a consensus on the measures needed to stimulate ICZM in Europe. Based on the experiences and outputs of the demonstration programme, the EC adopted two documents:

- A proposal for a Recommendation on the implementation of ICZM in Europe (COM/00/545; EC, 2000a), which requested that coastal EU Member States produce national ICZM strategies and set out how these should be developed.

- A Communication *Integrated Coastal Zone Management: a Strategy for Europe* (COM/00/547; EC, 2000b), which explained how the EC would promote ICZM.

During 2006 /7, the EC reviewed the implementation of the Recommendation and published a Communication *Evaluation of Integrated Coastal Zone Management (ICZM) in Europe* (COM(2007)308 final; EC, 2007), which presented the conclusions of the evaluation exercise and set out the main policy directions for further promotion on ICZM in Europe. The main information sources for this Communication were the Member States' national reports and EEA's 2006 coastal report.

Climate change is also taking its toll on marine ecosystems. The EC is working to achieve a healthy marine environment and make ecosystems more resilient to climate change through the European Union's (EU) Marine Strategy Framework Directive (2008/56/EC; EU, 2008).

The aim of the Directive is to protect Europe's marine environment, to achieve good environmental status of marine waters by 2020, and to protect the resources upon which marine-related economic and social activities depend.

The Directive established European Marine Regions (and sub-regions) on the basis of geographical and environmental criteria:

Baltic Sea
North-east Atlantic Ocean
- Greater North Sea (including Kattegat and English Channel)
- Celtic Seas
- Bay of Biscay and Iberian Coast
- Macaronesian biogeographic region (waters surrounding Azores, Madeira and Canary Islands)

Mediterranean Sea
- Western Mediterranean Sea
- Adriatic Sea
- Ionian Sea and Central Mediterranean Sea
- Aegean-Levantine Sea

Black Sea

Each EU Member State (cooperating with other Member States and non-EU countries within a marine region) is required to develop a strategy for its marine waters. This must contain a detailed assessment of the state of the environment, a definition of good environmental status, clear environmental targets and monitoring programmes, and proposals for cost-effective remedial measures.

Whilst the Marine Strategy Framework Directive established four sub-regions in the North-east Atlantic Ocean, the OSPAR Convention (1998)[1] identified a fifth: Arctic Waters (Region 1). This sea abuts the EEA member countries[2] of Iceland and Norway, but is not covered in this review. However, a brief description is given here: *Arctic Waters are characterised by extreme seasonal variations in air and water temperature, ice cover and daylight, which have a major influence on ecological conditions. Ice edge plant growth in spring and summer supports large populations of fish and marine mammals, and one of the most important breeding populations of seabirds in the world. Human population density is low, with fishing and petroleum production being the most important activities* (OSPAR, 2010).

1.3. Scientific basis

Messages from the Intergovernmental Panel on Climate Change

In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change cites six policy-relevant messages that are important globally to low-lying coastal areas (IPCC, 2007).

[1] The current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic.
[2] The 32 member countries include the 27 European Union Member States together with Iceland, Liechtenstein, Norway, Switzerland and Turkey.

1. **Coasts are experiencing the adverse consequences of climate change and sea-level rise.** Global sea-level rise is contributing to increased coastal flooding, erosion and ecosystem losses. The effects of rising temperatures include loss of sea ice and associated coastal retreat, and more frequent coral bleaching and mortality. Coasts are also susceptible to extreme events, such as storms.

2. **Coasts will be exposed to increasing risks due to climate change and sea-level rise.** Sea-levels are projected to rise by up to 0.6 m or more and sea surface temperature by up to 3°C by 2100. Other changes are likely to include an intensification of tropical and extra-tropical cyclones, larger extreme waves and storm surges, altered precipitation/run-off patterns and ocean acidification. Sea surface temperature increases of 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality (corals are vulnerable to thermal stress and have low adaptive capacity). Coastal wetland ecosystems, such as salt marshes, are especially threatened where they are sediment starved or constrained on their landward margins. Degradation of coastal wetlands and coral reefs has serious implications for the well being of societies dependent on them for goods and services. Increased flooding and degradation of fisheries, freshwater and other resources could impact hundreds of millions of people, and socio-economic costs on the coast will escalate as a result of climate change.

3. **Impacts of climate change on coasts will be exacerbated by increasing human pressures.** Use of the coast increased dramatically during the 20th Century and is set to continue through the 21st Century. Increasing numbers of people and assets on the coast are at risk from climate change and subject to additional stresses due to land-use and hydrological changes in catchments. Populated deltas and low-lying coastal urban areas are key societal hotspots of coastal vulnerability.

4. **Adaptation on the coast will be determined by constraints on adaptive capacity.** Human populations and natural systems can be significantly influenced by physical exposure to the impacts of climate-related changes. However, lack of adaptive capacity is the most important factor in determining their vulnerability. Adaptive capacity is largely dependent on nations having the necessary resources and capabilities to protect or relocate people who live on vulnerable coasts. The coasts of developing countries are likely to be more vulnerable than those of developed counties due to constraints on adaptive capacity.

5. **Adaptation costs for vulnerable coasts are much less than the costs of inaction.** The costs of adaptation to climate change are much lower than the damage costs without adaptation. Post-event impacts on coastal societies, economies and the environment generally go unrecognised in disaster cost accounting, so the full benefits of adaptation are even larger. Under high sea-level rise and climate change scenarios, some low-lying coastal areas are likely to be rendered unviable by 2100 without adaptation.

6. **Sea-level rise frequently conflicts with human development patterns and trends.** Sea-level rise has substantial inertia and will continue for many centuries beyond 2100. Settlement patterns also have inherent inertia, which presents challenges for long-term coastal planning. Irreversible breakdown of the West Antarctica and/or Greenland ice sheets would significantly increase sea-levels and threaten the viability

of many coastal settlements. The most appropriate response to sea-level rise is, therefore, a combination of adaptation to deal with inevitable impacts and mitigation to stabilize climate so that longer-term impacts remain at a manageable level.

Sea-level rise and coastal flooding

In north-west Europe, the North Atlantic Oscillation (NAO) influences coastal climates, winter wind speeds and patterns of storminess and coastal flooding. The NAO also has a strong influence on sea surface height and the geographic distribution of sea-level rise on Europe's Atlantic coasts.

Wind-driven waves and storms are the primary drivers of coastal processes on many European coasts. Wind speeds and storm intensities are likely to increase in the north-eastern Atlantic and decline eastwards into the Mediterranean by the 2030s, but with localized increases in storminess in parts of the Adriatic, Aegean and Black Seas (IPCC, 2007). There could also be fewer storm surges in the Baltic and southern North Sea by the 2080s (IPCC, 2007). However, those that do occur are likely to be more extreme, with higher wave heights, leading to erosion and flooding in estuaries, deltas and embayments.

Global mean sea-level is projected to rise by 0.18 to 0.59m by 2100 (IPCC, 2007). Regional influences could result in sea-level rise in Europe being as much as 50% higher than global estimates. The impact of the NAO and melting of Greenland ice and other ice stores adds additional uncertainty to these figures. Sea-level rise is likely to cause flooding, land loss, destruction of buildings and infrastructure, and salination of groundwater on Europe's coasts.

Isostatic crustal movement is a crucial component of sea-level rise in Europe, and is varies spatially due to the differing extent of European ice cover during the Holecene. Vertical land movements resulting from glacial isostatic adjustment, tectonics, subsidence and sedimentation influence local sea-levels and affect global mean sea-level through alteration of the shape and hence volume of ocean basins (Bindoff, 2007).

The continued decline in isostatic uplift of formerly glaciated coastlines is bringing many areas within the range of sea-level rise; the Baltic and Arctic coasts, for example, are likely to be at increased risk of flooding and coastal erosion after 2050 (IPCC, 2007). In areas of coastal subsidence or high tectonic activity, such as the Mediterranean and Black Sea regions, climate-related sea-level rise could significantly increase potential damage from storm surges and tsunamis.

Coastal flooding due to sea-level rise could annually affect areas with high population densities in the southern North Sea and coastal plains and deltas of the Mediterranean and Black Sea by the 2080s (IPCC, 2007). Around 20% of existing coastal wetlands may also be lost. Although the degree of coastal erosion that may result from sea-level rise is very uncertain, adaptation strategies for low-lying coasts have to address sediment loss from marshes, beaches and dunes.

Messages from the Millennium Ecosystem Assessment

Coastal ecosystems are diverse, highly productive, ecologically important and extremely valuable for the services that they provide. Humans have been a natural component of coastal ecosystems for thousands of years. However, dependence on and exploitation of these systems has greatly increased in the last centuries, with impacts having become so severe in the last few decades that their productivity and functioning has been altered. The Millennium Ecosystem Assessment identified 10 key messages in relation to coastal ecosystems and the services that they provide (MA, 2005). Whilst these are drawn from a global assessment, they nonetheless have considerable relevance to Europe.

1. **Coastal ecosystems are among the most productive yet threatened systems in the world.** These ecosystems are experiencing some of the most rapid environmental changes. Coastal wetland loss, for example, has in some places reached 20% annually.

2. **Coastal ecosystems are experiencing growing population and exploitation pressures.** Nearly 40% of the world's population live within 100 km of the coast. Coastal populations are increasing rapidly and their densities are almost three times that of inland areas.

3. **Coastal communities establish near ecosystems that provide the most services.** Over 70% of coastal populations live within 50 km of estuaries. However, many of these ecosystems are unprotected or marginally protected and their services often vulnerable.

4. **Human pressures on coastal resources are compromising many ecosystem services.** Coastal fisheries deplete fish stocks and cause habitat damage. Over-exploitation of other resources (e.g. construction sand) also undermines the functioning of these ecosystems.

5. **The greatest threat to coastal ecosystems is development-related loss of services.** Urban, industrial and commercial development, engineering works, and some fishing practices cause widespread destruction of coastal habitats, increased coastal erosion and flooding, and declines in water quality.

6. **Degradation of coastal ecosystems is a severe problem.** Despite human activities increasing sediment loads in rivers, reservoirs and water diversion schemes are causing a net reduction in delivery to the coast. A doubling of nitrogen loading in the last century has resulted in eutrophication driving irreversible changes in coastal ecosystems.

7. **The health of coastal ecosystems is intimately linked to that of adjacent systems.** Land-based sources of pollutants account for over 75% of coastal pollution. These are delivered to coastal ecosystems by rivers, from run-off, and through atmospheric deposition.

8. **The well being of people living on the coast is higher than those living in inland areas.** However, coastal populations are at risk of having their well being severely compromised, as many degraded coastal ecosystems are close to their thresholds for healthy functioning and also vulnerable to sea-level rise, erosion, and storm events.

9. **Conflicts exist within coastal ecosystems and between these systems and inland areas.** Activities within coastal ecosystems, such as developments that bring short-term economic benefits, often incur longer-term costs as regulating and provisioning

services are lost. Activities outside coastal areas, such as diversion of water for agriculture, can reduce flow to estuaries and threaten coastal ecosystems.

10. **Management of coastal systems to maxi mize the supply of services has been inadequate.** However, some negative trends are slowing and degradation can be halted with policy reform and the integration of management across sectors. Watershed management, marine protected area networks, comprehensive ocean zoning and restoration of coastal habitats are all necessary elements of effective coastal management.

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2. Synthesis

The European Marine Regions (and sub-regions) used to categorise this review of evidence on impacts, adaptation and vulnerability of Europe's coast are based on the EU's Marine Strategy Framework Directive (2008/56/EC; EU, 2008) for the exception of the Adriatic, which for ease of reporting purposes in this technical paper has been combined with the Ionian and Central Mediterranean Sea. The locations of the European Marine Regions are outlined in the figure below (Figure 1).

Figure 1 Location of European Marine Regions and sub-regions (as defined by the Marine Strategy Framework Directive 2008/56/EC) (source: Google Earth, 2010)

Number	European marine regions and sub-regions
1	**Baltic Sea**
2	**North-east Atlantic Ocean: Greater North Sea**
3	**North-east Atlantic Ocean: Celtic Seas**
4	**North-east Atlantic Ocean: Bay of Biscay and Iberian Coast**
5	**North-east Atlantic Ocean: Macaronesian biogeographic region**
6	**Mediterranean Sea: Western Mediterranean Sea**
7	**Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea**
8	**Mediterranean: Aegean-Levantine Sea (Eastern Mediterranean)**
9	**Black Sea**

2.1. Key messages from across the European Marine Regions

Climate change impacts and vulnerabilities

The following climate-related impacts, when coupled with the cumulative effects and interactions of climate change with other human pressures (e.g. pollution, over fishing, damage and loss of habitats), will render many coastal systems in European marine basins vulnerable to impact, particularly where there is insufficient planning control or regulation of adverse human influences:

- Changing precipitation patterns
- Changing sedimentary regimes and loads
- Rising sea levels and more storm surges
- Increasing air and sea temperatures
- Changing river and sea water quality.

The key vulnerable areas include low-lying deltas, lagoons, tidelands and islands. These areas are often close or home to major population and economic centres, including cities such as London, Rotterdam and Venice. Here, industry, urban development and infrastructure are particularly vulnerable to sea-level rise, storms and floods. Many low-lying coastal areas also have high biodiversity value and the risk from climate change is loss of the very habitats and ecosystems services that protect urban and agricultural areas further inland from coastal changes. Tourism and human health are also likely to be vulnerable to climate change and associated impacts in these areas.

The vulnerability of marine ecosystems may be higher than anticipated. Current understanding of the impacts and adaptive capacity of marine systems is less advanced than that of land-based systems. However, fisheries (an economic sector that relies on the resilience of the marine ecosystem) could become vulnerable as human activities and climate change affect the structure and distribution of fish stocks.

Climate change adaptation

At the EU level, the need for adaptation was initiated through the wide-ranging consultation on the Adaptation Green Paper (2007) and the subsequent launch of the White Paper on Adaptation to Climate Change (2009). One of the four pillars of the White Paper is to mainstream adaptation by integrating it into EU policies and statutory instruments for different sectors (Table 1).

Table 1 Overview of main EU instruments facilitating marine and coastal adaptation to climate change (source: OSPAR, 2009).

EU instruments	What they regulate
EU White Paper on Adapting to Climate Change (COM(2009) 147/4_	Framework for adaptation measures and policies to reduce the EU's vulnerability to the impacts of climate change
Marine Strategy Framework Directive (2008/56/EC)	'Good environmental status' of the marine environment
Water Framework Directive (2000/60/EC)	'Good ecological status' of coastal and transitional waters
Floods Directive (2007/60/EC)	Assessment and management of flood risks
Integrated Coastal Zone Policy (COM/2000/547)	Integrated planning and management of human uses of the coastal zone
Birds (79/409/EC & 2009/147/EC) and Habitats (92/43/EEC) Directives	Cornerstones of Europe's nature conservation policy. Protection of bird species and habitats in Europe, including marine

The EEA keeps a regularly updated online overview of progress towards the development and implementation of national adaptation strategies (EEA, 2010). To date, 11 European countries (Denmark, Finland, France, Germany, Hungary, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom) have adopted national adaptation strategies, while several others are expected to adopt such a strategy in the next few years (Austria, Estonia, Ireland, Latvia and Switzerland by 2011, and Belgium by 2012). Their development depends on the magnitude and nature of the observed impacts, assessments of current and future vulnerability and the capacity to adapt. In addition, countries have also submitted information on adaptation plans in their 5th National Communication to the UNFCCC (due on 1 January 2010) (Isoard, in press).

Examples of the types of adaptation measures and actions that have resulted from the implementation of national adaptation strategies across Europe include:

- Improvements to or installation of coastal defences/flood barriers/drainage dikes
- Adaptation of conservation management of ecosystems and their services
- Adaptation of agriculture and water management
- Integration of climate change into spatial and urban planning
- Implementation of beach nourishment schemes
- Improvements in the climate change knowledge base.

2.2. Key messages from w ithin the Euro pean Marine Regions and sub-regions

As each Marine Region and sub-region varies in its human and physical geography, and level of progress in adaptation, specific key messages from each are outlined below.

2.2.1. Baltic Sea

Key messages on climate change vulnerabilities for the Baltic Sea

- The potential loss of marine ecosystems and biodiversity due to climate change is likely to be a key issue for the Baltic Sea region.
- The most imminent problems that climate change will cause in the Baltic Sea Region, especially as the concentration of large parts of the population and many larger cities are on the coast, are changes in the occurrence of floods (river floods as well as storm surges) and sea-level rise caused by climate change as well as impacts on water availability and quality can be expected to become imminent (BaltCICA, 2010).

Key messages on climate change adaptation for the Baltic Sea

- Almost all Baltic countries have (Denmark, Finalnd and Germany) or are currently developing climate change adaptation strategies (Estonia, Latvia and Lithuaina) in which coastal zones are briefly considered.
- To date, these are predominantly high level, without concrete implementation plans or dedicated financial resources.
- An exception is Poland, which has implemented coastal protection measures since 1985 and within these has recently taken climate change into account.
- Finland developed a National Adaptation Strategy in 2005, which includes actions relevant for the coastal zones and devotes much attention to co-ordinated land use planning in relation to climate change (EC, 2009).
- In the Baltic Sea region, most countries implement accommodation and retreat measures in the coastal zone by means of spatial planning regulations.
- Coastal protection measures against flooding, erosion and extreme weather events are only undertaken when there is a concrete need for them.
- No (additional) expenditure has been made to date or will be made in the near future on climate change adaptation at the Baltic coast.
- Most countries on the Baltic still consider climate change to be too uncertain for proactive investment. Moreover, when measures are taken, priority is given to accommodate actions in regional development and building regulations, which do not appear as a cost as they are not usually monetised.
- The Baltic Sea Action Plan was initiated by HELCOM (the governing body of the Helsinki Convention). Through the action plan, HELCOM hopes to improve the capacity of the Baltic marine environment to cope with the stresses of climate change.
- In June 2009, the European Commission adopted an EU strategy for the Baltic Sea region (COM (2009)248). This strategy acknowledges that climate change adaptation is a growing challenge in the area and proposes in its related action plan to "establish a regional adaptation strategy at the level of the Baltic Sea region". Such action could be seen as a good example of cross-border cooperation between member states of the region.

Key messages on climate change evidence gaps for the Baltic Sea

- More evidence is required not only the assessment of the impacts, but also on the development, appraisal and implementation of adaptation measures (structural as well as organisational and institutional measures) (BaltCICA, 2010).

2.2.2. North-east Atlantic Ocean: Greater North Sea

Key messages on climate change vulnerabilities for the North-east Atlantic Ocean: Greater North Sea

- The Greater North Sea is vulnerable to climate change due to the geographical characteristics, demographic and economic concentration in its bordering areas, and high nature value.
- Climate change affects the Greater North Sea coast in various ways: directly through increasing storm surges, increasing (water) temperature, and ocean acidification; indirectly through sea-level rise, salinisation and loss of property and infrastructure.
- These impacts on coasts will continue to be exacerbated by projected climate change.

Key messages on climate change adaptation for the North-east Atlantic Ocean: Greater North Sea

- Numerous research projects have been initiated to assess the vulnerability of the Greater North Sea in more detail and to define appropriate adaptation options.
- Various initiatives at national, EU and international level help to define adaptation strategies and options for the Greater North Sea. As such, its coastal areas have become the focus for testing new national regulations, EU directives and international treaties and programmes concerning the coastal environment.
- Most countries bordering the Greater North Sea (Denmark, France, Germany, The Netherlands and the UK) have launched national climate change adaptation strategies in recent years (PEER, 2009; OSPAR, 2009).
- Coastal defence has been a key issue in defining precise measures.
- A number of coastal defence measures are available and these can be implemented in different ways, however beach nourishment is often cited because of its cost-effectiveness, even under extreme increases in sea-level (PBL, 2007).

Key messages on climate change evidence gaps for the North-east Atlantic Ocean: Greater North Sea

- Appropriate and tested adaptation options for the Greater North Sea region.
- Ways to facilitate enhanced co-operation and economic burden-sharing between parties for research and planning of coastal adaptation, especially where larger coastal areas spanning national boundaries are affected (OSPAR, 2009).

2.2.3. North-east Atlantic Ocean: Celtic Seas

Key messages on climate change vulnerabilities for the North-east Atlantic Ocean: Celtic Seas

- Low-lying sedimentary coasts in Ireland are more vulnerable to an increase rate of localised coastal erosion from sea-level rise, increased storminess and wave height (Lozano *et al.*, 2004; OSPAR, 2009).
- One of the most vulnerable sectors in Ireland is aquaculture because salmon production is near its southern range of species distribution (Sweeney *et al.*, 2003).
- 25% of Ireland's population live in coastal municipalities (Sweeney *et al.*, 2003).
- Considerable investment in transport and energy infrastructure has taken place within a few meters of the high water mark (Sweeney *et al.*, 2003).

- Sand dune habitats have been identified as critically vulnerable to climate change in Ireland (Sweeney *et al.*, 2003).
- Flooding from climate change is expected to be worse on the urbanised east coast of Ireland, especially at the three major cities of Dublin, Cork and Galway (Sweeney *et al.*, 2003).
- A tool developed to assess estuaries for vulnerability to sea-level rise has shown that deep, narrow estuaries are likely to be more resilient than shallow, coastal estuaries in England and Wales (Environment Agency, 2010).

Key messages on climate change adaptation for the North-east Atlantic: Celtic Seas

- Adaptation policies for those countries with coastline on the Celtic Sea include two adopted (England and Scotland), and three in preparation (Ireland, Wales, Northern Ireland).
- In the UK the Climate Change Act 2008 provides a legally binding framework to tackle the dangers of climate change and for building the UK's ability to adapt to climate change. It requires public sector bodies and statutory undertakers to report on climate risks to and responses for their work.
- Guidelines in England and Wales have been have been issued recommending sea-level rise be taken into account in flood and coastal defence project grants aided by the Department for Environment, Food and Rural Affairs (Defra) (Defra, 2006).
- Defra’s departmental adaptation section of their climate change plan (Defra, 2010) identifies five actions Defra will take in England and Wales to address flooding and coastal erosion, and a further nine adaptation actions in relation to Ocean and Seas.
- Scotland's Climate Change Adaptation Framework was published in December 2009 (Scottish Government, 2009). 10 adaptation actions are identified and assigned to responsible parties under marine and fisheries, and one action under biodiversity and ecosystem resilience is related to vulnerable coasts in Scotland.
- The Republic of Ireland has a national adaptation strategy in preparation. Both the Welsh Assembly Government and Government of Northern Ireland have begun work on their own action plan for adapting to climate change.

2.2.4. North-east Atlantic Ocean: Bay of Biscay and Iberian Coast

Key messages on climate change vulnerabilities for the North-east Atlantic Ocean: Bay of Biscay and Iberian Coast

- The level of vulnerability of coastal ecosystems and societies differs depending on local characteristics.
- Low-lying areas are more vulnerable to sea-level rise, storms, floods and erosion.
- There will be a loss of valuable ecosystem services, especially those of those habitats (saltmarsh, sand dunes and coral reefs) that provide protection at the coast.
- The cumulative effects and interaction of climate change with other human pressures (pollution, over fishing, damage and loss of habitat) will render coastal systems more vulnerable.

Key messages on climate change adaptation for the North-east Atlantic Ocean: Bay of Biscay and Iberian Coast

- National adaptation strategies have been adopted by countries (France, Spain and Portugal) bordering the Bay of Biscay and Iberian Coast. These strategies are land

and coastal defence based, focusing on responding to sea-level rise and coastal erosion, not on the marine environment which is more challenging.
- A better understanding of local risk is essential for the development of operational adaptation strategies, where local risk assessments are required that take account of spatial development and changes in coastal protection.
- Adaptation to coastal vulnerability will require transboundary co-ordination and co-operation where sea-level rise and coastal erosion span national borders (OSPAR, 2009). Some EU policy instruments are already in place to aid adaptation are already in place – EU adaptation White Paper, Marine Strategy Framework Directive (2008/56/EC), Water Framework Directive (2000/60/EC) and Integrated Coastal Zone Management.

Key messages on climate change evidence gaps for the North-east Atlantic Ocean: Bay of Biscay and Iberian Coast
- Evidence on vulnerability of marine areas.
- Experience of adaptation in the marine environment.
- Few marine adaptation tools available.
- Currently has to rely on existing and new policy frameworks.

2.2.5. North-east Atlantic Ocean: Macaronesian biogeographic region

Key messages on climate change vulnerabilities for the North-east Atlantic Ocean: Macaronesian biogeographic region
- Shifts in community balance are occurring where climate change is modifying composition and abundance of fish stocks, and sea water acidification is dropping pH levels constraining coral reef growth and regeneration. Over fertilization of the oceans is also promoting marine algae growth around the Canaries, Madeira and the Azores and is linked to increased fish and bid population mortality and therefore reduced economic activity in fishing and tourism.
- Socio-economic vulnerability to heatwaves is apparent in the Macaronesian. Their geographical location give extensive long periods of hot weather now, and under heatwave conditions this put the resident and tourist population at risk from associated health issues – heat-related illness, an increase in tropical diseases, increased wind borne dust causing allergies and respiratory problems.
- There is a dependence on coastal aquifers which are at risk of salt water intrusion in Macaronesia, making the island's drinking water vulnerable.

Key messages on climate change adaptation for the North-east Atlantic Ocean: Macaronesian biogeographic region
- National adaptation strategies have been adopted at a policy level by Spain and Portugal but only progress in these countries outermost regions has been made in the Canaries.

Key messages on climate change evidence gaps for the North-east Atlantic Ocean: Macaronesian biogeographic region
- Monitoring and assessment of sea temperature and acidification and the interaction with other human pressures in the Macaronesian will be essential for a better understanding of vulnerable marine ecosystems at the coast.

2.2.6. Mediterranean Sea: Western Mediterranean Sea

Key messages on climate change vulnerabilities for the Mediterranean Sea: Western Mediterranean Sea

- The richness of microclimates in the Mediterranean makes any prediction of biodiversity change at large spatial scales difficult. Indeed, most effects of climate change (or climate anomalies) on marine biodiversity have so far been identified only at regional scales.
- These results indicate that: i) Mediterranean fauna is highly vulnerable to climate change; ii) both structural and functional biodiversity of continental margins are significantly affected by very small temperature changes; and iii) the impact of climate change on marine biodiversity might be irreversible.
- These events indicate that not only coastal ecosystems, but also continental margin ecosystems may experience abrupt climate-driven temperature shifts, which reflect changes in the prevailing climate conditions occurring on a regional scale (Béthoux *et al.,* 1990).
- Many parts of the Western Mediterranean coastline are at risk of flooding and erosion due to rising sea-levels and the increasing frequency and intensity of storm events. Low-lying coasts (e.g. deltas, lagoons, tidelands and some islands) are particularly vulnerable.
- Fisheries could become vulnerable as human activities and climate change affect the structure and distribution of fish stocks.
- In most Mediterranean countries, specialised technical standards and guidelines for the design of coastal defence structures are lacking. Planning measures for land and sea are also failing or do not exist. As a result, investments in protective measures are mainly provided for *ad-hoc* hard defences such as breakwaters and groins, often resulting in mal-adaptation causing further impacts (i.e. increased erosion rates) on other parts of the coastline.
- The protection of coastal zones against freshwater scarcity is, at present, the greatest problem for the Mediterranean region.

Key messages on climate change adaptation for the Mediterranean Sea: Western Mediterranean Sea

- The availability of national (France and Spain are the only two Western Mediterranean Countries with national adaptation strategies) and regional policies and guidelines, and the governance structures put in place to deliver climate change adaptation and coastal zone management, varies considerably between the countries of the Mediterranean.
- Spain is a forerunner in the Mediterranean for adaptation. It published a National Climate Change Adaptation Plan in 2006 and will complete its National Strategy for Coastal Management in 2010; a number of regional strategies have also been prepared.

Key messages on climate change evidence gaps for the Mediterranean Sea: Western Mediterranean Sea

- Mediterranean countries do not take climate change explicitly into account when defining actions to overcome freshwater shortage. It is, therefore, difficult to indicate the extent to which expenditure on freshwater protection is related to climate change or to the increase in demand and over-use of available resources.

2.2.7. Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea

Key messages on climate change vulnerabilities for the Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea

- Climate change is likely to pose major threats to marine biodiversity. One of the vulnerable groups is cetaceans (marine mammals). Their habitat is already limited by prey availability. The additional impacts of climate change can consequently affect the health, physical strength and abundance of the cetacean population. Such incidents have already been observed in the bottlenose dolphins of the Ionian Sea (Gambaiani *et al.,* 2008).
- Several natural systems in Albania are vulnerable to sea-level rise. Losses of wetlands, coastal floodplains and coastal forests are projected (UNDP Albania, 2009). The national parks of Kune-Vain (Lezha District) and Velipoja (Shkodra District) are located along the Drin and Buna river deltas and are particularly vulnerable.
- Fresh water systems and marshes along the Adriatic coast are among the most vulnerable coastal ecosystems in Croatia, particularly the Krka River, Neretva River and Vrana Lake Nature Park. Vrana Lake is the only large swamp on the Adriatic coast; it is a habitat for endangered bird species, and has immense biodiversity and unique scientific and ecological value. It is likely to be inundated by a sea-level rise of 0.5 m.
- As the entire Croatian coast is situated on carbonate rocks and karst habitats – which are rare and extremely vulnerable to physical changes – the management of those ecosystems (which are also connected to fresh water reservoirs) is a top priority for nature protection (UNDP Croatia, 2008).
- A number of commercial fishing ports and fixed marinas are threatened, and a number of beaches may be destroyed or become submerged. Historical centres of coastal towns are just one or two metres above present sea-levels. In Croatia, Zadar, Trogir, Split, Dubrovnik, Stari Grad and many others could be prone to flooding.
- Recreational areas along the Croatian Adriatic Sea and Greek Ionian Sea may be threatened by erosion and/or beach flooding (e.g. the famous and popular Zlatni Rat Beach in Croatia). At the beach of Shengjin, the tourist facilities are all threatened by sea-level rise in the coming 50–100 years.
- In Greece, increases in summer temperatures to above 40°C are expected, which can lead to increased incidences of heat stress and mortality. During high tourism season in Greece, increase in water supply restrictions, combined with increased summer temperatures and heat wave frequencies, forest fires and urban smog are expected to impact the tourism sector negatively.
- The Po delta and Italy's Emiligia-Romagna region, on the western Adriatic coast, is highly vulnerable to flooding due to sea level rise and land subsidence.
- The city of Venice is already highly vulnerable to modest flood events, with peak heights of 1m (Zanchettin *et al.*, 2007). A 1m rise in sea level would also affect large areas around the Po delta, if these areas remain unprotected.

Key messages on climate change adaptation for the Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea

- At the national level, most countries bordering the Adriatic Sea, and the Ionian Sea and Central Mediterranean Sea either have legislation on coastal zone management or have incorporated it in other relevant legislation (Croatia and Montenegro). However, fewer countries (only Greece and Albania) have national climate change strategies or adaptation action plans and/or measures targeted at adaptation.

- There are major constraints to the development of adaptation strategies in Albania and Montenegro. Natural and human systems are already under great pressure and many are highly vulnerable, often beyond their intrinsic capacity to adapt. Climate change adds to existing stresses and the ability of these countries to respond is low. The problems and constraints to adaptation are institutional, technical, methodological and financial in nature and are of considerable concern, as they constrain the complex multi-disciplinary activities and planning schemes necessary for effective adaptation.
- There is a lack of institutional and legal frameworks to facilitate the preparation of national communications and other climate impact, vulnerability and adaptation studies. The limited knowledge and awareness of climate change issues and the need for adaptation amongst stakeholders and the wider public is also a major constraint.

Key messages on climate change evidence gaps for the Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea

- A persistent problem lies in data availability, consistency and transparency. Monitoring of climate and groundwater, and climate forecasting and modelling, are plagued by ongoing human resource constraints, operation problems, out-of-date equipment, and reductions in monitoring networks.
- Basic maps and databases are very old and/or unavailable (e.g. soil maps, vegetation maps, land use maps, etc.). Increased technical capabilities for monitoring and updating basic data sets are required, together with modern assessment tools for almost all vulnerable sectors and training in modern adaptation techniques.
- The most important methodological problems relate to: uncertainties linked with climate change scenarios; lack of finer resolution regional climate models; lack of methods for simulating extreme weather events; lack of socio-economic scenarios for use in vulnerability assessment; lack of models for cost/benefit analysis (uncertainty about the future and about the effectiveness and costs of adaptation options are common obstacles to action); and lack of know-how for implementing new technologies.
- With regard to the coastal areas of Albania and Montenegro, further research is needed to:
  - Evaluate and plan for the potential impacts of coastal flooding associated with sea-level rise
  - Evaluate the impacts of sea-level rise on ground water and water availability
  - Develop climate information services for the tourism sector and promote among stakeholders
  - Assess the suitability of the climate for coastal tourism in 2020, 2050 and 2080
  - Evaluate the impacts of climate change on fisheries and other marine species
  - Develop and transfer adaptation technologies.

2.2.8. Mediterranean Sea: Aegean-Levantine Sea

Key messages on climate change vulnerabilities for the Mediterranean Sea: Aegean-Levantine Sea

- Although sea level rise in the Mediterranean Sea is not expected to be as high as in the oceans, low-lying areas and estuaries, which are the most productive agricultural areas, the location of key urban centres and the focus for tourism, are none-the-less threatened.

- In Turkey, coastal areas at high risk of inundation (elevations of 1 m) include: five major coastal plains on the Levantine coast; five on the Aegean coast; and 2 on the Marmara coast (Demirkesen, 2007).
- Many 'flagship' cultural sites are also expected to be damaged or destroyed by sea level rise and increased wave activity (e.g. the ancient cities Phaselis and Patara). Other historical sites could be buried by active sand dunes; indeed, the ancient city of Pompeipolis [Viransehir] has already lost (UNDP Turkey, 2007).
- Several alien plant and animal species have already been introduced to the Levantine Sea from the Red Sea through the Suez Canal. Known as the Lessepsian migration or Erythrean invasion, the impacts of some of these species has been considerable as they are replacing native species (Galil & Zenetos, 2002).
- A rapid reduction in abundance of the herbivorous sparid (*Salpa salpa)*, a common species throughout the Mediterranean, *has* occurred in the Levantine Sea. It is being replaced with a competitor, *Siganus rivulatus*, which was first recorded in the Levantine in the early 1990s (Baric *et al.,* 2008).
- Red mullet *Mullus barbatus* and hake *Merluccius merluccius* have also been replaced by Red Sea competitors (Por, 1978). More species are expected to migrate from the Adriatic and Black Sea.
- Rain-fed crops are likely to be most vulnerable to climate change and summer crops are likely to be more vulnerable than winter crops due to longer dry seasons. In Turkey, the negative impacts of climate change on the agriculture sector are expected to cause an increase in migration from rural areas to big cities (e.g. Istanbul, Ankara and Izmir).

Key messages on climate change adaptation for the Mediterranean Sea: Aegean-Levantine Sea

- In addition to national scientific research institutes in Greece and Turkey, a number of international institutions can contribute to the development of climate change adaptation activities in coastal zones, both in terms of increasing adaptive capacities and providing appropriate governance structures.
- At the national level, the countries bordering the Aegean-Levantine Sea are addressing the impacts of climate change in the coastal zone (however, only Greece has published a national climate change strategy).
- In Greece, a strategy to cope with the consequences of climate change in coastal zones is already embedded in coastal planning law.
- In Turkey, the Ministry of Environment is planning to establish a coastal zone department. The Authority for the Protection of Special Areas has declared several protection areas in coastal zones and has been developing special environmental programmes.
- A number of research projects and adaptation studies have been carried out in the countries bordering the Aegean-Levantine Sea. Among them there are the following; Disaster Risk Mitigation and Adaptation (AL-DRMAP) to reduce the region's vulnerability and; the *Global Climate Observing System* (GCOS) which developed a Regional Action Plan for the Mediterranean basin in 2006.

Key messages on climate change evidence gaps for the Mediterranean Sea: Aegean-Levantine Sea

- A number of key issues have been identified to address problems of coastal zone management associated with climate change and anthropogenic pressures in countries bordering the Aegean-Levantine Sea (Hallegatte, 2009). These include:
  - Information exchange and technology transfer
  - Additional research: assess impacts and develop and transfer adaptation technologies
  - Other needs: Build/upgrade monitoring/warning systems to assess vulnerabilities of coastal zones and; create integrated impact scenarios for coastal areas.

2.2.9. Black Sea

Key messages on climate change vulnerabilities for the Black Sea

- Intertidal habitats and ecosystems on the Black Sea coast are vulnerable to sea-level rise due to their low tidal range and limited scope for on-shore migration (Alpar, 2009).
- Heavy rain storms and rivers draining into low-lying coastal areas are the main factors affecting coastal flood risk.
- The Black Sea's coastal areas are expected to become increasingly vulnerable to the effects of erosion, partly due to climate change and sea-level rise, but largely due to the lack of effective coastal planning regulations.
- Fishing communities whose markets are based on just a few species are vulnerable to fluctuations in stocks, whether due to overfishing, climate change or other causes.

Key messages on climate change adaptation for the Black Sea

- The Black Sea Commission's first involvement in climate change matters was in October 2008, when it organised a conference aimed at understanding and dealing with the consequences by using science, information technology and policy.
- At national level, institutional, political and financial constraints are among the main handicaps towards taking effective adaptation measures, and no national adaptation strategies have been adopted.
- However, projects to protect coastal areas from erosion are being undertaken in Bulgaria and Romania, although coastal strategies/legislation do not exist in either country.
- Also in Romania, the Danube Delta Biosphere Reserve Authority published a master plan for its protection in 2005.
- In addition, the International Commission for the Protection of the Danube River, which was established to implement the Danube River Protection Convention, works to ensure the sustainable and equitable use of waters and freshwater resources in the Danube River basin.

Key messages on climate change evidence gaps for the Black Sea

- There is a significant lack of data regarding the costs and benefits of adaptation, and uncertainty surrounding future climate impacts.

2.3. Recommendations for further research on European coastal climate change impacts, vulnerability and adaptation

Evidence based recommendations

To address the evidence gaps identified across the European coastal regions the following recommendations are given:

1. Continue to build on and share knowledge on the evidence base of developing, appraising, testing, costing and implementing coastal adaptation measures that acknowledge the uncertainty in climate models and emissions scenarios.
2. Identify barriers and solutions on ways to fund and share trans-boundary coastal adaptation research and planning.
3. Identify barriers in progressing, and the tools needed for, marine ecosystem impacts, adaptation and vulnerability assessments.
4. More support and research is needed on marine ecosystem vulnerability (particularly sea temperature and acidification) in Europe's outermost regions.
5. Implement ways to better share what knowledge there is on adaptation options for the marine environment
6. Identify barriers, funding and technical capability solutions, to enable Eastern Mediterranean countries to build an up to date, consistent and transparent evidence base to address data suitability and availability issues.
7. Identify the impacts of climate change adaptation measures on the achievement of Water framework Directive objectives in coastal areas, including transitional waters.

Recommendations for further work by the EEA in the area of coastal climate change impacts, vulnerability and adaptation

This Technical Paper provides an overview of evidence, drawn from the scientific literature and policy publications, of some of the key issues relating to climate change impacts, vulnerability and adaptation on European coasts. The following recommendations build on the overview and will be important next steps in further developing this area of work and informing EEA's 2012 coastal report:

- Better use should be made of Member State reporting, indicators and cooperation to comprehensively assess the state of Europe's coastal and marine environment in the context of climate change impacts, vulnerability and adaptation.
- Some of the examples and case studies cited in this review are based on only a small number of, or even single, references. Whilst these might provide only partial evidence and insights (e.g projected sea-level rise based on one specific model), they can nonetheless be used as starting points for further investigation.
- The synergies and conflicts between coastal and maritime sectors (e.g. aquaculture, fisheries, ports/harbours/marinas, tourism, energy etc) and their responses to climate change should be explored more systematically within all European Marine Regions.
- The Adriatic Sea exhibits very specific traits and trends, and should therefore be considered separately in any further work.

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3. Baltic Sea

The Baltic Sea is a 'European Marine Region', established under the EU's Marine Strategy Framework Directive (2008/56/EC) (EU, 2008) to protect the resources upon which marine-related economic and social activities depend (Figure 2).

Figure 2 Map of the Baltic Sea area (source: HELCOM)

3.1. Physical geography and oceanography

The Baltic Sea is a small, semi-enclosed brackish water basin (Figure 2). It is connected to the North Sea by a narrow entrance - the Danish Straits - that limits the exchange of water between the two seas. The Baltic Sea is characterised by closed circulation, low salinity and low biodiversity. Its waters are a mixture of sea water and fresh water from a catchment area that is four times larger than the sea itself. The same water remains in the basin for up to 30 years. At an average depth of just 53 m, the Baltic Sea is much shallower than most of the world's seas. Water level is generally far more dependent on regional wind direction than on tidal effects.

There are 14 major river systems in the Baltic Sea catchment area. They include the Oder, the Vistula, the Neman, the Daugava and the Neva. These vary in size, the number of countries sharing the system, the environmental problems experienced and the way they are managed. Nearly half of the Baltic Sea's catchment area is forested. Forests, wetlands and lakes make up 65 to 90% of the catchment in Finland, Russia, Sweden and Estonia. A further 20% is used primarily for agriculture. In Germany, Denmark and Poland, 60 to 70% of the catchment area consists of farmland, particularly near the coast. About 17% is unused open land.

Because of its proximity to the Scandinavian ice sheet, the Baltic Sea has never been in a steady state. Post-glacial processes have shaped its coastline, topography, chemistry and sedimentary environments. The basin is still emerging isostatically from its subsident state, which was caused by the weight of ice during the last glaciation. Consequently, the surface area and the depth of the sea are diminishing. Climate variability and human activity in the last 150 years have led to considerable changes in its biogeochemistry.

On average, about 45% of the Baltic Sea is ice covered annually. Ice coverage during a typical winter extends to the Gulf of Bothnia, the Gulf of Finland, Gulf of Riga, the Estonian archipelago, the Stockholm archipelago and the Archipelago Sea, with ice reaching its maximum extent in February or March. The remainder of the Baltic Sea does not freeze during a normal winter.

3.2. Biodiversity and ecosystems

The Baltic Sea is the second largest brackish water basin in the world. It is ecologically unique and highly sensitive to the environmental impacts of human activities. Compared with other aquatic ecosystems, relatively few animal and plant species live in its waters. However, this limited biodiversity does include a unique mix of marine and freshwater species adapted to brackish conditions, as well as a few true brackish water species. Where salinity levels are low, particularly in northern and eastern waters, fewer marine species exist. Elsewhere, marine habitats are dominated by freshwater species, especially in estuaries and coastal waters. Seasonal ice cover is an important breeding and feeding habitat for seals. Sea ice is also important for several species of algae that live both below and in brine pockets in the ice.

3.3. Human geography

The countries with Baltic Sea coasts include Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Germany; all but Russia are EU Member States. Over 85 million people live in its catchment area - 26% of them in large metropolitan areas, 45% in smaller urban areas, and 29% in rural areas.

Population densities vary from over 500 inhabitants per square kilometre in urbanised regions of Poland, Germany and Denmark to fewer than 10 inhabitants per square kilometre in northern parts of Finland and Sweden. Almost 15 million people live within 10 km of the coast (Figure 3 and Table 2).

Figure 3 Population density of the Baltic Sea catchment area (Source: Grid Arendal)

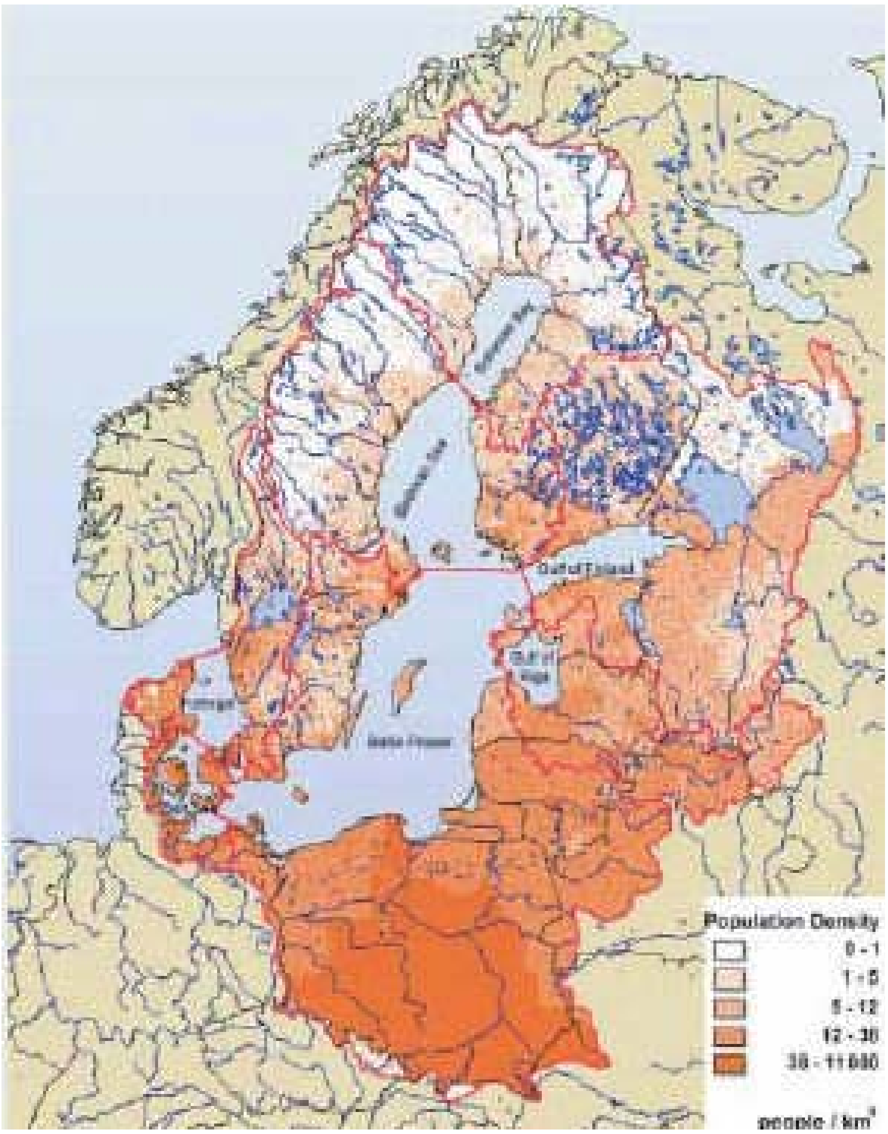


Table 2 Major cities on the Baltic coast.

Baltic Sea Coast Countries	Baltic Sea Coastal cities
Denmark	Copenhagen (0.5m)
Sweden	Malmoe; Stockholm (0.8m); Sundsvall; Lulea
Finland	Helsinki (0.6m); Oulu (0.13m); Vaasa; Turku
Russia	St. Petersburg (4.7m); Kaliningrad (0.4m)
Estonia	Tallinn (0.4m)
Latvia	Riga (0.72m)
Lithuania	Klaipeda (0.2m)
Poland	Gdansk (0.46m); Gdynia (0.25m)
Germany	Rostock (0.21m); Luebeck (0.22m); Kiel (0.25m)

3.4. Economic activities

The Baltic Sea region is one of the fastest growing economic regions in Europe, with the Baltic countries and western Russia being among the fastest growing economies and the Nordic countries and northern Germany the wealthiest economies. The Baltic Sea Region is also an emerging European mega-region. The eight EU member states in the region meet the necessary requirements for further regionalisation, as they share common norms, similar policy-making processes and comparable economic structures.

However, the economic potential of the Baltic Sea region has not yet been fully realised. There is a tension between so-called ‘catching-up’ economies that seek welfare through growth and ‘keeping-up’ economies that focus on retaining their well-being. The biggest challenge for the Baltic Sea region is to ensure that all economies contribute to the development of the ‘Baltic Sea engine of growth’. The global financial crisis has demonstrated just how fragile the rapid economic growth in the region has been. Figures for industrial production and growth in Estonia and Latvia in particular show a marked fall (Adenauer-Stiftung, 2009).

Shipping is steadily increasing in the Baltic Sea. Around 2,000 sizable vessels are normally at sea at any one time in the Baltic Sea, which has some of the busiest shipping routes in the world. Sea-borne transported goods are expected to double by the year 2017 (BACC, 2008). Consequently, there is a trend to build larger cargo ships and to increase shipping traffic, challenging harbour reception facilities and threatening marine environments.

Tourism is an important economic activity in the Baltic countries. It is relatively stable and dominated by domestic tourism. It is projected to profit (moderately) from climate change, as the climate is likely to become more tourist-friendly (BACC, 2008).

Agriculture in the Baltic Sea region is primarily concerned with the production of cereals and vegetables and with animal husbandry. By comparison with other European coastal regions, it is not expected to be affected significantly by climate change.

The fishing industry in the Baltic Sea is focused on far fewer species than in other marine areas of comparable size. This is reflected in the dominance of sprat, herring and cod in commercial catches (ICES, 2004). Fish landings increased substantially during the 20th Century, as fishing effort increased and new technologies were introduced; this led to over-exploitation of many cod and salmon populations (BACC, 2008).

3.5. Climate change impacts

During the period 1871-2004, there was a significant positive trend in annual mean temperature for the Baltic Sea region, with increases of 0.10°C/decade to the north of 60°N and 0.07°C/decade to the south of 60°N. This trend is greater than the global average of 0.05°C/decade (1861-2000). Mean daily minimum temperatures increased more than mean daily maximum temperatures. A general tendency was for the strongest warming to occur in the spring, with the season starting earlier (and autumn starting later). Changes in extreme temperature broadly followed changes in mean temperature. The number of cold nights decreased, while the number of warm days increased. These changes were stronger during winter than summer.

Northern Europe became wetter over the latter part of the 20th Century. However, the increase in precipitation was not spatially uniform. Within the Baltic Sea region, the largest increases occurred in Sweden and on the eastern coast, and in winter and spring. Changes in summer were characterised by increases in the northern and decreases in the southern parts of the region. In winter, the number of heavy precipitation events increased.

Observations of cloudiness and solar radiation show remarkable inter-annual and inter-decadal variation in the Baltic Sea region. There are no long term trends in storminess indices, although there are indications of increasing impacts from extreme wind events. The inter-annual variability in river run-off is considerable, but no statistically significant trend has been found. Recent decreases in snow cover duration have been observed in southern parts of all the Fennoscandian countries, while the opposite trend prevails in the north. Changes of snow depth are quite similar (i.e. decrease in south-western regions and increase in the north-eastern regions).

The salinity of the Baltic Sea decreased during the 1980s and 1990s; similar decreases also appeared earlier in the 20th Century, but no long term trend has been found. There are indications of more rapid eustatic sea-level rise in the 20th Century than in the 19th Century. Changes in the maximum annual extent of sea ice and the length of the ice season provide evidence of climate warming in the region. The shift towards a warmer climate started in the latter half of the 19th Century and corresponds with the ending of the Little Ice Age**.** Coastal damage in various parts of the southern Baltic Sea region generally result from a combination of the increasing intensity and number of storms, accelerating sea-level rise and decreasing presence of winter ice cover (BALTEX, 2006).

Climate change simulations using different regional climate models, hydrological models and circulation models (GCMs) for a number of greenhouse gas emission scenarios give variable results for the Baltic Sea region. Nonetheless, some general trends are projected (Graham *et al.,* 2006). All scenarios and all models show temperature increases during all seasons, with mean air temperatures increasing by 3ºC to 5ºC and sea surface temperatures by 2ºC to 4°C by the end of the 21st Century. One consequence is a 50% to 80% decrease in sea ice over the same period. Projected changes in precipitation are variable.

Winters will probably be wetter and, in southern parts of the region, summers are shown to be drier under many scenarios. River run-off during winter is expected to increase by as much as 50%, with decreases occurring in summer.

The BACC Project (Assessment of Climate Change for the Baltic Sea Basin; BALTEX, 2006) projected future warming in the Baltic Sea region to generally exceed the global mean warming in GCM simulations. Based on the annual mean from an ensemble of 20 GCMs, regional warming would be some 50% higher than global mean warming. In northern areas, the largest warming is generally simulated in winter; further south, the seasonal cycle of warming is less clear. The warming of northern areas from late the 20th Century to the late 21^{st} Century could range from as low as 1°C in summer (lowest scenario for summer) to as high as 10°C in winter (highest scenario for winter). The simulated warming would generally be accompanied by an increase in precipitation, except for in the southernmost areas in summer.

Consistent with the GCM studies, all available downscaling studies indicate increases in temperature during all seasons for all parts of the Baltic Sea region. Combined results show a projected warming of the mean annual temperature by some 3 to 5 ºC. Seasonally, the largest part of this warming would occur in northern areas during winter months and in southern areas during summer months. Corresponding changes in temperatures would be 4 to 6 ºC in winter and 3 to 5 ºC in summer, as estimated from a matrix of regional climate model experiments.

Projected changes in precipitation from downscaling studies are more sensitive to statistical uncertainty than temperature results, particularly at regional scales. Winters are projected to become wetter in most of the region and summers to become drier in southern areas for many scenarios. Northern areas could generally expect winter precipitation increases of some 25 to 75%, while the projected summer changes lie between -5 and 35%. Southern areas could expect increases ranging from some 20 to 70% during winter, while summer changes would be negative, showing decreases of as much as 45%. Taken together, these changes lead to a projected increase in annual precipitation for the entire region.

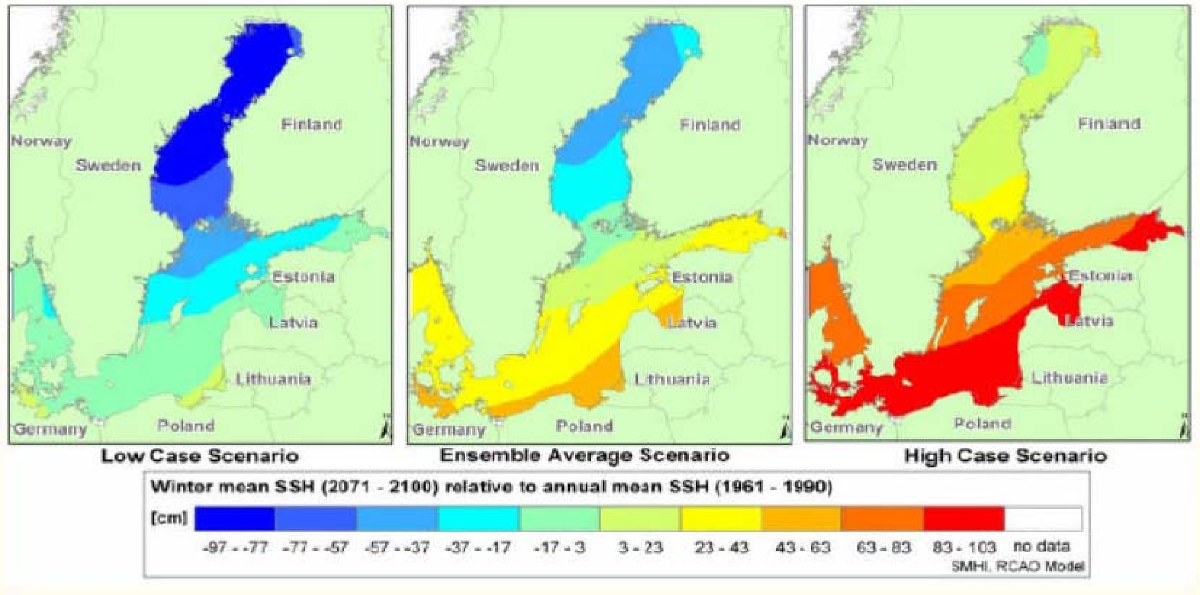
Projected changes in wind differ widely between climate models. For some, the changes are small and not statistically significant. For others, a mean annual increase of some 8% and a maximum mean seasonal increase of up to 12% during winter are projected. However, projected changes in large-scale atmospheric circulation from numerous GCMs indicate that an increase in windiness for the region would be somewhat more likely than a decrease.

Hydrological studies show that increases in mean annual **r**iver flow from northernmost systems would occur, together with decreases in southernmost systems. Seasonally, summer river flows would tend to decrease, while winter flows would tend to increase by as much as 50%. The southernmost systems would be affected by a combination of both decreased summer precipitation and increased evapo-transpiration.

Oceanographic studies show that annual mean sea surface temperatures could increase by some 2 to 4ºC by the end of the 21st Century. Ice extent in the sea would then decrease by some 50 to 80%. The average salinity of the Baltic Sea is projected to decrease between 8 and 50%. However, it should be noted that these findings are based on only four regional scenario simulations, using two emissions scenarios and two global models.

Mean sea-level in the Baltic could rise by 20 cm by 2050 and 50 cm by 2100 compared with 2000 levels (Pruszak, 2005). However, sea-level rise is likely to differ across the region. Isostastic emergence is likely to be greater than sea-level rise in northernmost parts (e.g. Gulf of Bothnia), whereas the south (e.g. Denmark, Germany and Poland) can expect considerable sea-level rise in the future. The impacts and uncertainties of future sea-level rise were modelled by Meier (2006). Three winter sea-level scenarios were considered: a 'high case scenario', using the upper limit for global average sea-level rise of 88 cm; an 'ensemble average scenario', assuming a global average sea-level rise of 48 cm; and a 'low case scenario', using the lower limit for global average sea-level rise of 9 cm (Figure 4).

Figure 4 High, average and low winter sea-level rise scenarios for the Baltic Sea
(source: Meier *et al.*, 2006).



In the low case scenario, the future winter mean sea-level was lower compared to the control mean sea-level, except in areas close to the German and Polish coasts. This could be explained by overall land uplift, which is larger than the assumed global mean sea-level rise of only 9 cm in this scenario. The calculated sea-level increase in the southern Baltic is very small. In the ensemble average scenario, the future mean sea-level is higher in the southern Baltic, Baltic proper and Gulf of Finland and lower in the Gulf of Bothnia compared to the annual mean sea-level for 1961-1990. The largest increase is noted in the southern Baltic and in the eastern Gulf of Finland. In the high case scenario, future mean sea-level increases in the whole Baltic Sea, with a significantly higher sea-level of about 1m projected for the eastern and south-eastern coasts of the Baltic.

The influence of rising sea-levels on the height and frequency of future storm surges is of particular interest to stakeholders. Unfortunately, it is very difficult to estimate the effect of sea-level rise on storm surges. These events are rare and depend on several additional factors (e.g. bathymetry of the coast, main wind direction and velocity, coastal morphology). A standardized methodology for combining sea-level rise scenarios with standard extreme value statistics was developed by Hunter (2009). However, methods allowing the assessment of future risks of storm surges in combination with sea-level rise scenarios are still insufficient.

3.6. Climate change vulnerabilities

Biodiversity and ecosystems

Changing climate and other associated environmental and anthropogenic changes are expected to affect the structure and function of ecosystems and threaten the services they provide to society. Significant changes in climate, including increasing temperatures and changing precipitation patterns, have occurred over the Baltic Sea region in recent decades (see above). Other associated changes include continuously rising atmospheric CO_2 concentrations and increases in deposition loads of atmospheric pollutants, including nitrogen compounds and acidifying pollutants. A variety of impacts on terrestrial and freshwater ecosystems have been identified over recent decades (BALTEX, 2006; BACC, 2008):

- An advancement of spring phenological phases, such as budburst and leaf expansion, is apparent for many plant species, likely reflecting increasing mean temperatures. Many species also show delayed autumn phases, but trends are less consistent. Phenological trends are stronger in northern Europe than for Europe as a whole, possibly reflecting stronger climate warming.

- Species distributional shifts tracking isothermal migration are apparent for both plant and animal species. Possible related changes include weaker migratory behaviour, for example in some bird species. Tree line advance has been observed in the Fennoscandian mountain range.

- Increased growth and vigour of vegetation at high northern latitudes generally is apparent from satellite observations and can be attributed to increased growing season warmth and an extended growing season. Other observations, such as tree ring data, support the existence of a positive growth trend. The magnitude of the positive growth trend within the Baltic Sea region is representative of high latitude areas in Eurasia and strong compared with similar latitudes in North America.

- Physiological stress related to the combined effects of atmospheric pollutants and extreme weather events, such as spring frosts and drought, is a possible explanation for late 20th Century dieback in boreal and temperate forests.

- Degradation of discontinuous permafrost in the sub-Arctic north may be causing a shift towards a greater representation of wet habitats in tundra areas. Possible consequences include an increased release of methane through (anaerobic) decomposition, which would accentuate greenhouse forcing.

- Climate-related changes in lakes, including higher water temperatures, advancement of ice break-up, lower water levels and increased influxes of dissolved organic matter from land, have consequences for lake ecosystems, including dominance shifts in phytoplankton communities, higher summer algal biomass, and shifts in trophic state. Studies of past and recent ecosystem changes have demonstrated the sensitivity of the Baltic Sea itself to climatic variations and other environmental changes.

- Northern Baltic annual peaks of the most abundant cladoceran species were found to co-vary with surface water temperature. Higher temperatures during the 1990s were associated with a shift in dominance within the open sea copepod community from *Pseudocalanus* spp. to *Acartia* spp.. Increased production and survival rates of sprat and herring populations during the last 5 to 10 years co-varied with high temperatures and high North Atlantic Oscillation (NAO) indices.

- Range shifts in birds were observed in Fennoscandia during 1870 to 1940 warming period, both on the northern and southern borders, and in spring and autumn migrations. Furthermore, extreme winter temperatures have long been documented to influence water bird mortality in the Baltic Sea, and winter conditions in the region are known to determine the range of land birds as well as water birds. Spring migration has generally occurred earlier in recent years, although there is a high variation between and within species.

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- Changing salinities have been associated with marked changes in ecosystems. An increase in salinity during the first half of the 20th Century resulted in a spread of several marine species (e.g. mesozooplankton, barnacles, jellyfish, larvaceans) towards the north and the east in the Baltic Sea. Correspondingly, the decrease in salinity after the late 1970s in the northern Baltic was reflected in biomass decline of the large neritic copepod species and increase of the freshwater cladoceran species. In the deep basins of the open Baltic, the decrease in salinity resulted in reduced standing stocks of *Pseudocalanus elongatus*, an important player in the pelagic food web. In contrast, temperature-sensitive species (e.g. Acartia spp.) increased their population sizes. A retreat towards the south has been found in benthic fauna (e.g. *Scoloplos armiger*). The decrease in herring and sprat growth has been related to a salinity-mediated change in the copepod community. A top predator in the pelagic food chain is the cod, a key species in the Baltic proper, which usually regulates the sprat and herring stocks, has seen a decrease. This decrease and the climatically enhanced reproductive success of sprat induced a switch from cod-domination to sprat-domination.

- Eutrophication and climatic changes have resulted in changes in phytoplankton biomass and species composition. Eutrophication may also be promoted directly by climatic factors, such as run-off and rainfall. There is some evidence that increased primary production has led to an increase in biomass at higher trophic levels (e.g. zooplankton and fish). Above halocline macro-faunal biomass in the 1990s was about five times higher than in the "pristine" conditions of 1920s and 1930s.

Climate scenarios consistently point to increased temperatures throughout the Baltic Sea region by the end of the 21st Century. Precipitation scenarios are more variable, but generally point to increased precipitation in winter, with southern areas experiencing decreased rainfall in summer. Combined with the effect of higher temperatures on evapo-transpiration, this suggests that ecosystems of the temperate zone may face increasingly unfavourable growing season water budgets in the future. Potential impacts of these and other associated environmental changes on terrestrial and freshwater ecosystems and their services over the remainder of the 21st Century include:

- Increasing temperatures will stimulate pelagic bacteria growth more than primary production, thus the ratio between bacteria biomass to phytoplankton is expected to increase with temperature in eutrophic waters. Higher temperatures could lead to an increase in the carrying capacity for sprat stocks and likely alter food web structure (Möllmann *et al.,* 2005). Higher temperatures during winter may result in a shift from cold to warm water species. Elevated winter temperatures may also prevent convection in late winter and early spring, with the result that nutrients are not mixed into the upper euphotic zone. This might result in a shift in species composition of phytoplankton in spring. Changing diatom spring blooms are likely as winters become milder. Furthermore, it has been suggested that the diatom bloom itself may disappear after milder winters and be replaced by dinoflagellates. Increasing summer temperatures may enhance cyanobacterial blooms.

- Increases in precipitation will result in higher river run-off, reduced salinity, higher nutrient input by rivers, and enhanced eutrophication in coastal areas with higher phytoplankton and benthic biomass (Dippner & Ikauniece, 2001).

- Diminishing ice cover suitable for breeding could lead to the extinction of southern sub-populations of the Baltic ringed seal. The grey seal, however, has been shown to have the capability to breed extensively on land, even in the Baltic.

- Possible increases in windiness during late winter would lead to stronger vertical mixing, with the consequence that nutrients would be mixed into the euphotic zone and would be directly available for primary production. This process would provide higher than normal phosphate concentrations in early spring, which would be used by cyanobacteria later in summer (Janssen *et al.*, 2004). An increase in windiness might also cause remobilisation of contaminants from bottom sediment.

- Decreasing salinity will result in changes in species' distributions, growth and reproduction. Decreases in species' numbers due to changes in species' distribution areas are expected across the entire region. A decrease in marine fauna is likely to occur first in the northern Baltic because of intensified rainfall. In the western Baltic, the common starfish (*Asterias rubens*) and common shore crab (*Carcinus maenas*) are among the species expected to decline if salinity decreases. Lower salinity would cause osmotic stress for phyto- and zooplankton and may result in a shift from marine to limnic species. This would influence food quality and, therefore, the growth rate and fat content of fish. Decreasing salinity, in combination with oxygen-poor and oxygen-depleted conditions due to cyanobacteria blooms, would result in benthic deserts in the deep basins and poor survival conditions for cod eggs. Decreasing salinity would also favour the invasion of non-indigenous species and enable freshwater species to enlarge their distribution. In conditions of increasing water temperature, not only spontaneously spreading European invaders, but also more exotic species from warmer regions of the world can be expected to establish in the Baltic.

- Accelerated eutrophication due to freshwater run-off is expected to determine most of the nutrient load in the Baltic Sea, especially in coastal areas. Eutrophication will enhance production and biodiversity up to a certain point, after which the ecosystem will collapse due to chemical and biotic interactions. A new ecological balance, characterized by low biodiversity and high variability due to episodic outbursts of dominant species, will develop. Some effects of eutrophication are clear and predictable, such as a general increase in primary production, but other effects, such as species-specific intra- and interactions are extremely hard to predict because of the non-linearity and complexity of the marine ecosystem (BALTEX, 2006).

Uncertainties associated with the assessment of future ecosystem changes are substantial and include uncertainties due to understanding of the biological phenomena being modelled or projected, including system-internal feedbacks and complexity, as well as variation among climate and greenhouse gas emissions scenarios on which the assessments are based. The most important source of uncertainty with regard to many impacts is the future development in non-climatic, anthropogenic drivers of ecosystem dynamics, including deposition of atmospheric pollutants, land use changes, changes in forest management and agricultural practices, changes in human populations, markets and international trade, and technological development (BALTEX, 2006).

Coasts, fisheries and tourism

Many parts of the Baltic Sea coastline are at risk of erosion due to rising sea-levels and the increasing frequency and intensity of storm events. Low-lying coasts (e.g. southern Baltic) are particularly vulnerable, with coastal damage resulting from a combination of an increase in strong storms, accelerated sea-level rise, and a decrease in ice cover in winter, when the most intense storms occur (BACC, 2008). Coastal groundwater aquifers could also suffer from saline intrusion. Fisheries could become vulnerable as human activities and climate change affect the structure and distribution of fish stocks. A combination of high levels of exploitation and declining salinity will challenge the sustainability of the cod population. In contrast, rising temperatures would increase the carrying capacity for the sprat population (BACC, 2008). The region could become more attractive to summer tourists due to increases in summer temperatures and the projected extension of the summer season (BACC, 2008).

3.7. Climate change adaptation

Almost all Baltic countries have or are currently developing climate change adaptation strategies in which coastal zones are briefly considered. To date, these are predominantly high level, without concrete implementation plans or dedicated financial resources. An exception is Poland, which has implemented coastal protection measures since 1985 and within these has recently taken climate change into account. Finland developed a National Adaptation Strategy in 2005, which includes actions relevant for the coastal zones and devotes much attention to co-ordinated land use planning in relation to climate change (Table 3).

Table 3 Overview of climate change adaptation and coastal protection in the Baltic Sea Area (source: EC, 2009).

Member state	*Responsibility level*	*Research*	*Strategic climate change adaptation plans (including coast) or coastal adaptation plans*	*Operational coastal plans and programmes*	*Climate scenario*
Denmark	Local and private	Limited	General Strategy for Climate Change Adaptation (2008)	Not available, but strict spatial planning regulation	Some municipalities
Estonia	Unclearly defined	Very limited	*Not available*	*Not available*	No
Finland	Local and private	Advanced	National Adaptation Strategy to Climate Change (2005)	*Not available* , much attention to co-ordinated land use planning in relation to climate change	Most municipalities
Germany	Regional (states) (partly financed national)	Advanced	Master Plan for Coastal Defence per coastal state and Climate Change Adaptation Strategy announced	Implementation of Master Plan for Coastal Defence per coastal state	Yes
Latvia	Local (partly financed national)	Limited	*Not available*	*Not available*	No
Lithuania	Local (partly financed national)	Very limited	*Not available*	Lithuanian Coastal Zone Programme (limited activities)	No
Poland	National	Advanced	Long-Term Coastal Protection Strategy 2004-2023	Long-Term Operational Programme 2004-2023	Yes
Sweden	Local and private	Advanced	Some local plans e.g. Ystad Policy for the Management and Protection of the Coast (Ystad) (2008), Water Plan (Göteborg) (2003)	Some local plans e.g. Ystad action plan and maintenance plan linked to Ystad Policy (forthcoming - 2009) and implementation of Göteborg Water Plan	Some municipalities

Adaptation response to and expenditure on sea-level rise and storm surge

In the Baltic Sea region, most countries implement accommodation and retreat measures in the coastal zone by means of spatial planning regulations. They allow flooding and erosion in uninhabited areas, and apply strict laws and regulations defining set-back zones and building restrictions elsewhere. Coastal protection measures against flooding, erosion and extreme weather events are only undertaken when there is a concrete need for them. In these cases, public or private property owners need to obtain permission at the national level, and beach nourishments or soft defences are preferred options. In Finland for example, national authorities consider carefully coordinated planning as an important tool to meet major land use challenges such as urbanisation, as well as potential climate change risks in coastal zones.

The cumulative cost of coastal protection across Baltic countries amounts to about € 0.7 billion over the period 1998 to 2015, corresponding to 4% of Europe's total expenditure. No major expenditure is made in specific hot-spots. The cumulative annual expenditure increased from around € 30 million in 1998 to € 35 million over the period 1999 to 2007, to an actual expenditure of € 45 million (which will decrease slightly in the future). Germany (56%), Sweden (19%) and Poland (17%) account for the majority of this expenditure.

No (additional) expenditure has been made to date or will be made in the near future on climate change adaptation. Most countries still consider climate change to be too uncertain for proactive investment. Moreover, when measures are taken, priority is given to accommodate actions in regional development and building regulations, which do not appear as a cost as they are not usually monetised.

Adaptation response on marine ecosystems and biodiversity

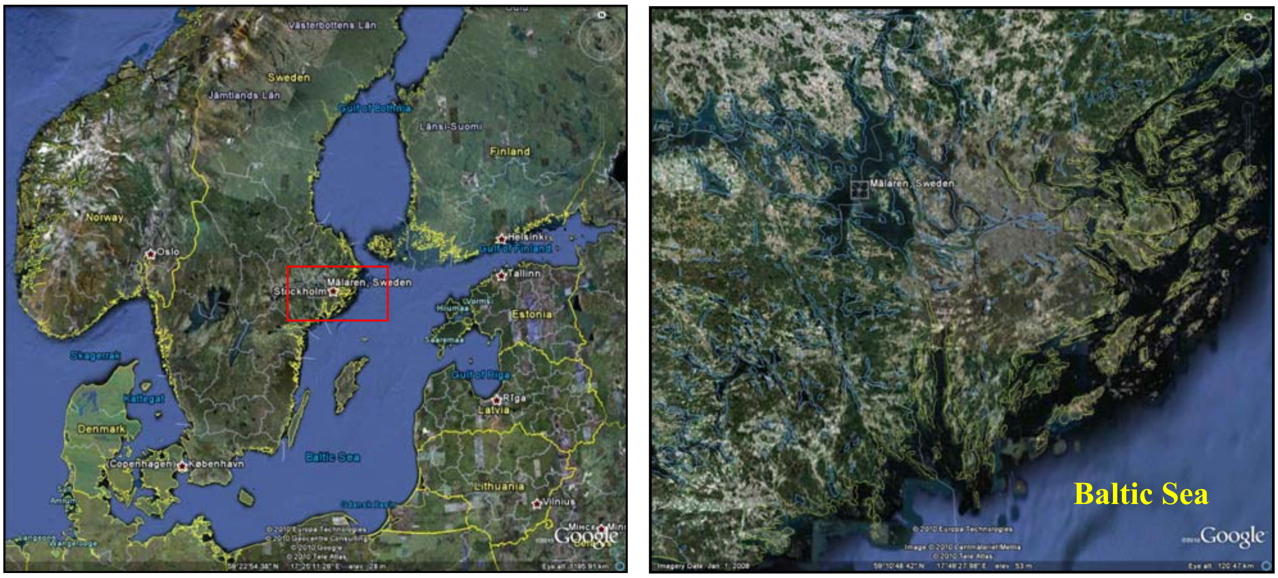
The potential loss of marine ecosystems and biodiversity due to climate change is likely to be a key issue for the Baltic Sea region. In 2007, the surrounding countries agreed the Baltic Sea Action Plan. This aims to restore good ecological status of the marine environment by 2010 and is seen as a crucial starting point for wider and more efficient action to combat the continuing deterioration of the marine environment resulting in the first instance from human activities. The main objectives are to intensify measures that ensure water quality, to reduce emissions from marine transport and to enhance the protection of marine and coastal landscapes and habitats. The Baltic Sea Action Plan was initiated by HELCOM, the governing body of the Helsinki Convention. Through the action plan, HELCOM hopes to improve the capacity of the Baltic marine environment to cope with the stresses of climate change. In June 2009, the European Commission adopted an EU strategy for the Baltic Sea region (COM (2009)248). This strategy acknowledges that climate change adaptation is a growing challenge in the area and proposes in its related action plan to "establish a regional adaptation strategy at the level of the Baltic Sea region". Such action could be seen as a good example of cross-border cooperation between member states of the region.

3.8. Case Study

Lake Mälar Region, Sweden

Changes to the climate in the Baltic Basin are expected to result in an elevated sea level in a future perspective. The precipitation patterns, as well as evapouration, are also expected to alter. This, in turn, will affect the totoal amount of fresh water flowing into the sea. Both sea-level rise and changed runoff may lead to major flooding events having severe impacts on the spatial development of cities and regions as well as sustainble development of the entire Baltic Sea region. The Stockholm-Mälar region (Figure 5) consists of five counties and more than three million inhabitants, the lake itself is the water reservoir for around two million inhabitants and several cities are situated along the lake, not least the capital of Sweden. The lake is important for sea transportation as well recreational purposes and has high environmental qualitities (Persson *et al*., 2004a, Persson *et al*., 2004b).

Figure 5 Location of Lake Mälar Region in Sweden and Baltic Sea (source: Google earth, 2010)



This study by the Swedish Meterological and Hydrological Institute, addressed the region as a whole, and was part of the SEAREG (Sea Level Change Affecting the Spatial Development in the Baltic Sea Region) which focuses on the socio-economic and environmental assessment of the effects of climate change on sea-level rise and river runoff in the Baltic Sea region. Future increasing sea level and changed runoff paterns were modelled and the results showed that maximum sea water level for 2071-2100 in relation to today's mean is about the same as today if the ensemble mean value is taken. However, the worst case scenario shows an increase in sea level of 50cm. Higher hydrological flows in autumn and winter are also shown. These conditions may lead to diverse problems; flooding but also too low water levels for transportation (Persson *et al*., 2004a).

The lake has been regulated since 1943 which has led to level water level variations and a lowered risk for saltwater intrustion. Four out of the five locks are within Stockholm and the results show that the maximum water outlet capacity is too low, at 710 m^3/s, as this studies' calculations indicate that a rebuilding of some locks is needed to increase the discharge capacity to reach the estimated need of 1370 m^3/s (Persson *et al*., 2004b, Persson *et al*., 2004a).

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4. North-east Atlantic Ocean: Greater North Sea

The Greater North Sea is a sub-region of the North-east Atlantic Ocean 'European Marine Region', established under the EU's Marine Strategy Framework Directive (2008/56/EC) (EU, 2008) to protect the resources upon which marine-related economic and social activities depend. It is also one of five regions (Region IV) identified by the OSPAR Convention (1998), which aims to protect the marine environment of the North-east Atlantic. The Greater North Sea includes the North Sea, the Kattegat and English Channel, and is bordered by Denmark, Norway, Sweden, Germany, the Netherlands, Belgium, France and the UK (Figure 6).

Figure 6 Map of the Greater North Sea and its bordering countries (source: Google earth, 2010)

4.1. Physical geography and oceanography

The Greater North Sea comprises the English Channel in the south, the central North Sea (including the German Bight), and the northern North Sea (including the Norwegian Trench and the Skagerrak). The shallow Kattegat is a transition zone between the Baltic Sea and the northern North Sea. The Greater North Sea has a surface area of about 750 thousand km^2 (OSPAR, 2000). In general, it is a shallow sea with a mean depth of 90 m. However, the variation in depth is large, ranging from a maximum of about 725 m in the eastern part of the Norwegian trench down to less than 10 m in the Waddensea.

Climatologically, the Greater North Sea is located in temperate latitudes, strongly influenced by the inflow of water from the Atlantic and westerly air circulation with frequent low pressure areas – the North Atlantic Oscillation (NAO) (OSPAR, 2000). The NAO is important for the climate in the Greater North Sea and its surrounding countries. If it is strong, more western advection brings milder and wetter weather, especially in winter. Weaker or blocked western circulation causes generally colder and drier winters and hotter and drier summers.

Variable amounts of Atlantic water enter the Greater North Sea (OSPAR, 2000; Kabuta *et al.* 2003). The dominant source of fresh water is the Baltic Sea, with a catchment area twice as large as the area of rivers directly flowing into the Greater North Sea (OSPAR, 2000). These include the Rhine, Meuse, Scheldt and Ijssel Lake in the Netherlands, the Elbe and Weser in Germany, the Seine in France the Thames and Humber in the UK, and the Glomma in Norway and Göta älv in Sweden.

Geologically, the North Sea shelf is an ancient depression, overlain by several kilometres of sedimentary deposits which originated from the surrounding land masses. During glacial times, glaciers from Scotland and Scandinavia spread over the area, causing large sea-level changes and depositing large amounts of sediment. This shaped the underwater topography of the present day (OSPAR, 2000).

The coastline of the Greater North Sea includes a rich variety of landscapes arising from differing geologies and earth movements. The coastlines of Norway, Sweden and Scotland are rocky, partly with tall cliffs and many small islands. The east coast of England is characterised by river estuaries, and sand and mud flats in many areas. The coastline of south east England is dominated by low cliffs and flooded river valleys, whereas the French coast is a mixture of maritime plains, estuaries, cliffs, and rocky shorelines. Sandy beaches and dunes, with numerous estuaries, tidal inlets and islands, prevail northwards to the west coast of Denmark. The natural coastline has been heavily influenced by human activities, such as the development of urban and industrial areas, ports and harbours, and land reclamation and coastal protection schemes.

4.2. Biodiversity and ecosystems

The Greater North Sea has a rich and varied biodiversity, including viruses, bacteria, plankton, fish, birds and mammals (OSPAR, 2000). For example, over 230 species of fish and many marine mammals (e.g. seals, dolphins and whales) live in the area. The coastlines provide feeding and breeding habitat for large numbers of bird species, some of them migratory. It is estimated that around 10 million seabirds are present in the Greater North Sea at most times of the year, while more than four million seabirds of 28 species breed along its coasts during summer (OSPAR, 2000). Populations of black legged kittiwake, Atlantic puffin, northern fulmar, and species of petrel, gannet, seaduck, loon (divers), cormorant, gull, auk and tern, and many other seabirds make these coasts popular for bird-watching.

Ecologically important estuaries and wetlands in the Greater North Sea are found in the Limfjord, the Wadden Sea, the Wash, and the estuaries of the English and French Channel coasts. The Wadden Sea, which extends along the Dutch, German and Danish coast for about 500 km and with a total area of around 10,000 km², is the world's largest tidal wetland (Wikipedia, 2009). It is typified by extensive but mobile tidal mud flats, tidal creeks and deeper trenches, and islands, which move continually due to the large spatial and temporal variability of the wind and wave regimes (OSPAR, 2000). Due to these dynamics, the Wadden Sea has a high floral and faunal diversity and is particular important for both breeding and migratory bird populations. Six to 12 million birds of more than 50 different species occur in the Wadden Sea annually, and use it as a migration stopover or wintering site (OSPAR, 2000). The number of seals has also increased considerably since the 1980s (Reijnders & Reineking, 1999, Reijnders *et al*., 2005).

Furthermore, many salt marshes and intertidal mudflats exist along the North Sea coastal zones. These areas are the upper coastal intertidal zone between land and salty or brackish water, dominated by dense stands of salt-tolerant plants such as herbs, grasses, or low shrubs (Woodroffe, 2002). Salt marshes and mudflats are important for wildlife and biodiversity (Berry *et al.,* 2007) and as sea defence (King and Lester, 1995). Salt marshes are characterized by strong tidal influences and show distinct patterns of zonation (Woodroffe, 2002). The tidal inflow is an important process in delivering sediments, nutrients and plant water supply to the marsh (Gedan *et al.,* 2009).

Most salt marshes are often directly and indirectly affected by human influences. Various marsh lands have been converted firstly into agriculture and later into urban, residential and industrial land (Gedan, *et al*., 2009). Indirectly, marshes are prone to receiving increased nitrogen loads. This has ecological consequences, as marshes are normally nitrogen limited, resulting in growing conditions for many new species (Bertness *et al*., 2002).

4.3. Human geography

The Greater North Sea is surrounded by densely populated, highly industrialised countries (Table 4). About 250 million people (about 50% of the EU27's population) live in the countries that border the Greater North Sea, about 189 million people live in its catchment area, and about 35 million people (14%) live within 50 km of the coast (up to 65% in the Netherlands and Denmark) (OSPAR, 2000; Eurostat, 2009).

Table 4 Greater North Sea countries and their socio-economic characteristics

Countries	2010 Population[1] (million)	Population change (%) 2030	2050	Population in coastal area of Greater Nor th Sea[2]	2005 GDP (in Billo n euro's) [1]	% GDP in coastal zone[4]
Belgium	10.8	+9%	+13%	3.9[4]	293	33%
Denmark	5.5	+5%	+7%	2.2[3]	165	63%
France	62.9	+8%	+13%	7.4	1733	15%
Germany	82.7	-3%	-9%	5.8[1,4]	2318	5%
The Netherlands	16.5	+4%	+2%	8.9[4]	536	45%
UK	62.0	+12%	+20%	4.6[1]	1724	63%
Norway	4.8	+14%	+22%	3.3[3]	205	-
Sweden	9.3	+10%	+15%	2.4[3]	250	48%
Total	253	+6%	+7%	35.2[1]	7224	28%

[1] based on Eurostat
[2] coastal area implies within 50km from coast
[3]based on OSPAR, 2000, providing information for the catchment area of the Greater North Sea
[4] based on European Commission, 2009

4.4. Economic activities

The Greater North Sea region is one of the most economically important parts of the EU (Eurostat, 2009). It contains centres of national, regional and global importance, including a number of member state capitals. The region also has the highest GDP *per capita* of all European coastal regions (Eurostat, 2009). On average, about 28% of GDP is generated in the coastal zones of countries bordering the Greater North Sea, with especially high values for Denmark and the UK (Table 4) (EC, 2009).

More than 70% of Gross Added Value is generated by the service sector in the coastal areas of the Greater North Sea, whereas agriculture accounts for only 1-3% (Eurostat, 2009). Other important sectors include transport, tourism, fishing, and oil and gas exploration/production.

The Greater North Sea is particularly important for marine traffic and its shipping lanes are among the most heavily used in the world. In addition, several large ports (e.g. Rotterdam and Hamburg) are found in the region, and numerous canals and waterways facilitate traffic between and among rivers and the sea.

Tourism is an important social and economic activity in the Greater North Sea region. The beaches and coastal waters are popular tourist destinations and more than 15,000 hotels (16% of all coastal hotels in Europe) are located along its coastline (Eurostat, 2009). The concept of sustainable tourism has recently been development to utilise the cultural assets and protect the natural environment of the region (DG Regio, 2008).

Despite over-fishing and shrinking economic importance, the Greater North Sea remains one of the world's most important fishing grounds. Over 5% of international commercial fish are caught in the Greater North Sea. Of the 230 fish species that live in the Greater North Sea, 13 are the main targets of commercial fisheries (i.e. cod, haddock, whiting, saithe, plaice, sole, mackerel, herring, Norway pout, sprat, sand-eel, Norway lobster, and deep water prawn). Fishing activities are particularly important to the economies of Denmark and Norway (OSPAR, 2000). The European Commission developed a Common Fisheries Policy to address over-fishing and its economic and environmental implications.

The Greater North Sea is also a major supplier of natural resources. Millions of tonnes of sand and gravel are dredged annually from the sea floor and used in beach nourishment, land reclamation and construction. The exploration/production of oil and gas has been a major economic activity since the early 1970s (OSPAR, 2000). Norway and the UK are leading producers and the revenues generated add considerably to their GDPs. Other countries (e.g. Germany and Denmark) have used the Greater North Sea to pioneer off-shore wind energy. There are now plans for large off-shore wind parks that will produce around 10% of the EU's electricity (more than 100GW of energy). Off-shore wind energy will play a major role in a so-called European renewable super-grid.

4.5. Climate change impacts

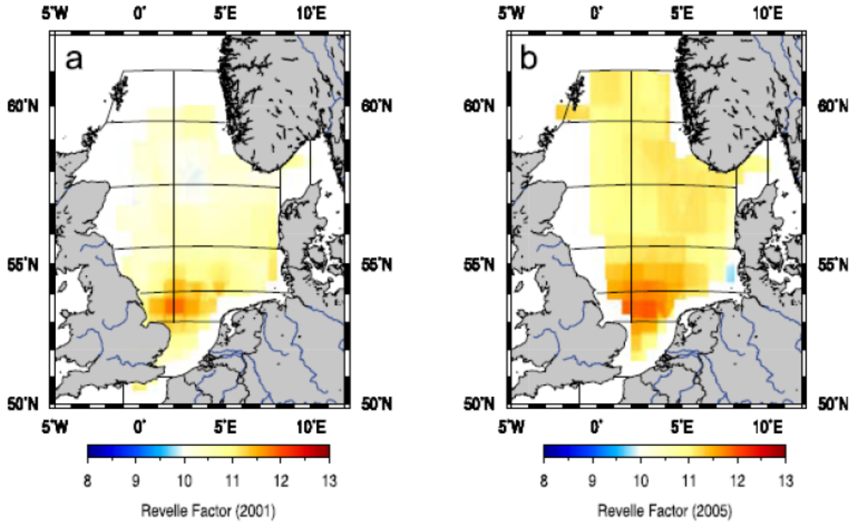
The Greater North Sea and its coasts are among the most vulnerable areas of Europe. Climate change is adding a new pressure to areas already experiencing the effects of tourism, over-fishing, eutrophication and pollution from toxic chemicals. Climate change affects coastal waters and coastal areas both directly and indirectly. Direct impacts include increasing frequency and intensity of storms, increasing air and water temperatures (which degrade water quality, alter food chains, and affect marine ecosystem function and composition), and ocean acidification (which also affects marine ecosystems) (Hoffman & Schellnhuber, 2009). Indirect impacts are predominantly related to sea-level rise and include coastal erosion and flooding, salinisation of wetlands and low-lying areas, and loss of property and infrastructure. Saline intrusion affects soil characteristics (and therefore land use) and coastal aquifers (and therefore freshwater availability). Many large European cities (e.g. London, Rotterdam and Hamburg) are vulnerable to coastal flooding as they are low-lying and located close to the sea - and therefore heavily depend upon artificial coastal defences.

Many impacts of climate change have already been observed. For example, north-western Europe has become 1.2°C warmer since pre-industrial times (EEA, 2008). The warming since 1950 is twice the global average (KNMI, 2008). The average water temperature of the Greater North Sea has increased 0.5°C since 1955 (EEA, 2008), and the increase in the Dutch Wadden Sea has been 1°C. These increases have affected the biological activity in the region (Edwards *et al.,* 2001).

North-western Europe has also experienced more precipitation over the last decades, especially in the Netherlands and Denmark (EEA, 2008; KNMI, 2008). However, no long term changes in storm intensity and frequency have been observed, although there has been considerable variation.

Rising atmospheric CO_2 levels have led to acidification of sea water (measured as Revelle factor, Figure 7) (Thomas *et al.,* 2007). The pH value of the southern, shallow part of the North Sea has become notably more acid.

Figure 7 Acidification of sea water measured as Revelle factor and its changes in the Greater North Sea. The Revelle factor, computed from observed data, is shown for 2001 (left) and 2005 (right) (Thomas *et al.,* 2007)



The long term average level of the Greater North Sea has increased at a rate of 1.5-2 mm/yr over the past century, and increased up to about 3±0.7 mm/yr over the past 15 years (Church & White, 2006; Rahmstorf *et al.,* 2007; Bessembinder, 2008). A number of vulnerable countries bordering the Greater North Sea (e.g. the Netherlands and UK) have already included sea-level rise in their coastal policies, although additional measures may be required in the longer-term (PBL, 2007, 2009).

Several studies have revealed that climate change is already impacting biodiversity in the Greater North Sea (Table 5). Regional climate warming, for example, has influenced northerly migration of fish species like sardines and anchovies (Brander *et al.,* 2003). Likewise patterns of overwintering of migratory birds on the British coast appear to have changed in response to temperature rise (Rehfisch *et al.*, 2004).

Table 5 Observed and projected climate change impacts on the biological environment in the North-east Atlantic, including the Greater North Sea. Note that the projected impacts are limited by uncertainties in ocean climate projections and species and community responses (source: OSPAR, 2009).

Impact	What might happen	What has already been observed
Plankton	Northwards shifts in species in shelf and open ocean	1000 km northward shift of many plankton species over the last 50 years Changes in timing of seasonal plankton blooms
Harmful algal blooms	Potentially increasing incidence as a result of changes in sea temperature, salinity and stratification	Anomalous phytoplankton blooms (often harmful) in specific habitats affected by lower salinities (e.g. Norwegian trench) or higher temperatures (German Bight).
Fish	Northward shifts in population but lack of knowledge of the underlying mechanisms make projections uncertain. Increased temperature could increase the incidence of disease for farmed	Northwards shifts of both bottom dwelling and pelagic fish species, most pronounced

Impact	What might happen	What has already been observed
	species of fish and shellfish	
Marine mammals	Loss of habitat for mammals dependent on sea ice Changes in availability of prey species are likely I due to mismatches in production	Data on distribution, abundance and condition of marine mammals is limited.
Seabirds	Impacts on seabirds are likely to be more important through changes in their food supply than through the losses of nests due to changed weather	Seabird breeding failure in the North Sea has been linked to variations in food availability as a result of increased sea temperatures
Non-indigenous species	Increased invasions and establishment may be facilitated by climate change and pose a high risk to existing ecosystems	Establishment of pacific oyster Crassotrea gigas and the barnacle Elminius dodestus has been linked to climate change
Intertidal communities	Continues extension and retraction of the ranges of different intertidal species	Some warm water invertebrates and algae have increased in abundance and extend ranges around the UK over last 20 years
Benthic ecology	Benthic sessile organisms are largely tolerant to moderate environmental changes over reasonable adaptive time scales but are very vulnerable to abrupt and extreme events	Anomalous cold winter conditions have seen outbreaks of cold water species and die-offs of warm water species. Species composition changes have occurred but not major shifts or changes in gross productivity

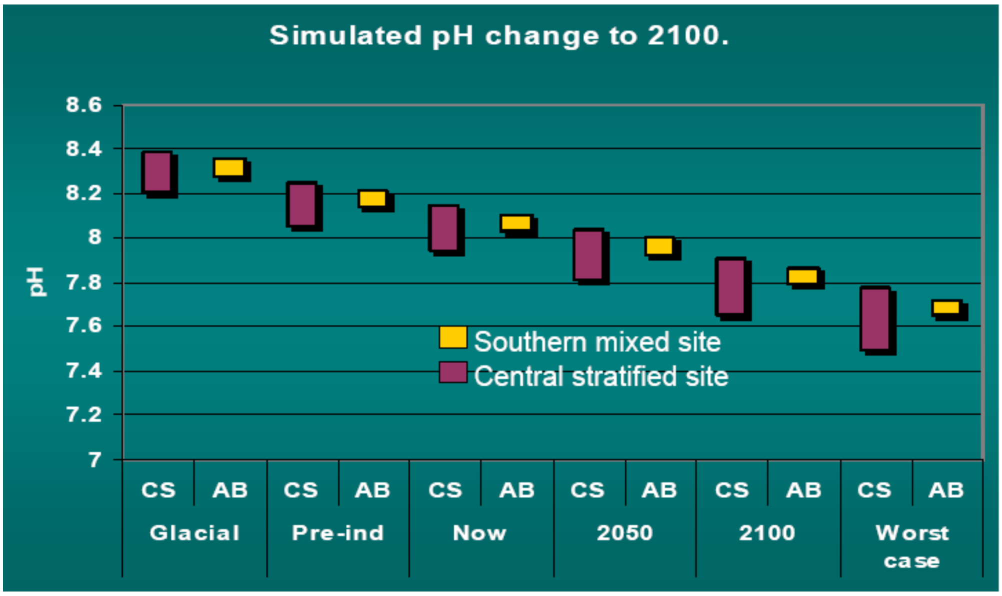
Information on projected physical and socio-economic impacts of climate change on the Greater North Sea area can be derived from various national, EU and international studies. Many of these studies do not focus on the Greater North Sea alone, but are much wider in perspective (e.g. North-east Atlantic Ocean or the European continent). This is partly due to the resolution of the models used.

In north-western Europe, temperature is projected to increase less than in other parts of Europe. Nevertheless, the Netherlands, for example, is likely to see a temperature increase within the range of 1.8-5.2°C by 2100, and possibly even more than 7°C (KNMI, 2006). Similar, but delayed, increases in water temperatures of the Greater North Sea are also likely (OSPAR, 2009). Various studies project an increase in storminess in many oceans and seas – including the North-east Atlantic. However, fewer but more extreme surge events have been projected for the southern part of the central North Sea (Alcamo *et al.,* 2007). Extreme storms (so-called super-storms) are yet not projected for the Greater North Sea (Van den Brink, 2008).

It is projected that the pH value of the Greater North Sea will decrease due to increasing atmospheric CO_2 levels and that this will differ according to depth and salinity (

Figure 8). The impacts on ecosystems will be substantial due changes in nutrient balance and the abundance of zooplankton. Decreasing salinity, particularly in coastal areas with increasing river discharge rates, will also have an impact on ecosystems.

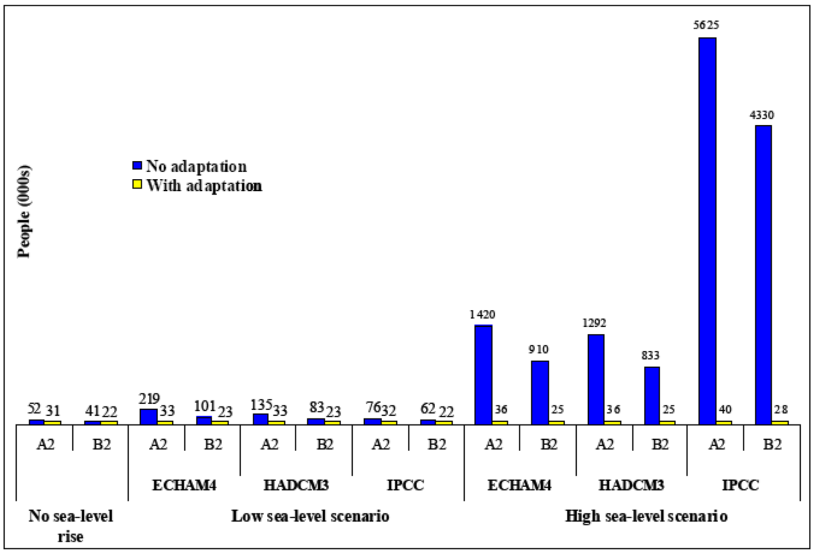
Figure 8 Historical and projected ocean acidification in the Greater North Sea (Turley *et al.*, 2006)



Several studies project future trends in sea-level. Projected changes for Europe under IPCC SRES scenarios are in the range 20-85 cm by 2100, depending on the scenario, climate model and water model used (Katsman, 2008; Ciscar, 2009). Under plausible high-end/extreme climate scenarios (up to +6°C globally by 2100), the sea-level in the Greater North Sea may increase by 0.40-1.05 m by 2100, and more than three times these values by 2200. Peak water levels due to extreme storms are projected to be largely unaltered by 2100, as wind directions are unlikely to change significantly (Katsman, 2009). Wind direction affects wave regimes and also erosion patterns, and can have a damaging effect on ecosystems.

The PESETA study projects that, under the A2 (high) emission scenario and assuming no adaptation, 2,000-17,000 km² of land in coastal Europe could be permanently lost due sea-level rise and storm events by 2085, with 0.1-1.3 million people experiencing coastal floods every year. The cost of these impacts is valued at 12-18 billion Euros a year (Ciscar, 2008). However, when adaptation measures are also considered (estimated cost 1 billion Euros a year), the damage, number of people affected and residual costs nearly disappear entirely (Figure 9).

Figure 9 Number of people flooded in the EU with and without adaptation by 2085, using the DIVA model (Ciscar, 2008)



The projected impacts of climate change on the Greater North Sea's coastal biodiversity and ecosystems are also important (Figure 9). Habitats could be severely reduced or disappear due to sea-level rise during the 21st Century because of the low tidal and limited scope for onshore migration in many coastal areas. Sea-level rise is likely to cause an inland migration of beaches and the loss of up to 20% of coastal wetlands (Alcamo *et al.,* 2007). This, however, strongly depends on the rate of sea-level rise. It is estimated that much of the Wadden Sea will remain with a sea-level rise of up to 3-6 mm per year. Beyond this level, salt marshes may drown, causing loss of habitat for benthos consuming birds and seals (RWS/Deltares, 2008; Heijmans *et al.*, 2009). However, it is likely that the Wadden Sea's biodiversity will be able to adapt to most projected sea-level rises. In addition, rising sea-levels may cause salination of coastal freshwater ecosystems and phenological changes in marine ecosystems will continue to accelerate as species move further northwards (EEA, 2008).

4.6. Climate change vulnerabilities

The Greater North Sea and many of its bordering coasts are amongst the most vulnerable areas in Europe to climate change. A number of inhabited coastal areas in countries such as Denmark, the Netherlands and the UK are already below normal high tide levels, and many low-lying areas are prone to flooding from storm surges. Mudflats, dunes, wetlands and freshwater ponds are the most vulnerable coastal habitats (Table 6). Sand dunes, which help protect coastal ecosystems from flooding and salinisation, are already eroding and this is likely to be exacerbated by sea level rise (Berry *et al.,* 2007). Climate change is exerting an additional pressure on natural systems that are already 'in competition' for space required for economic development, and threatened by eutrophication and increasing concentrations of toxic materials.

Table 6 Vulnerabilities of coastal habitats to climate change (Berry *et al.,* 2007)

Coastal

saltmarsh	loss with rising sea level through erosion and/or inundation	disturbance activity of ragworm preventing accretion (Wolters and others 2005)
grazing marsh	low water levels in spring and winter leading to sub-optimal conditions for breeding waders (RSPB undated)	pressure for water resources
cliff habitats	faster erosion with more frequent storms (National Trust 2005)	coastal protection schemes can interrupt the movement and deposition of sediment

Coastal ecosystems, coastal lands, areas of transitional waters and near-shore marine areas are among the most productive yet highly threatened systems in the world. The Greater North Sea is no exception and has experienced a high wetland conversion during the last decades (LIFE, 2007). Other valuable ecosystems, such as coastal dunes in many parts of mainland Europe and the UK and sea grass beds in the southern North Sea and English Channel, remain under threat. Degradation and loss of vulnerable habitats, in combination with other climate-related issues (e.g. acidification, changing salinity and water temperature) can have major impacts on biodiversity.

There is clear evidence of the responsiveness of coastal and marine ecosystems to climate change. For example, previous warming of the North Atlantic from 1920 to 1960 led to a northerly expansion of a range of marine organisms, from plankton to commercial fish such as cod and herring (EEA, 2004b). Changes in phenology, species distribution and community composition in some components of marine ecosystems can be attributed directly to climate change. The extent to which this is also valid for the Greater North Sea is uncertain. Climate change impacts have been observed on individual species and species subsets. However, it remains to be seen whether they are systematic, coherent, assemblage-wide responses to climate change that could be used as a representative indicator of changing biological state (Dulvy *et al.*, 2008).

On the coasts of the Greater North Sea, the space available for wildlife will shrink as sea level rises. In some places, habitats will disappear, in other places decisions have to be made about prioritising space between important habitats (Berry *et al.,* 2009). All countries surrounding the Greater North Sea will have to cope with this to a certain extent under current climate scenarios.

In the UK, saltmarsh, sand dunes and shingle habitats are likely to decline on the south coast. One example is Hurst Spit, a 2 km long, artificially maintained, partly vegetated shingle barrier, protecting saltmarsh and intertidal mudflats on its landward side. The saltmarsh has been receding at a rate of 3-6 m/yr. By 2080, the complete saltmarsh could disappear, assuming current defences are maintained (Berry *et al.,* 2009). The mix of species that these coastal areas currently support will change, affecting the food sources for bird and mammal species.

The Netherlands, Germany and Denmark are home to one of the largest coastal ecosystems. It is typified by extensive tidal mud flats, deeper tidal trenches and saltmarsh, and is threatened by sea level rise. With no natural growth, a high-end sea level rise scenario of 80-85 cm this century would cause the ecosystem to disappear. However, with natural growth of 3-6 mm/yr (up to 8 mm is possible); it is likely that the system will survive (RWS/Deltares, 2008).

In France, dune systems are being eroded and saltmarsh is expanding, reducing the area of mudflat for wading birds.

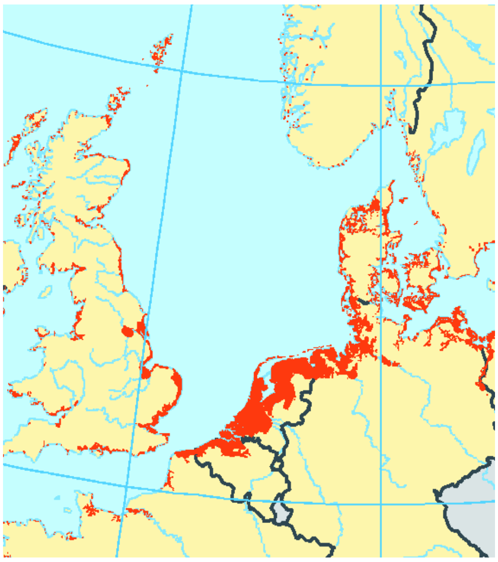
It is possible that conflicts will occur between protecting socio-economic activity and sustaining the function of ecosystems in the Greater North Sea as sea levels rise. Whilst coastal tourism can be synergistic with ecosystem-based adaptation strategies, oil and fisheries are examples of sectors with conflicting interests. Spatial planning of coastal communities can also lead to conflict, particularly where fixed sea defences obstruct natural onshore migration of ecosystems in response to rising sea levels.

Climate models predict a 2-4°C rise in sea water temperature. This will have major implications for species, ecosystems and food webs, and spatial distributions, life histories, phenologies and biotic interactions will be altered. Archaeological evidence from the waters around Denmark (Kattegat, Skagerrak, Belt Sea and Bornholm) during a warm period from 7,000-3,900 BC shows the presence of several warm-water fish species. Species such as smooth-hound, common stingray and European sea bass currently have a more southerly distribution and their presence near Denmark in the past was due, in part, to warmer temperatures at that time. Some of these species are again being caught by fishermen in the area. Warmer temperatures are expected to continue to change the composition and increase the diversity of fish species in the Greater North Sea (MARBEF, 2009).

Ocean acidification as a result of climate change and rising CO_2 emissions poses a threat to reproduction, growth and survival at species level, and could lead to a loss of biodiversity and profound ecological changes. To date, comparatively little is known about the precise biological responses that might occur (European Science Foundation, 2009). Changes in salinity due to increasing river run-off could also pose a threat to ecosystems.

Human and economic vulnerability in coastal areas is primarily related to sea level rise, although changes in water temperature, wind speed, the direction and height of waves and the frequency of extreme weather events are also relevant. The highly populated and economically important low-lying coasts of the Greater North Sea (Figure 10) are particularly at risk from higher water levels and storm surges (EC, 2009). This includes more than 85% of the Dutch and Belgian coastline and the cities of London, Hamburg, Rotterdam and Antwerp. Many coastal areas will face additional pressures during the 21st Century (EEA, 2006).

Figure 10 Lowland in coastal area (below 5 m. elevation) (source: EEA, 2006)



The potential impacts of flooding and storm damage on human and economic systems can be significant. However, the actual impacts are highly uncertain, as the adaptive capacity of these systems and the use of appropriate adaptation measures could help avoid or effectively manage many impacts. If adaptive measures are integrated into coastal development, the number of people actually flooded each year is likely to remain relatively stable until the 2080s (JRC, 2009).

4.7. Climate change adaptation

Adaptation to the impacts of climate change in the Greater North Sea region can be divided in options concerning the coastal and the marine ecosystems. Adaptation related to the marine environment is more challenging than on land and fewer options are available (OSPAR, 2009). The few options of marine adaptation include, for example, fishery quotas and establishing protection for areas that are most likely to suffer the adverse effects of climate change. This chapter, however, focuses on the more relevant coastal adaptation, as the measures are diverse.

Coastal adaptation is diverse because coastal systems bordering the Greater North Sea are diverse, from the sandy beaches of Belgium and Holland to the salt marches of Germany and Denmark to the rocky shores of Norway. Current adaptation measures focus mainly on protective options, building on existing measures to minimise risk of flooding and coastal erosion, both possibly the result of sea level rise and changes in storm surges (Tol, 2008). Most of the vulnerable coastline is protected against erosion by dikes, groyne fields and seawalls. Natural coastal defences like sandy beaches and dunes that are strongly influenced and thus most affected by coastal dynamics (currents and displacement of marine sediment) are protected by beach nourishment schemes. The latter is regarded as a ‘soft’ coastal defence technique and is considered an environmentally accepted method of beach and dune protection and widely implemented due to relatively low costs. Moreover, beach nourishment represents a flexible option because it can be implemented on various scales (Hanson *et al.*, 2002, PBL 2007).

Adaptation measures in the populated coastal zones of the North Sea can only be effective in a framework of strategic planning including shoreline and estuarine management plans. Various initiatives at national, EU and international level help to define adaptation strategies and options for the Greater North Sea. As such, its coastal areas have become the focus for testing new national regulations, EU directives and international treaties and programmes concerning the coastal environment. For example, ecosystem-based approaches are being used in designing coastal protection measures (Figure 11), but to be fully effective, ecosystem management has to be an integral part of coastal zone management (OSPAR, 2009).

Figure 11 An example of ecosystem-based adaptation at Abbotts Hall Farm on the east coast of England, where salt marsh and grassland is being used as a natural coastal defence (source: OSPAR, 2009).

North Sea (coastal) adaptation measures are competing with many other claims on space and possibilities the region has to offer. In this context the Integrated Coastal Zone Management (ICZM), a concept born at the 1992 Earth Summit in Rio de Janeiro, is generally recognised as the most effective tool for incorporating conservation and sustainable use of marine and coastal biodiversity aspects into the planning of coastal areas (Pickaver *et al.,* 2004).

Most countries bordering the Greater North Sea have launched national climate change adaptation strategies in recent years (PEER, 2009). Although the process often started with assessing the need for adaptation and setting-up research programmes, coastal defence has been a key issue in defining precise measures. A number of coastal defence measures are available and these can be implemented in different ways (Table 7). However, beach nourishment is often cited because of its cost-effectiveness, even under extreme increases in sea-level (PBL, 2007).

Table 7 Overview of current national coastal adaptation strategies in countries bordering the Greater North Sea (note emphasis on sea-level rise and coastal erosion) (source: OSPAR, 2009).

Country	Adaptation Strategy (y/n)	Adaptation measures	Comments
Belgium	N (foreseen for 2012)	• Beach nourishments • Primary defences	
Denmark	Y (2008)	• Beach nourishments • Dyke foreland management • Primary defences	Along western coast of Jutland, beach nourishment is regularly adjusted to the actual changes of sea-level and coastal erosion. Dyke foreland is considered as coastal protection measure, however at present, no measures are undertaken to adapt to climate change. Adaptation of primary flood defences is usually considered a local issue.
France	Y (2006)	• Flood risk mapping	Adaptation is under way as result of “Le Grenelle de la mer”, a process to set a new integrated policy for the sea and the coastal zone. First consideration e.g. on risks and costs of coastal adaptation have already been undertaken.
Germany	Y (2008)	• Primary defences • Beach nourishments • Dyke foreland management • Secondary dike lines	Master plans coastal defence Lower Saxony and Schleswig-Holstein.
The Netherlands	Y(2008)	• Large scale beach nourishment • Dams, including novel techniques • Storm surge barrier (re)design • Land reclamation and coastal defence structure	
UK	Y(2008)	• Primary defences • Managed realignment • Dyke foreland management • Conversion of farmland to salt • marshes and grasslands	

At the European Union level, the need for adaptation was initiated through the wide-ranging consultation on the Adaptation Green Paper (2007) and the subsequent launch of the White Paper on Adaptation to Climate Change (2009). One of the four pillars of the White Paper is mainstreaming adaptation by integrating adaptation policies into EU policies for different sectors. For the Greater North Sea, this includes a number of EU instruments (Table 8).

Table 8 Overview of main EU instruments facilitating marine and coastal adaptation to climate change (source: OSPAR, 2009)

EU instruments	What they regulate
EU White Paper on Adapting to Climate Change COM(2009) 147/4	Framework for adaptation measures and policies to reduce the EU's vulnerability to the impacts of climate change
Marine Strategy Framework Directive 2008/56/EC	'Good environmental status' of the marine environment
Water Framework Directive 2000/60/EC	'Good ecological status' of coastal and transitional waters
Floods Directive 2007/60/EC	Assessment and management of flood risks
Integrated Coastal Zone Policy (COM/2000/547)	Integrated planning and management of human uses of the coastal zone
Birds (79/409/EC & 2009/147/EC) and Habitats (92/43/EC) directives	Cornerstones of Europe's nature conservation policy. Protection of bird species and habitats in Europe, including marine

At the international level, the Greater North Sea is covered by the OSPAR Convention, which was established in 1972 to protect the marine environment of the North-east Atlantic. Although there is not a separate climate change strategy, the OSPAR Commission is establishing ways in which to incorporate both climate change and ocean acidification into future work. OSPAR's Quality Status Report for 2010 will, for example, reflect the current knowledge of climate change impacts on the marine environment. Likewise, OSPAR is trying to facilitate enhanced co-operation and economic burden-sharing between parties for research and planning of coastal adaptation, especially where larger coastal areas spanning national boundaries are affected (OSPAR, 2009).

4.8. Case study

The Dutch system of coastal defences (dykes and sand dunes) are designed and maintained to withstand a worst case one in 10,000 year event. Rising sea levels increase the duration and forces of high tides, but timely maintenance and strengthening of defences can sustain a minimum chance of disaster. A plausible future extreme sea level rise scenario for the Netherlands, based on paleoclimatological data, is 1.5 m/century (PBL, 2007). Given the technical adaptive capacity of the Netherlands and its safety margins, it can be concluded that the delta region could be kept safe using available techniques, even with extreme sea level rise, but that additional measures may be required in the longer-term (PBL, 2007). In 2008, the Delta Commission presented a high-end estimate of sea level rise of 65-130 cm by 2100, based on a 6°C temperature rise scenario, and also concluded that technically the delta region of the Netherlands could be protected against flooding (Deltacommissie, 2008). The maximum range of sea level rise given by IPCC (2007) and KNMI (2006) were based on scenarios with a maximum of 4°C temperature rise. A 6°C temperature rise thus exceeds IPCC and KNMI's high end estimates, but still lies within the total range of uncertainty with respect to temperature rise.

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5. North-east Atlantic Ocean: Celtic Seas

The Celtic Seas extends between 60° N and 48° N and between 5° W and the west coast of Great Britain to the 200 m depth contour to the west of 6° W. The EEA member counties found in the Celtic Seas include the United Kingdom (the west Coast of England and Scotland, and the entirety of Wales and Northern Ireland) and Ireland (Figure 12).

The Celtic Seas region contains wide variations in coastal topography, from fjordic sea lochs, to sand dunes, bays, estuaries and numerous sandy beaches. The large range of habitats in the region supports a diverse fish fauna. Although traditional maritime activities, such as fishing, take place in the Celtic seas, there is ongoing development of tourism (OPSAR, 2010).

Figure 12 Location of the Celtic Seas in the North-east Atlantic Ocean (OPSAR Commission Region III) (source: OSPAR, 2010).

5.1. Physical geography and oceanography

The region contains wide variations in coastal topography, including fjordic sea lochs, rocky headlands, cliff formations, salt marshes, sand dunes, bays, estuaries and numerous sandy beaches (OPSAR, 2010). Many of Europe's major rivers enter the Celtic Seas, they include:

- The Severn, Mersey, Eden and Ribble on the west coast of England;

- The Dee, Towy, Teifi, Usk and Tâf in Wales;
- The Nith and Clyde on the west coast of Scotland;
- The Bann and Foyle in Northern Ireland and;
- The Shannon, Barrow, Liffey in Ireland.

5.2. Biodiversity and ecosystems

The large range of habitats in the region supports a diverse fish fauna, including many commercially important species. Many of these species have relatively short migration routes between feeding and spawning areas. The region has a large number of areas attractive to seabirds and waterfowl. The common or harbour seal and the grey seal are widely distributed throughout the region. The waters around Ireland and to the west of Scotland support a variety of cetaceans, but apart from the population of bottle-nose dolphins in Cardigan Bay, they are only occasionally seen in the Irish Sea (OPSAR, 2010).

5.3. Human geography

The general pattern of population change in the coastal areas of Region III is one of declining numbers in the largest city centres, growing populations in the suburbs of major towns, and stable or declining populations in more rural and remote regions. There are seasonal variations in the population of many coastal resort towns. The current trend in tourism and recreation towards a diverse range of more individual pursuits (such as angling and surfing) on less developed parts of the coast can result in new pressures on natural habitats and water quality.

5.4. Economic activities

Region III also contains a number of internationally important ports and harbours. Other human activities in the region include: fishing, mariculture, sand and gravel extraction, dredging and dumping, oil and gas exploration and production, shipping, coastal industry, military activities and agriculture (OPSAR, 2010).

5.5. Climate change impacts

Climate simulations re-enforce existing trends in storminess and indicate some further increase in wind speeds and storm intensity in the north-eastern Atlantic during 2010-2030, with a shift of storm centre maxima closer to European coasts (Knippertz *et al.*, 2000; Leckebusch and Ulbrich, 2004; Lozano *et al.*, 2004).

Projected storminess by Lozano *et al.,* (2004) shows that for most of the northern part of the study region (along the European North Atlantic Coastline from Scotland to Spain) covering Ireland and Scotland, results describe the establishment by ca. 2060 of a tendency for fewer but more intense storms.

In Ireland, the impacts of sea-level rise will be most apparent in the major cities of Cork, Limerick, Dublin and Galway. Sea-level rise presents itself as a serious problem where there is infrastructure at risk of inundation. The inability of the shoreline to adjust naturally to a change in conditions in areas of dense infrastructure may enhance any impacts as the system tries to attain a new equilibrium between erosion, transportation and deposition (Sweeney *et al.*, 2003).

5.6. Climate change vulnerabilities

The impacts of the changes in storminess projected by Lozano *et al.,* (2004) for the vulnerability of European Atlantic coasts reveal that for low-lying, exposed and 'soft' sedimentary coasts, as in Ireland, these changes in storminess are likely to result in significant localised increases in coastal erosion.

The risk of direct impacts of rising sea-levels will be lower along high and rocky coasts for example in Ireland, and some parts of the coastline in the UK. Increased storminess and higher and more forceful waves however may increase the rate of erosion of the coastlines in all OSPAR Regions. These impacts are expected to be highly location specific and responses would need to take place primarily at local level (OSPAR, 2009).

In Ireland, a study prepared for the Environmental Protection Agency by the Department of Geography, National University of Ireland (Sweeney *et al.*, 2003) revealed that several natural and human systems can expect to be particularly affected by anticipated changes in climate. These vulnerable natural and human systems relevant to the coast environments, include water, air and soil resources, ecosystem functioning and biodiversity and are summarised below.

Among the most vulnerable sectors of the marine economy in Ireland is aquaculture. The potential for disruption as a result of climate change related aspects is considerable. Salmon production in Ireland is near the southern range of the species distribution and temperature increases, together with changes in the incidence of algal blooms, pests and diseases, may have considerable commercial impacts requiring further study.

Twenty-five per cent of the population of Ireland live in a coastal District Electoral Division and considerable investment in transportation and energy infrastructure has taken place within a few metres of the high water mark in many highly urbanised areas. Exposure of people and facilities to risk as a result of rising sea-levels largely depends on their location and the protection offered to them by the make-up of the coast itself.

Some of Ireland habitats of nature conservation importance are considered to be particularly vulnerable to climate change and may require particular attention. Of these habitats identified, sand dunes are one of six identified as vulnerable. Sand dunes are also one of the two most critical in this category which are highly vulnerable to the climate changes projected.

According to the Irish National Spatial Strategy (2002-2020), for coastal zone management in Ireland, the greatest impact of flooding would be felt in the urbanised east coast and in the three major cities located on the coast, Dublin, Cork and Galway. On the west coast counties from Cork to Donegal and the Shannon Estuary, the likelihood is that some 150,000 Ha of land is vulnerable to loss by sea-level rise. In addition to loss of land through gradual inundation, the increased storminess and severity of storms expected as the climate changes will exacerbate the potential for coastal damage. The 100-year return period for incidences of extreme levels of water can be expected to be reduced to 5 years. Overall some 176,000 Ha of coastal land is at risk from sea-level change (Department for Environment, Heritage and Local Government, Ireland, 2002).

In England and Wales (and therefore this is relevant for the Greater North Sea section 4), the Environment Agency have developed a screening tool which will allow planners and policy makers to rapidly identify the estuaries within England and Wales that are most vulnerable to future change if there are changes in sea-level or other climate related factors, like storminess or river flow. These changes in sea-level may have a significant impact on the shape and size of some estuaries in England and Wales. The Environment Agency needs to understand what changes are likely to occur because it is required to maintain 'good status' in estuaries and the habitats found within them. This is to ensure that The Environment Agency complies with the European Union's Water Framework Directive (2000/60/EC) and the Habitats Directive (92/43/EC). The tool is based on four measures or 'indices' of vulnerability that describe important estuary characteristics and how they are likely to be affected by global climate change. These are mass flow, vertical mixing, energetics and salinity intrusion. The resulting tool combines theory and observational data to provide an idea of the likely morphological and environmental changes over the next century across the diverse range of estuaries in England and Wales. It indicates that deep narrow estuaries are likely to be far more resilient to global climate change than shallower, coastal estuaries (Environment Agency, 2010).

5.7. Climate change adaptation

Adaptation policies for those countries with coastline on the Celtic Sea include two adopted (England and Scotland), and three in preparation (Ireland, Wales and Northern Ireland). It is important to note that only Ireland, Northern Ireland and Wales, resides fully within the Celtic Sea region. The other adaptation policies for England and Scotland mentioned below are also relevant to the Greater North Sea region.

In the UK the Climate Change Act 2008 provides a legally binding framework to tackle the dangers of climate change. The 2008 act makes the UK the first country in the world to have a legally binding long-term framework to cut carbon emissions. It also creates a framework for building the UK's ability to adapt to climate change. The Climate Change Act enhances the UK's ability to adapt to the impact of climate change and establishes the following:

- A UK wide climate change risk assessment that must take place every five years;
- A national adaptation programme which must be put in place and reviewed every five years to address the most pressing climate change risks to England;
- The Government has the power to require 'bodies with functions of a public nature' and 'statutory undertakers' (companies like water and energy utilities) to report on how they have assessed the risks of climate change to their work, and what they are doing to address these risks;
- The Government is required to publish a strategy outlining how this new power will be used, and identifying the priority organisations that will be covered by it;
- The Government will provide Statutory Guidance on how to undertake a climate risk assessment and draw up an adaptation action plan; and

- The creation of an Adaptation Sub-Committee of the independent Committee on Climate Change in order to oversee progress on the Adapting to Climate Change Programme and advise on the risk assessment.

The Act extends throughout the UK, however the devolved administrations are each responsible for considering how climate impacts will affect their countries and are therefore legally bound to develop their own country-specific adaptation strategies. Guidelines in England and Wales have been have been issued recommending sea-level rise be taken into account in flood and coastal defence project grants aided by the Department for Environment, Food and Rural Affairs (Defra) (Defra, 2006). In July 2008 the English Government published "Adapting to Climate Change in England: a framework for action" (Defra, 2008) which summarised the Government's Adapting to Climate Change Programme. Individual government departments published Adaptation Plans in March 2010, setting out how they are assessing and managing the risks from climate change. Defra's Adaptation section of their Plan (Defra, 2010) identifies five actions with regards to flooding and coastal erosion, and a further nine adaptation actions in relation to Ocean and Seas.

Both the Welsh Assembly Government and Government of Northern Ireland have begun work on their own action plan for adapting to climate change.

Scotland's Climate Change Adaptation Framework was published in December 2009 (Scottish Government, 2009). In the Marine and Fisheries sector, 10 adaptation actions are identified and assigned to responsible parties. Within the Biodiversity and Ecosystem Resilience sector, one action is related to vulnerable coasts.

The Republic of Ireland has a national adaptation strategy in preparation. In response to sea-level rise and coastal erosion, Local Authorities and State agencies are involved in:

- flood hazard mapping
- tidal defences
- coastal zone management

Research on adaptation planning including issues like vulnerability and adaptation in the coastal zone is also ongoing (OSPAR, 2010).

Adaptive response to and expenditure on sea-level rise and storm surge
A recent study on estimating the current level of actual coastal adaptation showed that there is a general tenancy to spend less than the scientific estimates of the PESETA (PESETA, 2009) study on model projected economic costs of coastal adaptation (EC, 2009).

Ireland spends less than the scientific investment calculated. The gap might relate to the fact that Ireland does not take a sea-level rise scenario into account in current coastal protection operations. Ireland moreover tends to the use of accommodate and retreat actions in the future, which have not been accounted for by PESETA (2009).

5.8. Case studies

Current economic vulnerability: Ireland case study – key messages
(source: EC, 2009)

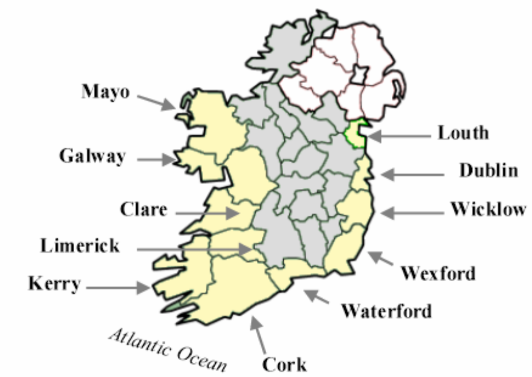
Ireland is the third largest European island. It is situated at the north-west of continental Europe. The coastline measures 4 577 km, bordering the Atlantic Ocean on the north-west and the Irish Sea on the south-east. More than 50% of the population lives within 15 km of the Irish coastline. Most of the population is concentrated in cities, with the major coastal cities being Dublin, Cork, Limerick and Galway.

Flooding and erosion in Ireland

High relief rocky cliffs and bays dominate the Atlantic coastline topography. The coast is also characterised by high wave energy generated by winds coming from the Atlantic Ocean, causing it to be more subject to erosion than the rest of the country. It also receives the full force of North-Atlantic storms. Coastal erosion may weaken the structure of these rocky cliffs, which are particularly vulnerable due to their geological nature, causing collapse.

The Irish Sea coast on the other hand is composed mainly of low-lying regions with non-consolidated sediments and glacial tills. Erosion rates reach values of 1-2 m annually. Approximately 20% of Ireland's entire coast is at risk of erosion. Sea-level Rise (SLR) combined with an increase in severity and frequency of coastal storms is expected to exacerbate the problems, especially along the Atlantic coast (Figure 13).

Figure 13 Counties of Ireland and overview of main physical and socio-economic indicators of the coastal zones (source: EC, 2009).



Physical and socio-economic indicators	*Atlantic Ocean*
Sea Level Rise	High
Coastline length	4 577 km
10 km coastal zone below 5 metres elevation	<5%
Coastline subject to erosion	912 km (20%)
GDP in 50 km zone (€ million)	71 505 (58%)
Population in 50 km zone	3 343 018 (83%)

A national study of 2004 (DoCMNR, 2004) estimated that the county Wexford has the highest proportion of vulnerable coast, with 40% of it in need of protection. The same review indicated that the county Cork has, with 149 km, the longest stretch of coast needing protection.

Loss of coastal eco-systems in Ireland

Climate change may also impact natural areas. SLR and its subsequent increase in wave energy could cause salt marshes on the Irish coast to migrate landwards. As salt marshes and sand dunes are important migratory bird habitats, the loss of these habitats could present problems for species diversity. Ireland has designated many of such habitats as protected areas. Coastal protection in these designated areas is subject to EU directives as well as national environmental legislation. Proposed protection measures go through a system of consent involving the relevant stakeholders in order to ensure that no measures are contravened by the protection measures taken in these areas.

Coastal defence, risk reduction and adaptation plans in Ireland
Ireland does not have any national coastal defence plans available. Protection measures are proposed by local authorities but can be eligible for funding under the coastal protection sub-programme of the 2007-2013 National Development Plan.

At strategic level, Ireland established a Climate Change Strategy in 2007. In preparation of a national adaptation strategy, scheduled for 2009, the Irish government published preliminary 'Planning Guidelines on the Planning System and Flood Risk Management' and supports the national projects 'National Coastal Protection Strategy Study (CPSS)' and the 'Flood Risk Assessment and Management Studies (FRAM)'.

Past, present and future adaptation expenditure in Ireland
In Ireland, the expenditure to protect the coast from flooding and erosion over the period 1998-2015 totals € 95 million. About 75% is supported through National Development Plans; the remaining 25% has to be matched by local authorities.

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6. North-east Atlantic Ocean: Bay of Biscay and Iberian Coast

The Bay of Biscay and Iberian Coast in a sub-region of the North-east Atlantic Ocean 'European Marine Region', established under the EU's Marine Strategy Framework Directive (2008/56/EC; EU, 2008) to protect the resources upon which marine-related economic and social activities depend. It is also one of five regions (Region IV) identified by the OSPAR Convention (1998), which aims to protect the marine environment of the North-east Atlantic. The Bay of Biscay and Iberian Coast includes the Atlantic coastlines of France, Spain and Portugal, and extendes from north-west Brittany in the north to Gibraltar in the south (Figure 14).

Figure 14 Location of Bay of Biscay and Iberian Coast (OPSAR Commission Region IV). (source: OSPAR, 2010).

6.1. Physical geography and oceanography

The coastline of the Bay of Biscay and Iberian Coast is exceptionally diverse, with rocky cliffs and shores, estuaries and rias, shingle banks and beaches, sandy and muddy shores, and coastal lagoons and wetlands. These support a rich variety of coastal habitats and productive ecosystems (OPSAR, 2010). Coastal morphology ranges from long sandy beaches in Aquitaine and the Gulf of Cadiz to an almost continuous rocky shore along the northern and north-western Iberian coast. In the Galician region, the coast is dissected by a large number of rias - unique systems with wind-modulated estuarine circulation. Rias are highly productive and contain the world's largest mussel raft cultures (OSPAR, 2000).

Large river systems flow into the Bay of Biscay and Iberian Coast and represent the principal sources of fresh water input. These include the Loire, Dordogne and Garonne in France, the Minho on the northern Portuguese/Spanish border, the Douro and Tagus in Portugal, the Guadiana on the southern Portuguese/Spanish border, and Guadalquivir in southern Spain.

A wide continental shelf extends westwards from France. The shelf narrows considerably along the northern Spanish and Portuguese coasts, and widens again in the Gulf of Cadiz. Substrates range from rocky or sandy sediments on the inner shelf to predominantly muddy sediments on the outer shelf (ICES, 2008). Sediment transport is driven by tides and wind, with storm waves being the main agents of sediment mobilisation. Seabed disturbances are relatively short-lived and occur mainly during high energy events. Some remarkable topographic features are found in the area; these include seamounts and deep submarine canyons - two of which are amongst the most pronounced in the world (OSPAR, 2000).

Most of the water in the Bay of Biscay and Iberian Coast is of North Atlantic origin. Depending on latitude, the area is affected by both the sub-polar and the sub-tropical gyres, although the general circulation tends to follow the sub-tropical gyre in a relatively weak manner. During spring and summer, northerly winds are dominant along the coast, causing coastal up-welling and producing a southward surface current and a northward undercurrent. In autumn and winter, the surface circulation is predominantly northwards, partially driven by southerly winds and alongshore density gradients (ICES, 2008).

6.2. Biodiversity and ecosystems

Biologically the Bay of Biscay and Iberian Coast can be subdivided into a sub-tropical zone (from Gibraltar to Finisterre) and a sub-tropical/boreal transition zone (from Finisterre to Brittany). Within these zones, sedimentary and topographic diversity result in many different coastal habitat types. This is reflected in the biological richness of the area, which includes many fish species of commercial interest (OSPAR, 2000).

A variety of fish, seabirds and marine mammals occupy the many different habitats that typify the Bay of Biscay and Iberian Coast. Around 700 fish species occur in the area and many reach their southern or northern distributional limits in the Bay of Biscay. The majority live close to the sea bed (e.g. sole, dogfish and blue whiting) and have a limited geographical range, whereas pelagic species (e.g. sardine and mackerel) have a wider distribution. Albacore and blue fin tuna live in sub-tropical areas of the western Atlantic and migrate annually to the Bay of Biscay. Whilst the seabird community is dominated by sea gulls, the Iberian Peninsula is strategically important in the migratory behaviour of other seabird species. By comparison with other European Atlantic areas, the nesting seabird community is very poor, but improves during migrations and in winter. The autumn migration of the Balearic shearwater and great cormorant is particularly significant. The marine mammal community includes both boreal and temperate species. Seven species of seal and 30 species of cetacean have been recorded (OSPAR, 2010).

Primary production in the area is enhanced by coastal up-welling, coastal run-off and river plumes, seasonal currents, and internal waves and tidal fronts. The onset of spring phytoplankton blooms can occur as early as February on the Iberian Coast and in March in the Bay of Biscay. Blooms cover the entire offshore area by early April, but decline from May onwards as chlorophyll values drop sharply. Low chlorophyll values continue in summer. Autumn blooms are restricted to coastal areas. Zooplankton show a similar pattern to phytoplankton, declining after the spring bloom and with a patchy distribution associated with up-welling and river plumes thereafter (ICES, 2008).

6.3. Human geography

The coastline of the Bay of Biscay and Iberian Coast has a high population density, with a number of large urban population centres. The main cities surrounding the Bay of Biscay are Brest, Nantes, La Rochelle, Bordeaux and Bayonne in France and San Sebastián, Bilbao, Santander and Gijón in northern Spain. On the Iberian Coast, these include Porto and Lisbon in Portugal and Cádiz in southern Spain.

6.4. Economic activities

The main economic activities around the Bay of Biscay and Iberian Coast are tourism, fishing and aquaculture, shipping, sand and gravel extraction, and the development of wind, wave and tidal energy. Various types of industry, agriculture and other land-based activities are located along the coastal strip. Major rail and road networks link these coastal hubs with major regional, national and European inland cities.

6.5. Climate change impacts

The Bay of Biscay and Iberian Coast is situated in temperate latitudes, between 48°N and 36° N. Its climate is strongly influenced by the inflow of oceanic waters from the Atlantic and by low pressure systems frequently contained in large westerly air streams. Intense storms occur in the Bay of Biscay, particularly in winter.

The impacts of climate change are already becoming apparent in the area. Observed impacts include an increase in sea temperature, a rise in sea-level, and an increase in ocean acidity (OSPAR, 2009). Further changes can be expected in the physical, chemical and biological aspects of the environment and these are likely to have adverse effects on the functioning of ecosystems.

The rate of increase in sea temperature observed since 1994 has been greater than the global mean and is likely to continue during the 21st Century. The area could experience decreases in freshwater input, but changes in regional precipitation are difficult to project. Drier summers may already be contributing to a decrease in nutrient inputs. Severe winds and mean wave heights have increased over the past 50 years, but there is very low confidence in the projections of future storm events. A slowdown in the Atlantic Overturning Circulation is, however, very likely.

Global sea-level rose on average by 1.7mm/yr through the 20th Century, with a faster rate being evident in the 1990s. A rise of between 0.18 and 0.59m is projected by 2100, mostly through thermal expansion of sea water (although there is high uncertainty at the upper range due to ice sheet processes). Past changes suggest that a rise of 2m in a century should not be discounted.

The flux of CO_2 into surface waters reduced in 2002-2005 compared with 1994-1995. Future changes will be dependent on water temperature, stratification and circulation. A global average decrease in pH of 0.1 units has been observed since the start of the industrial revolution. During the 21st Century, ocean acidity could reach levels unprecedented in the last few million years, with potentially severe effects on calcareous organisms.

Whilst the combined effects of coastal erosion, infrastructure and sea defence have led to a narrowing of the coastal zone in many locations, future projections are very uncertain and highly location-specific.

6.6. Climate change vulnerabilities

The vulnerability of coastal and marine ecosystems and societies to climate change will differ widely around the Bay of Biscay and Iberian Coast and will depend on local physical characteristics and the rate and nature of the impacts.

Low-lying coastal communities, infrastructure and economies are vulnerable to sea-level rise, storms and floods, and coastal erosion. However, such impacts are likely to be highly location-specific. Coastal wetland habitats, such as salt marshes and sand dunes, act as natural flood barriers and dissipate wave energy during storm surges. These valuable ecosystems services may be lost as a result of sea-level rise. Coral reefs, which offer similar protection, are likely to decline due to increasing ocean acidity.

An increase in sea temperature is resulting in a general northward movement of fish and plankton, with Atlantic species moving to more northern seas and sub-tropical species moving into the area. Ocean acidification is beginning to affect the development of shell-bearing larvae. Changes in species reproduction and distribution could provide new opportunities for fisheries and aquaculture. However, better understanding of the potential impacts of climate change on the most vulnerable species and ecosystems at regional and local level is needed.

Many coastal and marine ecosystems are also under pressure from human activities, resulting in pollution, over-fishing, and damage and loss of habitats. Cumulative effects and interactions of climate change with other pressures and impacts will render coastal and marine ecosystems and biodiversity more vulnerable (OSPAR, 2009).

6.7. Climate change adaptation

Adaptation strategies that work with nature's capacity to absorb or control climate change impacts can be a more efficient and effective way of increasing the resilience of vulnerable systems than simply focusing on physical infrastructure. National adaptation strategies have been adopted at policy level by countries bordering the Bay of Biscay and Iberian Coast.

These focus mainly on land-based adaptation and on coastal defence. Adaptation actions are more challenging in the marine environment, as fewer tools are available.

In low-lying coastal areas, adaptation of current policies is imperative to minimise the potential risks, damages and residual costs of flooding, erosion, loss of ecosystems, and freshwater shortage caused by climate change (e.g. rising sea-levels, increased storminess, and higher and more forceful waves). In addition, adaptation options are available to accommodate sea-level rise and the increased risks of flooding and coastal erosion (Table 9).

Table 9 Examples of coastal adaptation options (source: EC, 2009)

Options	**Protect** (continue use of vulnerable areas)	**Accommodate** (continue use of vulnerable areas by adjusting living and working habits)	**Retreat** (abandon vulnerable areas)
“Hard”	Dykes, seawalls, groins, breakwaters, salt water intrusion barriers	Building on pilings, adapting drainage, emergency flood shelters	Relocating threatened buildings
“Soft”	Sand nourishment, dune building, wetland restoration or creation	New building codes, growing flood or salt tolerant corps, early warning and evacuation systems, risk-base hazard insurance	Land use restriction, set back zones

France, Portugal and Spain have adopted strategies to respond to sea-level rise and coastal erosion (Table 10). Current strategies focus mainly on protective measures and build on existing measures and practices to minimize the risk of floods and coastal erosion. A national initiative in Spain (see case study below) illustrates the development of policy and operational responses to the expected impacts of climate change on coastal areas.

Table 10 Overview of current coastal adaptation strategies and measures around the Bay of Biscay and Iberian Coast (source: OSPAR, 2009)

	National strategy	**Adaptation measures**	**Comments**
France	National strategy for the coast and its adaptation being prepared	Flood risk mapping	Consideration of risks and costs of coastal adaptation have been made
Portugal	National strategy for Integrated Coastal Zone Management (ICZM)	Regional Coastal Zone Management Plans	Strategy covers monitoring, and evaluation of vulnerability, risk and existing hard interventions
Spain	National Plan for the Adaptation to Climate Change (PNACC)	• Adaptation of coastal infrastructure and resources • Projections of impact and vulnerability • Integration of adaptation into ICZM	Includes assessment of climate change impacts in coastal areas

Most coastal strategies have tended to focus on 2020 as a planning horizon. Recently, the emergence of climate adaptation policies has shifted the focus towards longer-term strategies. However, knowledge about local impacts of climate change is limited or differs widely and is too uncertain to inform decisions about long term adaptation measures. A better understanding of changes in local risks is, therefore, essential for the development of operational adaptation strategies. Additionally, risk assessments need to take account of spatial developments and changes in coastal protection levels. A number of project-based platforms are already available for countries to exchange experiences and best practices in coastal planning and management and coordinate national approaches to coastal adaptation (e.g. Ourcoast). There is also a need for enhanced cooperation and sharing of economic burden between countries for research and planning in coastal adaptation, particularly where sea-level rise and coastal erosion affect coastal areas spanning national borders (OSPAR, 2009).

Experience of adaptation in the marine environment is limited and may have to rely, to a large extent, on the development of existing and new policy, legislative and regulatory frameworks. Adaptation measures will also depend on best available evidence of the vulnerability of marine ecosystems. Measures could include taking account of climate change in fisheries catch quotas, building climate change into the conservation of marine biodiversity, and considering climate change when planning and managing maritime activities and when implementing an ecosystem approach (OSPAR, 2009).

Adaptation to climate change in coastal and marine environments will require an integrated approach, with trans-boundary coordination and cooperation. Some instruments are already in place that can facilitate coastal and marine adaptation to climate change (Table 11) (OSPAR, 2009).

Table 11 Overview of main EU instruments facilitating coastal and marine adaptation (source: OSPAR, 2009).

EU instruments	What they regulate
EU White Paper on Adapting to Climate Change (2009)	Framework for adaptation policies and measures to reduce the EU's vulnerability to the impacts of climate change
Marine Strategy Framework Directive (2008/56/EC)	'Good environmental status' of the marine environment
Water Framework Directive (2000/60/EC)	'Good ecological status' of coastal and transitional waters
Floods Directive (2007/60/EC)	Assessment and management of flood risks
Integrated Coastal Zone Management (COM/2000/547)	Integrated planning and management of human uses of the coastal zone

6.8. Case studies

Spain's economy is highly dependent on its coastal areas and a significant percentage of its population is concentrated here. Tourism, fishing, industrial and farming activities, and other services are linked to coastal resources. Special efforts have, therefore, been dedicated to identifying threats to coastal areas when considering the country's key areas of vulnerability to climate change.

Since 2004, Spain has taken major steps towards defining a coherent set of policies to address climate change. A study by the University of Cantabria considered sea-level rise and other climate change impacts on coastal areas. Low-lying areas in the Gulf of Cádiz and Doñana (Andalucía) and the beaches of Eastern Cantabria are at significant risk of flooding if sea-level rises by 0.5 m.

One of the cornerstones of the institutional response to climate change is the Spanish National Climate Change Adaptation Plan (PNACC). Adopted in October 2006, its aim is to mainstream adaptation to climate change into the policies and planning processes of all relevant sectors. The PNACC is the reference framework for coordinating assessments of impacts, vulnerability and adaptation for the sectors likely to be affected (e.g. water resources, agriculture, forests, biodiversity, coasts, health, and tourism).

Work is underway to mainstream climate change adaptation into a national Sustainability Strategy for Spanish Coastal Areas and an Integrated Coastal Zone Management system. Building on the above-mentioned study, detailed projections of the impacts and vulnerability of small coastal units defined by socio-economic and natural features has been carried out. This was the starting point for a review of coastal planning, involving all relevant administrations and social and economic actors in a participatory process.

The University of Cantabria is undertaking a second study of climate change in Spanish coastal areas[3]. Its objective is to further improve data, methodologies and tools for assessing climate change impacts, taking into account a more refined spatial resolution and a special focus on costs and benefits of adaptation measures and their practical application in the tourism sector.

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[3] For further information, see:
http://www.mma.es/portal/secciones/cambio_climatico/areas_tematicas/impactos_cc/
http://www.mma.es/portal/secciones/cambio_climatico/areas_tematicas/impactos_cc/ini_amb_nac.htm

7. North-east Atlantic Ocean: Macaronesian biogeographic region

The Macaronesian in a sub-region of the North-east Atlantic Ocean 'European Marine Region', established under the EU's Marine Strategy Framework Directive (2008/56/EC; EU, 2008) to protect the resources upon which marine-related economic and social activities depend. It is a biogeographic region comprising the waters surrounding the Canaries, Madeira and the Azores. The Azores also fall within one of five regions (Region V - Wider Atlantic) identified by the OSPAR Convention (1998), which aims to protect the marine environment of the North-east Atlantic.

7.1. Physical geography and oceanography

The Canaries archipelago consists of seven main islands: Tenerife, Fuerteventura, Gran Canaria, Lanzarote, La Gomera, El Hierro and La Palma (Figure 15). The eastern-most island, Lanzarote, is 100 km to the west of Morocco. The islands have very rugged landscapes as a result of recent (and some current) volcanic activity. The El Teide volcano on Tenerife is the highest summit in the archipelago (3,718 m) and is designated as a World Heritage Site by UNESCO.

Figure 15 Map of Canaries archipelago (source: Canary Islands Tourist Board, http://www.turismodecanarias.com/canary-islands-spain/tourist-guide/tourist-information)

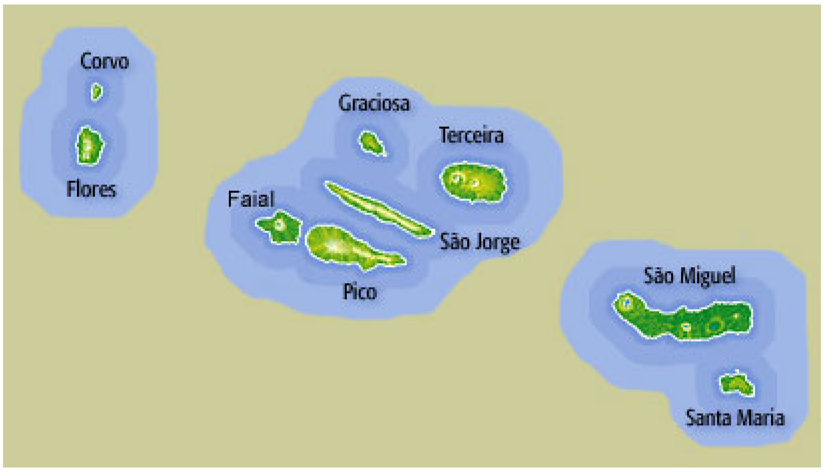
Madeira is the largest of a group of three main islands (Figure 16) and over 20 smaller islands and islets situated 520 km from the Moroccan coast and 1,000 km from the European continent. The archipelago is volcanic in origin, with Madeira being the top of a massive volcano that rises about 6 km from the floor of the Atlantic Ocean. The volcano formed on an east-west rift in the oceanic crust and is part of an underwater mountain range called Tore. Following a period of extensive erosion, which carved two large amphitheaters in the central part of the island, volcanic activity resumed and produced new cones and lava flows on top of the older eroded rocks. These created the mountain chain that forms the backbone of the island, from which deep ravines radiate to the coast. Madeira's steep sea cliffs are amongst the highest in Europe.

Figure 16 Map of Madeira and associated islands
(source: Wikipedia, http://en.wikipedia.org/wiki/Madeira)

The Azores is an archipelago of nine islands situated about 1,500 km west Portugal and Morocco and 3,900 km east of North America. It is divided into three groups (Figure 17):

- The eastern group of Sao Miguel and Santa Maria
- The central group of Terceira, Graciosa, Sao Jorge, Pico and Faial
- The western group of Flores and Corvo.

Figure 17 Map of Azores archipelago (source: Azores Tourist Board, http://www.azores.com/azores/azores.php)



The archipelago extends for 600 km from Santa Maria in the western group to Corvo in the eastern group. The Azores sit on the Mid-Atlantic Ridge and are of volcanic origin, revealed by volcanic cones and craters. Pico, a volcano that stands 2,351 m high on the island of the same name, is the highest point in the Azores. Santa Maria is the only island that shows signs of reef sediments. The seabed surrounding the islands is rugged with a sharply fluctuating topography, and crustal rocks exposed where the seafloor was formed relatively recently along the Mid-Atlantic Ridge (OPSAR, 2010).

The Azores lie close to the southern margin of OSPAR Region 5. The region includes a water mass known as the North Atlantic Deep Water, which is formed by cold waters mixing with ambient waters. This is one of the major driving forces for the thermohaline circulation of the world's oceans, with oceanic and climatic fluctuations being rapidly transferred to all other oceans. Movement in the upper layers of the water column is generally from west to east (OPSAR, 2000).

7.2. Biodiversity and ecosystems

The biodiversity of the Canaries is exceptionally rich. There are five main habitats types: xerophytic shrub, thermophilous forest, laurel forest, pine forest, and high mountain shrub (see 'Climate change impacts', below). The vegetation of the archipelago includes a total of 1,992 vascular plants. Endemism is very high for plants (21%), reptiles (100 %) and invertebrates (39%). The islands are also home to five species and 31 sub-species of endemic birds. Among them, the Bolle's laurel pigeon, the white-tailed pigeon and the blue chaffinch are threatened. The La Gomera giant lizard is another iconic endemic species of these islands. There are 145 protected areas in the Canaries and the island of El Hierro is a UNESCO biosphere reserve. Destruction of habitats, over-exploitation of resources and invasive species are the principal threats to the islands' biodiversity. The impacts of urban and tourist development and the effects of forest fires are among the most significant conservation concerns (Petit, 2008).

The marine biodiversity of the Canaries is also exceptional. Deep water coral reefs surround the islands at depths of 50 metres. The islands are a major hotspot for marine mammals: 29 of the world's 81 whale species are found in the waters of the archipelago. Four species of marine turtles also occur here, but reproduce elsewhere (Petit, 2008).

Madeira has an very rich biodiversity, with close to 500 vascular plants and 1000 insects (Petit, 2008). Many of these species are endemic - invertebrates, some lizards and birds, and a native bat. The island was once covered by indigenous laurel forests. Early settlers set fire to the forests to clear the land for farming. In the south, very little remains. However, the northern slopes contain the largest and best-preserved laurel forests in Macaronesia. They are designated as a World Heritage Site by UNESCO and are home to some unique species, including the Trocaz pigeon and the Madeiran Petrel (the most threatened bird in Europe). Madeira is also important for other breeding seabirds, including the North Atlantic little shearwater and Cory's shearwater. Europe's biggest tarantula is found on the Desertas islands. More than 250 species of land molluscs, most of which are endemic and vulnerable, are also found on these islands. Numerous species of marine mammal live in the waters around Madeira and deep water coral reefs grow to depths of 50 metres around the islands (Petit, 2008).

The Azores is home to important endemic species, most of which are relic European pre-glacial species. Since the arrival of the first settlers, the archipelago's biodiversity has been under severe pressure from deforestation, agriculture and the introduction of invasive species. Only 2% of the original laurel forest now remains and exotic species of tree threaten the survival of indigenous flora and fauna. The development of dairy farming has resulted in the conversion of about 50% of natural habitat to pasture over the last 10 years. The islands were once important for nesting seabirds, but the introduction of rats caused a decline in these populations, which are now confined to the steep cliffs and small islets (Petit, 2008).

In the marine environment, Pelagic faunas are twice as diverse in the area of the Azores (south of 40º N) than they are to the north, although the reverse is true of their biomass. Benthic communities show a similar latitudinal step, but are much richer in species than pelagic communities. Deeper-living species of fish are slower-growing, longer-lived and less productive than those in shallow water. High levels of by-catch in deep-sea fisheries may be posing risks to species such as whales, turtles and seabirds (although the risks to seabirds are probably small relative to the pressures they are under at nesting sites). A number of fragile deep sea habitats (e.g. hydrothermal vents, carbonate mounds, cold water coral reefs, coral gardens and sponge communities) have recently been discovered (OPSAR, 2000).

7.3. Human geography

With a population of about two million inhabitants, the Canaries are the most populated European overseas entity. Las Palmas de Gran Canaria (377,203 inhabitants) is the most populous city in the Canaries and shares the status as capital of the islands with Santa Cruz de Tenerife. Of Madeira and its associated islands, only Madeira itself and Porto Santo are inhabited. Funchal, Madeira's capital city, has a population of over 100,000. Human population in Ospar Region V is restricted to the Azores. Ponta Delgada, on the island of Sao Miguel, is the largest city in the archipelago and has about 55,000 habitants.

7.4. Economic activities

The Canaries is an autonomous region of Spain and an outermost region of the European Union. Tourism accounts for much of the economy of the islands. Their natural attractions, climate and beaches result in about 12 million visitors each year. Agriculture plays a minor role in the economy, with only 10% of the land area being cultivated for cereals, vines, bananas, tomatoes and tropical fruit.

Madeira is an autonomous region of Portugal and an outermost region of the European Union. The establishment of a Free Trade Zone has led to the installation of infrastructure, production facilities and essential services for small and medium-sized commercial enterprises. Tourism and agriculture (notably fruit and wine production) are the most important sectors in the region's economy.

The Azores is also an autonomous region of Portugal and an outermost region of the European Union. European Union grants have reversed a slow decline in population and resulted in improvements to the local infrastructure and the development of a thriving tourist industry. Tourism is of considerable importance to the economy of the Azores. The growth of the cruise industry has resulted in an increase in the size and number of ships visiting the islands. Inshore activities have also increased, as has ecotourism (e.g. whale watching). Other economic activities around the Azores include agriculture, inshore fisheries and sand and gravel extraction (OPSAR, 2010).

7.5. Climate change impacts

The Canaries' climate is clearly linked to the distribution of the five main habitat types. Precipitation is low and exposure to the sun high between sea-level and 400 m; here the vegetation is largely euphorbias cacti and succulent plants that are adapted to dry conditions. Climatic conditions are gentler between 300 and 700 m, where thermophilous forests dominate. The humid north trade wind influenced 'sea of clouds' zone occurs between 600 and 1,100 m and is characterised by relic laurel forests of conservation priority. Higher up are pine forests dominated by endemic species that are well-adapted to arid climatic conditions, with hot summers and harsh winters. The harshest climatic conditions are found only on Tenerife and La Palma, where high mountain shrub comprising mainly endemic species occurs (Petit, 2008).

The marine environment is also being affected by warming. Tropical fish species, which usually live further south, have been recorded in the waters of the Azores. Similarly, a rise in the temperature of the waters around Gran Canaria in 2004 led to a proliferation of micro-algae (Petit, 2008).

Madeira's geographical position and mountainous landscape result in an oceanic sub-tropical climate with mild humidity and low rainfall, which varies between the north and south sides of the island. A 'sea of clouds' hangs over the northern slopes and provides the conditions necessary for indigenous laurel forests to survive. The smaller islands in the archipelago (Porto Santo and Savages) experience a more desertic climate. The mean annual temperature on the coastline can reach more than 20 °C in the south. Influenced by the Gulf Stream, sea surface temperatures vary between 26 °C in summer and 17 °C in winter.

The climate of the Azores is influenced by prevailing south-westerly winds and associated depressions. The frequency and intensity of storms, which track from the south west, increase in winter. However, there is very low confidence in projections of future changes in storm events. The region also experiences oscillations in weather patterns (up to seven year cycles), which are linked to cyclic fluctuations in atmospheric pressure between high pressure over the Azores and low pressure over Iceland (the North Atlantic Oscillation - NAO). These oscillations, rather than climate change, may be responsible for at least some of the shifts in weather patterns seen in contiguous regions in recent decades (OSPAR, 2000).

Sea surface temperatures fluctuate seasonally in the region and have shown an average increase in recent decades - a trend that is likely to continue. Freshwater input is likely to decrease in line with decreasing precipitation. Sea-level rose in line with the global average of 1.7mm/yr through the 20th Century and is projected to rise by 0.18 to 0.59m by 2100, mostly through thermal expansion of sea water. Future projections of the effects of coastal erosion are very uncertain and highly location-specific. The uptake of CO2 may reduce, but this will be dependent on water temperature, stratification and circulation. Ocean acidity could reach unprecedented levels during the 21^{st} Century (OSPAR, 2009).

A significant temperature increase has already been observed across Macaronesia. IPCC projections (IPCC, 2007) suggest that average annual temperatures are likely to increase by a 2.1°C (1.9 to 2.4) and that sea-level will rise by 0.35 m by 2100. Rainfall projections are, however, less clear. Climate change could also have a major impact on the trade winds that are important to the biodiversity of these archipelagos. A decrease in the strength of the trade winds has been observed over the last 30 years. This is causing the 'sea of clouds' to fall to lower altitudes, which is leading to changes in bioclimatic conditions. Further changes in the north-westerly trade winds could lead to desiccation of exposed coasts. Laurel forests are likely to be detrimentally impacted by a further downward shift of the ‘sea of clouds’. Desertification of the islands would allow invasive species adapted to dryer conditions to displace indigenous species. More than 30 species of Saharan birds were recently observed for the first time in the Canaries. In 2004, a swarm of more than 10 million pilgrim crickets (desert locusts) from West Africa descended on the coasts of Lanzarote (Petit, 2008).

7.6. Climate change vulnerabilities

The coastal and marine ecosystems of Macaronesia are particularly vulnerable to climate change. Sea-level rise is likely to affect the biodiversity of marshes, dunes and beaches, and bring about major changes in coastal systems. Although the most important impact on marine habitats is currently fishing, physical and biological changes are occurring that are linked to increasing atmospheric CO2 concentrations. These are causing changes in ecological processes and leading to shifts in community balance (OSPAR, 2000).

Climate change could modify the composition and abundance of fish stocks and affect all marine ecosystems. Many species of tropical fish have already been observed in the area. The ocean triggerfish has been seen close to the Canaries, and the spined pygmy shark and lesser amberjack around the Azores. These sightings can be explained by a change in the spatial distribution of these species brought about by warming sea temperatures - a phenomenon that is likely to increase as temperatures continue to rise (Petit, 2008).

Macaronesia is home to a large number of deep water coral reefs, which develop at depths of 50 m or more and form part of a large belt of cold water reefs that stretches from Norway to West Africa. These ecosystems were seriously threatened by deep sea trawling, but the European Commission has prohibited such activity around the coasts of the Canaries, Madeira and the Azores since 2004. The fragile corals are also threatened by rising sea temperatures and acidification of sea water, the latter being directly related to increasing CO2 levels. A drop in pH reduces the rate of calcification of corals and constrains their growth and regeneration. This could affect all marine organisms with calcium skeletons, including most tropical corals, urchins, some molluscs and several species of zooplankton, and could have major consequences for the marine ecosystem as a whole (Petit, 2008).

Rising water temperatures are causing an increase in marine algae around the coasts of the Canaries and the Azores. A tide of cyanobacteria developed in the waters of Gran Canaria and Tenerife in 2004. Unusual climatic conditions led to exceptional blooming episodes. High temperatures facilitated the development of cyanobacteria and the retreat of the north trade winds allowed warm air from the Sahara to carry iron-rich dust to the area. The iron acted as a nutrient and caused over-fertilization of the ocean and further promoted the development of cyanobacteria. This affected the whole marine ecosystem (mortality among fish and seabirds) and led to public health problems. Algal flowering episodes are likely to increase in frequency with a rise in temperature of sea water (Petit, 2008).

The socio-economic implications of climate change in Macaronesia are numerous. The number of heat waves is likely to increase and will directly affect both the resident human populations of the islands and their tourist industries (their main economic pillars). The prospect of extreme heat waves similar to that of 2003 could discourage visitors during summer months and desertification would reduce the attractiveness of natural landscapes. Higher temperatures could also facilitate the spread of tropical diseases and an increase in wind-borne dust from the Sahara could cause allergies and respiratory problems. A decrease in fish stocks is likely to have an impact on the fishing industry and changing climate conditions could also affect aquaculture (Petit, 2008).

7.7. Climate change adaptation

Climate change is already affecting Macaronesia's coastal and marine systems and, directly and indirectly, will have increasing impacts on society and a number of socio-economic sectors. Sea-level rise, storms, floods and coastal erosion will affect coastal communities, infrastructure and tourism as the protective functions of coastal ecosystems are lost. Fisheries may also be lost as coastal wetlands disappear and sensitive marine habitats such as coral reefs decline as a result of ocean acidification. Climate change may also bring new opportunities for human activities. Changes in species reproduction and distribution and the establishment of non-indigenous species as sea temperatures rise could benefit fisheries and aquaculture practices (OSPAR, 2009).

Clearly, local societies and economies will have to adapt to the impacts of climate change. Whilst changes may bring economic opportunities, they may also add new pressures on ecosystems. However, working with nature's capacity to respond to and accommodate impacts is likely to be a more efficient and effective way of adapting than simply focusing on man-made solutions.

Whilst the Macaronesian islands have many similarities, their institutional frameworks and progress with adaptation differs greatly. National adaptation strategies have been adopted at policy level by Spain and Portugal (see the section describing the Bay of Biscay and Iberian Coast). As outermost regions of these countries, it might be expected that these strategies would have driven adaptation action in the Canaries (Spain) and Madeira and the Azores (Portugal). However, progress has only been made in the Canaries, as the Spanish government included the islands in the Spanish National Strategy for Sustainable Coastal Management. This focuses on protective measures and builds on existing practices to minimise the risk of floods and coastal erosion (EC, 2009).

The production of adaptation strategies for the marine environment is more challenging as fewer tools are available. Adaptation will need to take place at both regional and local levels. Measures will need to address rising sea temperatures and ocean acidification, both of which will affect species, habitats, and ecosystem functioning and associated services. There will be general northward movement of species, with Atlantic species moving to more northern seas and sub-tropical species moving to temperate regions. Monitoring and assessment of temperatures and acidification will be essential for a better understanding of the vulnerability of marine ecosystems, of the interactions with other human pressures and therefore of measures to adapt to climate change. Experience of marine adaptation is limited, so actions may, in the short term at least, have to be based on existing regulations and activities. Options could include taking account of climate change in fisheries catch quotas, building climate change implications into marine conservation plans and activities, and building climate change implications into sector plans and activities and into tools to implement an ecosystem approach (OSPAR, 2009).

7.8. Case studies

The Canaries, Madeira and the Azores share specific characteristics which make them particularly vulnerable to climate change. As most of their settlements, socio-economic activities and infrastructure are located on or near the coast, flooding and erosion due to sea-level rise is likely to pose a significant threat to local people and economies. Coastal erosion is likely to be aggravated by the expected increase in intensity and frequency of extreme weather events such as hurricanes and floods. The islands' dependence on water resources from coastal aquifers is likely to be threatened by sea-level rise and saltwater intrusion into the aquifers. The principal concern, however, is for the loss of biodiversity because of its importance to economic growth and the tourism industry, and for human well-being. The islands are home to a large number of endemic species and have a rich biodiversity compared to continental Europe. The threats to coastal ecosystems from human activities (e.g. pollution, over-exploitation of resources, urbanisation) are likely to be exacerbated by climate change. One of the main priorities the Operational Programme 'Madeira-Azores-Canaries', approved by the EU for the period 2007-2013, is to strengthen protection and management of coastal zones and marine resources (EC, 2009).

The Canaries

Responsibility for financing coastal protection and climate adaptation in the Canaries rests mainly at national level with the Spanish government. However, a Climate Change Agency, established by the regional government of the Canaries in 2007, is responsible for the islands' climate change strategy (which focuses primarily on mitigation) and for an adaptation strategy that will be adopted in 2010. The agency is analysing the climate impacts and vulnerabilities of 15 sectors (including tourism, fisheries, coastal and marine ecosystems) and identifying possible adaptation measures. The islands are also included in the Spanish National Strategy for Sustainable Coastal Management. The main challenges identified in this strategy are adaptation to climate change, slowing coastal urbanisation, and restoring the physical and ecological functionality of the coast. The regional government and the Canarian Institute of Marine Sciences have undertaken a study to determine the vulnerability of coastal areas to climate change, using the same assessment methodology as for mainland Spain. The results will drive policy development in coastal adaptation and determine adaptation needs to deliver the National Strategy for Sustainable Coastal Management.

Madeira and the Azores

In Madeira and the Azores, regional governments develop plans for their coastal zones independently of the Portuguese national government. Financing for coastal protection is also provided mainly by the regions. Most coastal zones are covered by coastal management/spatial plans - with the exception of port areas, which are the responsibility of port administrations. These plans are instruments to preserve the natural environment and maximise the natural value of coastal areas. Defence against flooding, erosion and extreme weather events is one of the objectives. Other key objectives include conserving environmental and landscape values of the coastline, as well as regulating the use of the beaches for tourism purposes. In the Azores, the regional government has produced 10 such plans and is developing a climate change strategy and a strategy for integrated coastal zone management.

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8. Mediterranean Sea: Western Mediterranean Sea

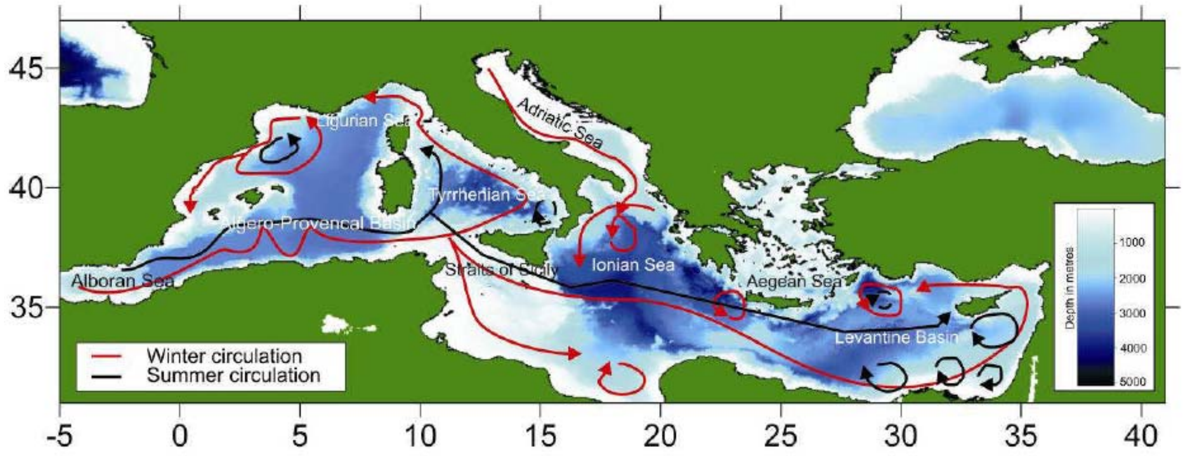
The Western Mediterranean Sea in a sub-region of the Mediterranean Sea 'European Marine Region', established under the EU's Marine Strategy Framework Directive (2008/56/EC; EU, 2008) to protect the resources upon which marine-related economic and social activities depend (Figure 18).

Figure 18 Location of the Western Mediterranean Sea (source: Google Earth, 2010)

8.1. Physical geography and oceanography

The Mediterranean Sea is semi-enclosed miniature ocean, which is divided into further smaller seas (Figure 19). It is characterised by limited freshwater input (evaporation exceeds precipitation and runoff), small amplitude tides, high oxygen concentrations, high deep-sea temperatures, and oligotrophic conditions (low nutrient concentrations that typically decrease eastwards). The major water exchanges are through the Straits of Gibraltar, with surface inflow of Atlantic waters and deep outflow of high-salinity Mediterranean waters. As a result of these characteristics, the Mediterranean exhibits different levels of primary productivity, with primary production being much lower in the east than in the west.

Figure 19 Map of the Mediterranean basin circulation (source: SAHFOS (UK) and Marine Institute (IRL))

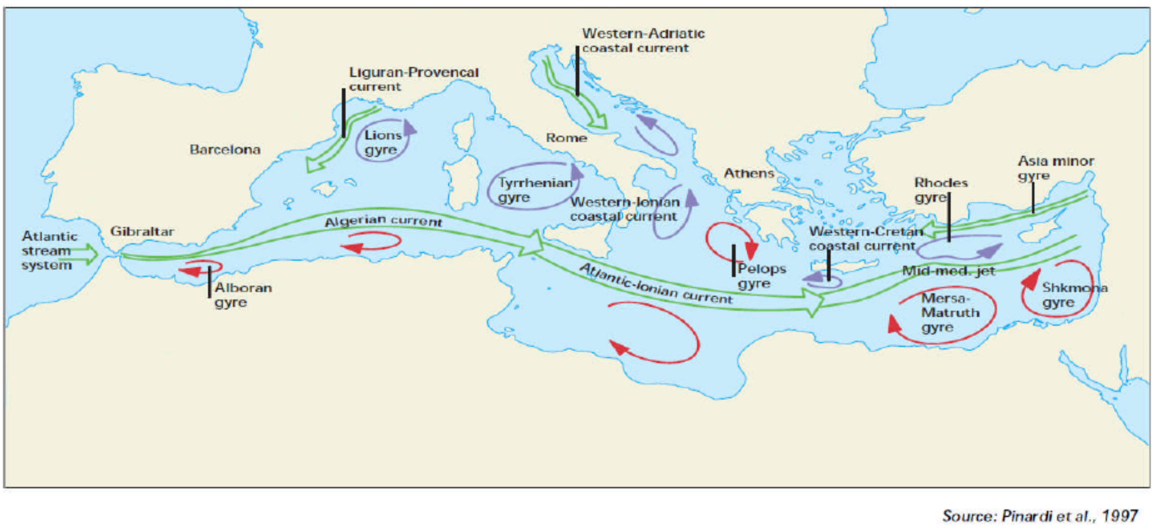


The Western Mediterranean Sea (mean depth 1,600 m) consists of two deep basins: the Algero Provençal Basin and the Tyrrhenian Sea. Rocky shores with sea cliffs, occasionally interrupted by sandy beaches associated with relatively narrow valleys or coastal plains (e.g. Rhône delta in southern France), typify the coastline. Corsica, Sardinia and the Balearic Islands are the most significant islands in the Western Mediterranean.

Only a few large rivers flow into the Mediterranean. They deliver vast amounts of sediment to the coast, creating sedimentary plains, which in micro-tidal areas have grown to form delta systems. The Rhône Delta in France and Ebro Delta in Spain constitute two of the most striking morphological features of the Western Mediterranean.

The large-scale circulation of the Mediterranean is composed of sub-basin scale gyres interconnected and bounded by currents and jets with strong seasonal and inter-annual variability (Figure 20). This general circulation flow impinges on coastal areas and strongly influences the local dynamics of currents. Transport of material from coastal areas to the open sea is enhanced by this mechanism and has important consequences for the maintenance of ecological cycles.

Figure 20 Mediterranean Sea cycles (source: Pinardi *et al*., 1997)



8.2. Biodiversity and ecosystems

The Mediterranean is a hot spot for biodiversity. It hosts both temperate and sub-tropical species and includes about 7% of the world's known marine fauna and 18% of the world's marine flora (28% are endemic). Around 12,000 marine species (with 8,500 species of macroscopic fauna) have been recorded in the Mediterranean: 67% of these are found in the Western Mediterranean and at shallow depths (0-50m). Although over 50% of marine species originate from the Atlantic, Mediterranean assemblages are different to their Atlantic counterparts and are typically characterised by smaller individual sizes. Two remarkable ecosystems, magnoliophytes grassbeds (such as Posidonia, a key Mediterranean ecosystem) and coralligenic concretions, can be found in coastal zones.

Of all known Mediterranean species, 19% are locally and globally threatened. The Mediterranean monk seal and 42% of shark species, for example, are threatened with extinction, and many other mammal and fish species have endangered status. Conservation initiatives to respond to biodiversity loss are now strengthened through the development of legislative and regulatory instruments, species identification and protection programmes, and the creation of protected areas (800 covering 144,000 km^2) (Figure 21).

Figure 21 Protected areas of Mediterranean interest (source: UNEP/MAP, 2009)

8.3. Human geography

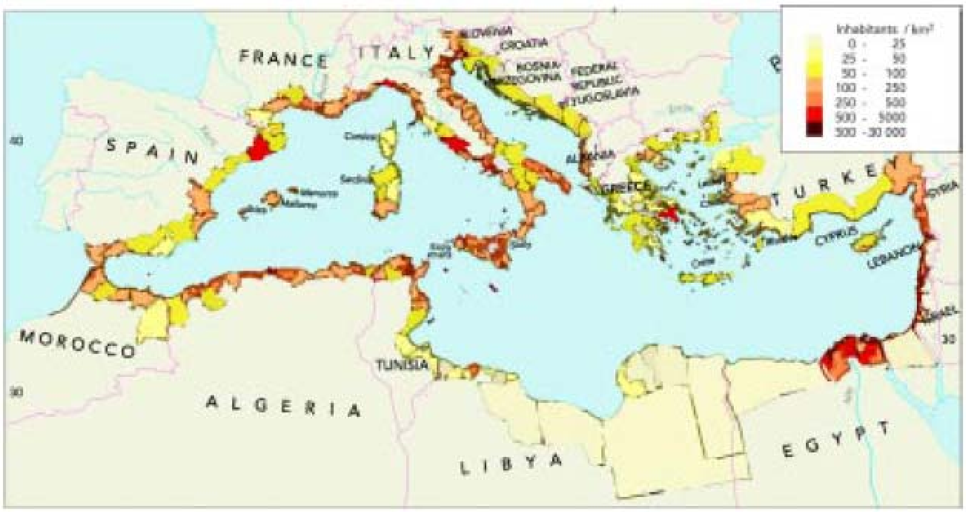
The countries bordering the Western Mediterranean include Spain, France and Italy in Europe, and Libya, Tunisia, Algeria and Morocco in North Africa. Those with European coastlines are of special interest in this sub-chapter.

The population of Mediterranean countries rose from 246 million in 1960 to 450 million by the end of the 20th Century, and is expected to reach 600 million by 2050. Population density is greatest in coastal regions, especially near big cities (Table 12 & Figure 22). The distribution of population between northern and southern countries has also changed: in 1950, northern countries accounted for two thirds of the total population, while today this has reduced to 50%. Two out of three Mediterranean inhabitants live in urban areas and over half of the urban population lives in small cities (less than 300,000 inhabitants). In many areas, migration towards major urban centres has overstrained labour and housing markets and associated public services. Climate change is posing an additional problem, with already vulnerable areas experiencing the threat of rising sea-levels and water shortages, and risks to public health. Many Mediterranean cities are therefore prime candidates for the development of adaptation strategies. An Integrated Coastal Zone Management Protocol (agreed in January 2008 under the Barcelona Convention) should strengthen the management of Mediterranean coastal areas and help countries develop coastal strategies, plans and programmes.

Table 12 Major cities on the Western Mediterranean coast (source: Eurostat, 2004)

Country Co	astal cities
Spain	Barcelona (1.58m); Valencia (0.79m); Malaga (0.55m); Alicante (0.31m)
France	Marseille (1.02m); Nice (0.50m); Montpellier (0.41m); Toulon (0.41m)
Italy	Naples (1.00m); Palermo (0.61m); Genoa (0.61m); Catania (0.31m); Reggio de Calabria (0.18m); Cagliari (0.16m); Salerno (0.14m)

Figure 22 Population density in coastal regions (source: UNEP Blue Plan)



8.4. Economic activities

Tourism is an essential economic activity in all Mediterranean countries and attracts 30% of the world's international tourist trade (e.g. 275 million visitors in 2007). The seasonal and spatial concentration of tourists strongly amplifies their impacts on the environment, generating pressures on water resources and the natural environment, and increasing waste production.

Agriculture in the Mediterranean is dependent on rainfall and focuses on the production of cereals, vegetables and citrus fruits. Productivity is highest in irrigated areas, which have grown by a factor of two over 40 years to exceed 26 million ha in 2005 (i.e. over 20% of cultivated land). Land degradation and the prospect of desertification is now a real issue in many European Mediterranean countries. Agricultural practices introduced to increase crop yields and maximize profits are a major contributor. Soil degradation due to increased run-off and erosion has proved detrimental to both soil fertility and the landscape, causing devastating and permanent damage. Current climatic patterns, future climate change and continuing human interference are likely to increase the risk of land degradation and desertification in the short to medium term.

Fishing in the Mediterranean is characterized by its biodiversity, which allows the development of region-specific fauna and fisheries. Production is concentrated on the continental shelf and coasts. There is, however, serious concern about the status of economically important species (i.e. hake, red mullet, common prawn, sole, sardine and tuna) due to unsustainable over-exploitation, and measures have been implemented to restore stocks and protect vulnerable habitats. Aquaculture has undergone significant growth since the 1990s, but its development has degraded the quality of the marine environment and habitats.

In the transport sector, there is a trend to build larger cargo vessels and to increase shipping traffic, challenging harbour reception capacities and threatening marine environments. In the field of industrial production, environmental policies have made progress over the past 10 years. However, possible synergies and exchanges of best practices are hampered by clean production initiatives not generally being covered by national policies applied to all stakeholders.

8.5. Climate change impacts

The Mediterranean Sea lies at the transition between the arid climate of North Africa and the temperate and rainy climate of central Europe and is affected by interactions between mid-latitude and tropical processes. Because of the interactions of processes at a wide range of spatial and temporal scales, the climate of the Mediterranean is characterised by a great diversity of features, resulting in a variety of climate types and great spatial variability (Lionello *et al.*, 2006a).

The westward movement of storms originating over the Atlantic, together with storms generated within the region, dominate winter climate. In summer, high pressure prevails, leading to dry conditions, particularly over the southern Mediterranean. Climate variability in summer is linked with both Asian and African monsoons (Alpert *et al.*, 2006) and with strong anomalies over central Europe (Xoplaki *et al.,* 2004; Trigo *et al.*, 2006).

The region's climate (Figure 23) is also affected by local processes induced by its complex physiography and the presence of a large body of water (the Mediterranean). For example, the Alpine chain is a strong factor in modifying travelling synoptic and meso-scale systems and the Mediterranean is an important source of moisture and energy for storms (Lionello *et al.*, 2006a & b). The complex topography, coastline and vegetation cover of the region modulate the climate signal at small spatial scales (e.g. Lionello *et al.*, 2006a). In addition, anthropogenic and natural aerosols of central European, African and Asian origin can reach the Mediterranean, possibly influencing its climate characteristics (Alpert *et al.*, 2006).

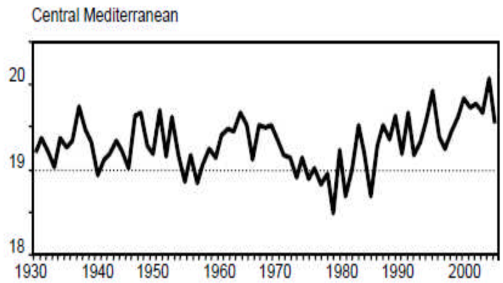
Figure 23 Range and location of climate change impacts in Mediterranean countries
(source: UNEP/MAP, 2009)

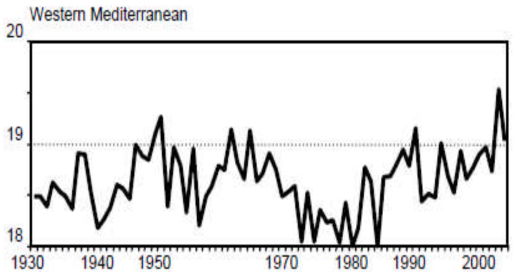
Over the 20th Century and with a clear acceleration since 1970, south-western Europe (the Iberian Peninsula and southern France) recorded an increase in temperature of almost 2°C. The rise in temperature is more marked in winter than in summer and for minimum rather than maximum figures. Rainfall has increased to the north of the Alps and diminished in southern Europe. Some parts of the Mediterranean region have recorded a 20% decrease in rainfall. From 1993 to 2003, the mean surface temperature of the Mediterranean increased 0.75°C (five times more than other seas and oceans); during the 1980s, the increase was 0.3°C in a decade.

The effects of sea-level rise in the Mediterranean are unequally distributed (Klein & Lichter, 2009). During the 20th Century, overall sea-level rise was similar to the global average, although this was not consistent throughout the whole of the period (Klein & Lichter, 2009). Rising air pressure has, at times, depressed sea-level rise. However, from 1990, most gauging stations have shown an extremely high rise in sea-level: 5 to 10 times the 20th Century average and notably higher than the global average for the same period (Klein & Lichter, 2009).

Impact studies have mainly focussed on low-lying areas like the Carmargue (Brunel & Sabatier, 2009) and Rhone Delta (Sabatier *et al.*, 2009), the Ebro Delta (Sanchez-Arcilla *et al.*, 2008), and regions where risk prone city infrastructure is located (e.g. Snoussi *et al.*, 2009). For the Carmague/Rhone Delta, assessments to distinguish the impact of rising sea-level from geomorphological factors (e.g. long-shore and cross-shore sediment transport) were made. The results indicate that sea-level rise was not the major influence on shoreline retreat during the 20th Century (maybe 5% only); the key factors were the gradient of long-shore transport and the weak redistribution of sandy inputs from the Rhone to the beaches (Figure 24).

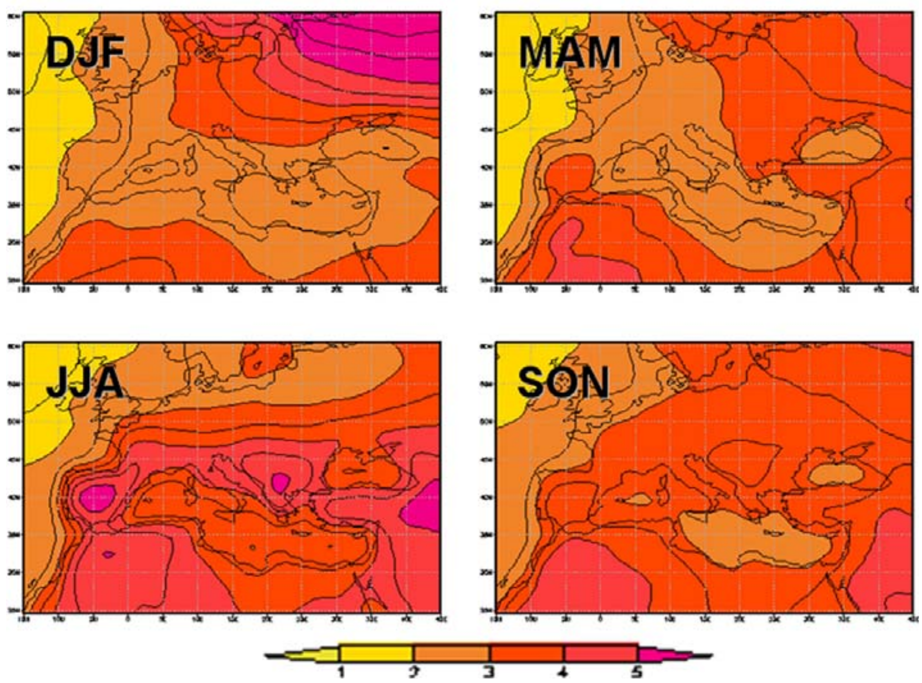
Figure 24 Long term variation in area-averaged sea surface temperatures (°C) in marine and coastal environments based on HadSST2 data (source: Marine Board, 2007)





The Mediterranean region has shown large climate shifts in the past (Luterbacher *et al.*, 2006) and it has been identified as one of the most prominent risk areas in future climate change projections. Giorgi (2006) present a detailed review of projections over the region based on the latest and most advanced sets of global and regional climate models (Figure 25). These simulations give a collective picture of a substantial drying and warming of the region, especially in the warm season (i.e. precipitation decrease exceeding −25 to 30% and warming exceeding 4 to 5°C). The only exception to this is an increase in precipitation during the winter over some areas of the northern Mediterranean, most noticeably the Alps. Inter-annual variability is projected to generally increase, as is the occurrence of extreme heat and drought events. These signals are robust in that they are present in most projections from both global and regional models, and are consistent across emission scenarios and future time slices.

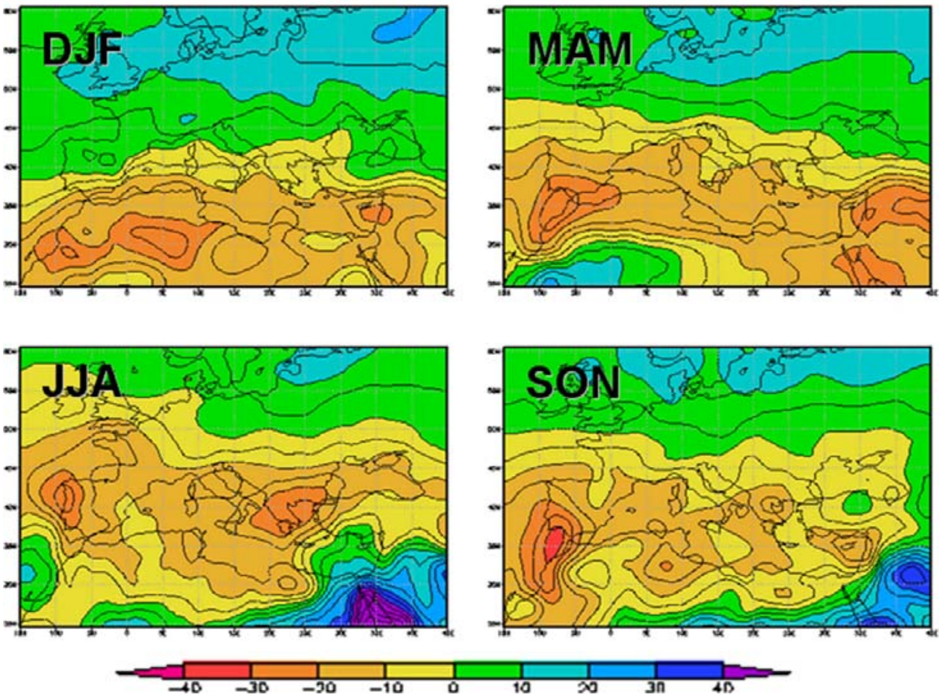
Figure 25 Ensemble average change in surface air temperature for the four seasons, 2071–2100 minus 1961–1990, A1B scenario (source: Giorgi, 2006)



Projections for average annual sea surface temperature suggest that the Mediterranean could be 1.1°C warmer by the period 2030-39, rising to 3.6°C by 2090-99 (Brochier & Ramieri, 2001). This will increase thermal expansion of seawater, causing further sea-level rise.

The change signals projected for the Mediterranean region could have devastating effects on water resources, natural ecosystems (both terrestrial and marine), human activities (e.g. agriculture, recreation, tourism) and health. An analysis by Giorgi (2006) places the Mediterranean among the most responsive regions to global climate change. The evidence from the models has the potential to profoundly modify the climatic characteristics of the region and indicates that it is likely to be especially vulnerable to global climate change (Figure 26).

Figure 26 Ensemble average change in precipitation for the four seasons, 2071–2100 minus 1961–1990, B1 scenario. Units are % of 1961–1990 value (source: Giorgi, 2006)



8.6. Climate change vulnerabilities

Biodiversity and ecosystems

In the Western Mediterranean, climate change influences the boundaries of biogeographic regions, with some warm water species extending their ranges and colonising new areas where they were previously absent. The northward migration of species with a warmer affinity has been demonstrated in several areas (Bianchi & Morri, 1994; Morri & Bianchi, 2001). The Ligurian Sea, one of the coldest areas in the Mediterranean, has a lower number of 59 sub-tropical species and a higher abundance of species characteristic of cold temperate waters. The warming of the Ligurian Sea (Béthoux *et al.,* 1990; Astraldi *et al.,* 1995) has favoured the penetration of warm water species, including the ornate wrasse *Thalassoma pavo*, which from 1985 onward established large and stable populations (Bianchi & Morri, 1994).

A large mass-mortality event was observed in 1999 (Cerrano *et al.*, 2000; Perez *et al.*, 2000). A positive thermal anomaly during summer combined with an increase in the warm mixed layer down to a depth of 40m (Romano *et al.*, 2000) and resulted in an extensive mortality of 28 invertebrate species (Perez *et al.,* 2000). The area impacted extended from the French to the Italian coast and, to a lesser extent, the island of Corsica. Among benthic organisms, the most severely affected were sponges and gorgonians, such as *Paramuricea clavata, Eunicella singularis*, *Lophogorgia ceratophyta* and *Eunicella cavolini* (Cerrano *et al.*, 2000; Perez *et al.*, 2000; Romano *et al.*, 2000; Garrabou *et al.*, 2001). It is evident that temperature anomalies, even of short duration, can dramatically change Mediterranean faunal diversity. Once a species disappears, other species, pre-adapted to the new conditions, can replace them, thus hampering the ecosystem resilience to pre-impact conditions. High thermal anomalies can also impact the fauna inhabiting marine caves, replacing endemic species by warm water species (Chevaldonne & Lejeusne, 2003).

Climate change in the Mediterranean also favours epidemiological outbreaks, as most pathogens are temperature sensitive. Studies performed on the coral *Oculina patagonica* identified the coral bleaching bacteria *Vibrio shiloi* as an agent involved in Mediterranean mass mortalities of coral (Kushmaro *et al.*, 1998). Mass mortalities of the gorgonian *Paramunicea clavata*, scleractinian corals, zoanthids and sponges observed in 1999 in the Ligurian Sea were promoted by a temperature shift, in conjunction with the growth of opportunistic pathogens - including some fungi and protozoans (Cerrano *et al.*, 2000). Furthermore, rising temperatures may promote viral life strategies. Although data are limited, morbilli viruses that cause disease epidemics in seals have been identified in Mediterranean monk seals (van de Bildt *et al.*, 1999), potentially impacting the survival of this rare and endangered species.

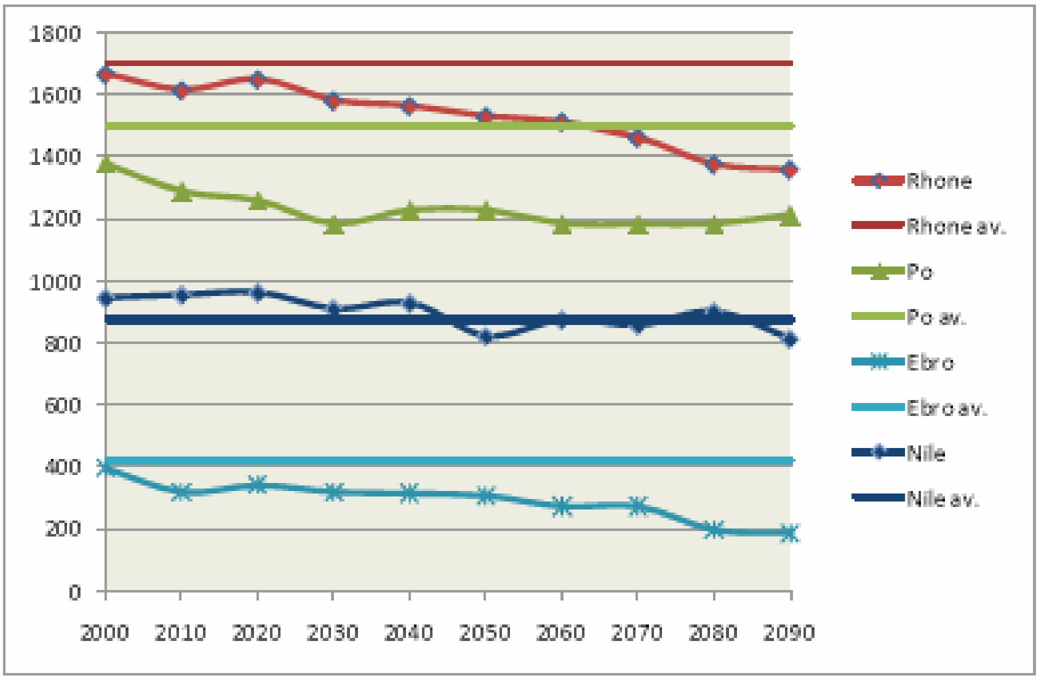
Due to its depth, rapid deep water turnover and the presence of many endemic species, it is expected that the impacts of climate change may be amplified, with earlier changes in biodiversity than witnessed in other seas. Recent evidence points to large scale warming of the Mediterranean basin (Béthoux *et al.*, 1990; Astraldi *et al.*, 1995; Walther *et al.*, 2002) and changing biodiversity in response (Francour *et al.*, 1994). However, the richness of microclimates in the Mediterranean makes any prediction at large spatial scales difficult. Indeed, most effects of climate change (or climate anomalies) on marine biodiversity have so far been identified only at regional scales.

These results indicate that: i) Mediterranean fauna is highly vulnerable to climate change; ii) both structural and functional biodiversity of continental margins are significantly affected by very small temperature changes; and iii) the impact of climate change on marine biodiversity might be irreversible. Moreover, these events indicate that not only coastal ecosystems, but also continental margin ecosystems may experience abrupt climate-driven temperature shifts, which reflect changes in the prevailing climate conditions occurring on a regional scale (Béthoux *et al.*, 1990). Since there are close interactions between deep sea and coastal ecosystems, the vulnerability of deep sea ecosystems to climatic changes may have important implication on the biodiversity and functioning of continental shelf ecosystems.

Rivers and coasts

Many parts of the Western Mediterranean coastline are at risk of flooding and erosion due to rising sea-levels and the increasing frequency and intensity of storm events. Low-lying coasts (e.g. deltas, lagoons, tidelands and some islands) are particularly vulnerable. Accelerated erosion of beaches and soft sediment cliffs is also likely, and estuaries will become more saline. Coastal groundwater aquifers could also suffer from saline intrusion and freshwater availability is likely to decrease as river run-off falls in response to increasing evaporation and decreasing rainfall (Figure 27). Fisheries could become vulnerable as human activities and climate change affect the structure and distribution of fish stocks. The region could also become less attractive to tourists due to increases in summer temperatures and the frequency of heat waves, and changes in the characteristic biodiversity and natural features that attract visitors to certain destinations.

Figure 27 Annual average flow of the main rivers in the Mediterranean, 2000 - 2090 (m^3/s) (Somot (2005) in UNEP/MAP, 2009)



Note: av. = average over the 20th century.

Human health

Human health is vulnerable to heat stress and to new vector-borne diseases. Increased mortality due to peaks in temperature is expected to show a relative drop in winter and a sharp rise in summer, less due to heat regulating mechanisms being compromised (e.g. hypothermia, heatstroke, acute dehydration) than to an upsurge in a range of cardiovascular, cerebrovascular, respiratory, metabolic and mental disorders. With regard to vector-borne diseases, the Asian mosquito *Aedes albopictus* has been colonising the northern half of Italy since 1990 and could now spread to the rest of Italy and southern France, before invading other parts of Europe as temperatures continue to rise. The mosquito is a carrier of Dengue Fever, Rift Valley Fever and West Nile Virus.

8.7. Climate change adaptation

The availability of national/regional policies and guidelines, and the governance structures put in place to deliver climate change adaptation and coastal zone management, varies considerably between the countries of the Mediterranean (Table 13). Environment ministries tend to assume responsibility for the development of policy and sectoral/cross-sectoral engagement, whilst experts researchers (scientists, economists etc) provide the detailed knowledge and evidence required to inform the decision making process. In the Western Mediterranean, Spain is a forerunner in this field. It published a National Climate Change

Adaptation Plan in 2006 and will complete its National Strategy for Coastal Management in 2010; a number of regional strategies have also been prepared.

Table 13 Overview of climate change adaptation and coastal protection in the Mediterranean (source: European Commission, 2009).

Member state	*Responsibility level*	*Research*	*Strategic climate change adaptation plans (incl coast) or coastal adaptation plans*	*Operational coastal plans and programmes*	*Climate scenario*
Cyprus	National (partly financed local)	Very limited	Not available	Master Plans (erosion) per coastal segment	No
France	Regional (partly financed national)	Advanced	Advanced National Adaptation Plan to Climate Change (2007)	Not available, CPERs55 may include measures	No
Greece	Greece (not clearly defined)	Very limited	Not available	Not available	No
Italy	Regional	Regional Limited	General Plan of Interventions (Venice); National Conference on Climate change organised in September 2007	Some regional plans e.g. General Plan of Interventions and Mose project (Venice), Coastal Protection Programme (Lazio) and Coastal Plan (Emilia Romagna)	No, except Venice
Malta	National	Very limited	Not available	Storm Water Master Plan (2009)	No
Slovenia	National	Very limited	Very limited	Not available	No
Spain	Spain	Forerunner	National Plan for Adaptation to Climate Change (2006); National Strategy for Sustainable Coastal Management (2010); Regional strategies e.g. Andalusian Strategy for Adaptation to Climate Change (2007) and Basque Plan for Climate Change	Directorate-General for the Sustainability of the Coast and the Sea allocates budget for coastal protection to the coastal regions; Drought management plans (not only coastal); implementation of National Strategy for Sustainable Coastal Management (2010)	Yes

Adaptation response to and expenditure on sea-level rise and storm surge

In most Mediterranean countries, specialised technical standards and guidelines for the design of coastal defence structures are lacking. Planning measures for land and sea also are totally failing or do not exist. As a result, investments in protective measures are mainly provided for *ad-hoc* hard defences such as breakwaters and groins, often resulting in mal-adaptation causing further impacts (i.e. increased erosion rates) on other parts of the coastline.

The cost of coastal protection across Mediterranean countries amounts to about € 1.6 billion over the period 1998 to 2015, corresponding to 10% of Europe's total expenditure. Expenditure at specific hot spots in Venice and the Slovenian saltpans account for 27% and 0.1% of this budget respectively, corresponding to € 4.2 billion. The cumulative annual expenditure increased from around € 45 million in 1998 to € 78 million over the period 1999 to 2007, to an actual expenditure of € 109 million (which will decrease slightly in the future. Italy (29%) and Spain (35%) account for the majority of expenditure in the Mediterranean region. In Spain, future expenditure can be expected to further increase with the implementation of the National Strategy for Coastal Management.

Adaptation response to counteract freshwater shortage
The protection of coastal zones against freshwater scarcity is, at present, the greatest problem for the Mediterranean region. In general, expenditure is much higher compared to the amounts spent to counteract flooding and erosion. Furthermore, Mediterranean countries do not take climate change explicitly into account when defining actions to overcome freshwater shortage. It is, therefore, difficult to indicate the extent to which expenditure on freshwater protection is related to climate change or to the increase in demand and over-use of available resources.

In Spain, actions to counteract water stress are aimed at increasing public water supply in order to overcome peaks in demand. Over the period 2005 to 2009, close to € 3.8 billion was invested to upgrade water supply. The areas that are eligible for support are situated along the Mediterranean coast. Expenditure is mainly dedicated to improving existing infrastructure and reducing leakage. Spain has also developed Drought Management Plans, which have been binding for all river catchments since 2007 (EC, 2009).

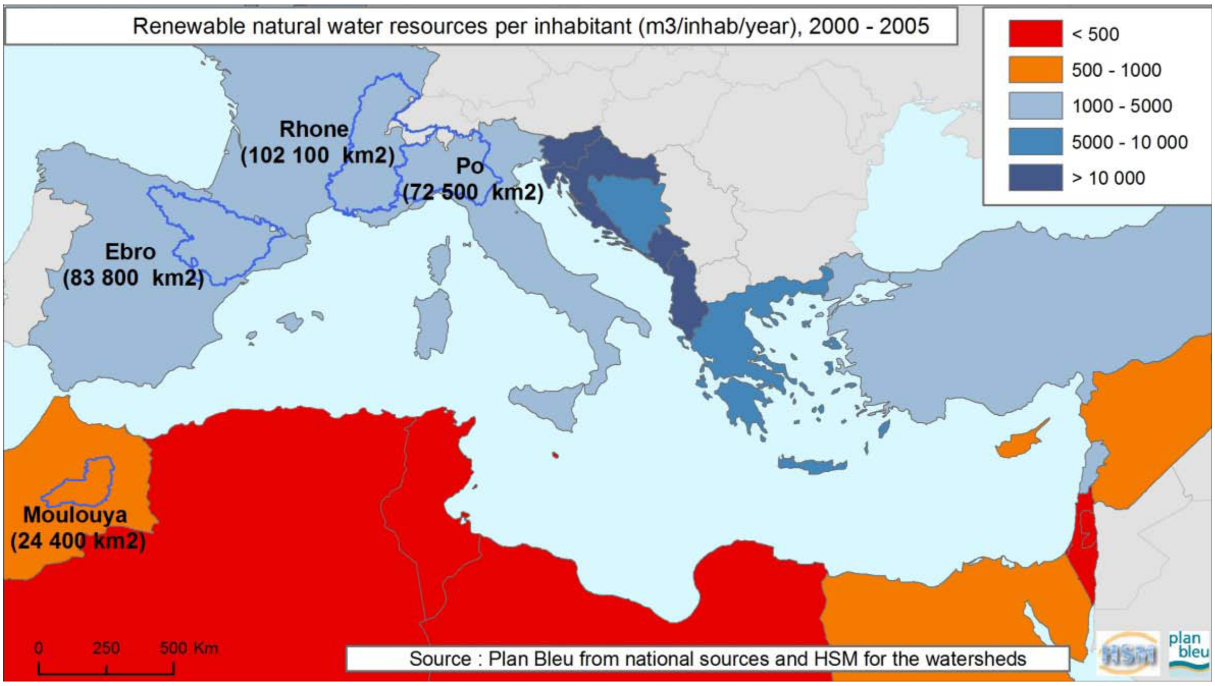
8.8. Case study

Variations in water flow for four Mediterranean catchment Basins

The use of a hydrological model at the catchment scale allows variations in water flow to be assessed. A decreasing trend in surface runoff has been identified in the Mediterranean region, more specifically in its southern countries. An initial assessment by Plan Bleu defines the hydrological risks the Mediterranean region might encounter shortly and underlies the need to promote adaptation policies to climate change based on improving integrated management of water resources and demand (Milano, 2010).

An initial assessment of climatic and hydrological variations at the 2050 and 2100 horizons was conducted by the Plan Bleu in conjunction with the Montpellier Hydrosciences laboratory for four basins representative of the Mediterranean area which were selected on the following basis (Figure 28): one basin per Mediterranean shore, the surface area of which is over 1 500 km² and which outlet is in a coastal region. Four catchment basins were thus chosen according to the availability of hydrological data: the Ebro in Spain (83,800 km²), the Rhone in France (102,100 km²), the Po in Italy (72,500 km²) and the Moulouya in Morocco (24,400 km²) (Milano, 2010).

Figure 28 Location of Mediterranean river catchments modelled and their water resources
(Source: Milano 2010 from Blinda and Thivet, 2009)



Results show that over the next century, the Mediterranean region will witness a drop in water resources: more evapotranspiration, less snow, less rain, therefore less surface runoff and less groundwater replenishment. This depletion of water resources will be particularly marked in the southern Mediterranean regions. A priori, the northern Mediterranean region is not likely to find itself in a water deficit situation overall and should be in a position to meet the needs of its people, although it may not be spared some tension at local levels (cf. the Catalonian basin in Spain, for example) (Milano, 2010).

Given the increase in water-related issues, it is becoming increasingly necessary to move water management policies (i) towards more rational use (water demand management), (ii) towards an increase in exploitable potential through better water and soil conservation and (iii) by making greater use of artificial groundwater replenishment. There is considerable scope for progress, since better demand management would mean that a quarter of all demand could be saved, in other words some 85 km3 in 2025 (Blinda and Thivet, 2009). Improving the integrated management of water resources and demand requires a more in-depth analysis on a wider spatial scale - preferably regional - in order to have a more global vision of the effects of climate change on water resources. Moreover, the identification and regular monitoring of indicators of the impact of climate change, tailored to the Mediterranean region and allowing hydrological variations to be monitored and pre-empted, will be highly useful in defining and implementing pro-active water management policies (Milano, 2010).

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9. Mediterranean Sea: Adriatic Sea, Ionian Sea and Central Mediterranean Sea

The Adriatic Sea, and the Ionian Sea and Central Mediterranean Sea are separate sub-regions of the Mediterranean Sea ‘European Marine Region’, established under the EU's Marine Strategy Framework Directive (2008/56/EC; EU, 2008) to protect the resources upon which marine-related economic and social activities depend. The Adriatic Sea separates the Italian Peninsula to the west from the Balkan Peninsula to the east, and has very specific trends which are unique, whereas to the south, the Ionian Sea and Central Mediterranean Sea borders Italy, the southernmost Balkans, Greece and North Africa. For ease of reporting the Adriatic has been covered alongside the Ionian Sea and Central Mediterrean Sea review for ease of reporting.

9.1. Physical geography and oceanography

Adriatic Sea

The Adriatic Sea is about 770 km in length and has an average width of about 160 km, although the Strait of Otranto, through which it connects at the south with the Ionian Sea, is only 85–100 km wide (Figure 29).

Figure 29 Location of the Adriatic Sea (source: Google Earth, 2010)

The western coast is Italian, while the eastern coast runs along Slovenia, Croatia, Bosnia and Herzegovina (26 km), Montenegro, and Albania. Major rivers joining the Adriatic are the Reno, Po, Adige/Etsch, Brenta, Piave, Soča/Isonzo, Zrmanja, Krka, Cetina, Neretva, and Drin (Drini).

The depths of the Adriatic near its shores share a close relationship to the physiography of the adjacent coastlines (average depth is around 0.45 km). Wherever the coasts are high and mountainous, the nearby sea depths are considerable (up to 1.0 km). The east coast is generally bold and rocky, with many islands. South of the Istrian Peninsula, which separates the Gulfs of Venice and Trieste from the Bay of Kvarner, an island fringe extends as far south as Dubrovnik. Cres is the largest island in the sea, slightly larger than nearby Krk.

The islands, which are long and narrow (the long axis lying parallel with the coast of the mainland), rise rather abruptly to elevations of around 100 m, with the exception of a few larger islands like Brač (Vidova gora, 778 m) or the peninsula Pelješac (St. Ilija, 961 m). There are over a thousand islands in the Adriatic, 66 of which are inhabited.

Very few islands are found off the coast of Montenegro. Its coastline is varied and includes a mountainous area with high peaks on its border with Albania and a narrow coastal plain (up to 6 km wide) that terminates abruptly in the north, where Mount Lovćen and Mount Orjen plunge into the inlet of the Bay of Kotor. Montenegro’s climate is generally continental, but Mediterranean on the coast.

In the Istrian and Dalmatian areas of Slovenia and Croatia, the shores are low and sandy, and the nearby sea is shallow. The waters are also predominantly shallow along the Italian coast, particularly in the vicinity of Venice and further south, near the delta of the Po River.

The western shore is generally low and merges in the north-west into the marshes and lagoons of the protruding Po delta. Sedimentation at the delta-front has extended the coastline for several kilometres within historic times; Adria is now some distance from the sea.

Ionian and Central Mediterranean Seas

The Ionian Sea is south of the Adriatic Sea, and is bounded by southern Italy to the west, and by south-western Albania and a large number of Greek islands to the east. The islands are collectively referred to as the Ionian Islands, and other islands include the Strophades, Sphagia, Schiza, Sapientza and Kythira. Further south of the Ionian Islands is the Central Mediterranean (Figure 30).

Figure 30 Location of the Ionian Sea and the Central Mediterranean Sea (source: Google Earth, 2010)

The Ionian Sea is one of the most seismically active areas in the world, notably along a line running from the mouth of the Butrinto River in Albania, around the north coast of Corfu, to Cape Santa Maria di Leuca in Italy.

The Albanian coast consists of the Adriatic and Ionian Sea coasts. Monthly variation in sea level is caused by non-uniform influences on hydro-meteorological factors. The highest levels are observed during November and December, because strong southern winds at this time push the water mass to the north and increase the sea level. The lowest levels are observed during July and August, which is the quietest period of the year.

The coastline of Greece is a wild and rocky, and comprises many large and small peninsulas, gulfs and caves. The Ionian Islands extend from southern Albania to the Peloponnesus. The group includes many uninhabited rocks and islets, as well as four large islands: Corfu (Kerkira), Leucas (Levkas), Cephalonia (Kefallinia) and Zacynthus (Zakinthos).

The climate of Italy's Ionian coast is stereotypically Mediterranean, with mild winters and warm and generally dry summers, although lowland valleys can be quite hot in summer.

9.2. Biodiversity and ecosystems

Although a small country, Albania is distinguished for its rich biodiversity. Coastal regions and lowlands have typical Mediterranean macchia vegetation, whereas oak forests are found at higher altitudes. Vast forests of black pine, beech and fir are found on higher mountains and alpine grasslands grow at altitudes above 1,800 m. Around 760 vertebrate species have been recorded in Albania. These include over 350 bird species, 330 freshwater and marine fish, and 80 mammal species. Of these, 91 are globally threatened, including the Dalmatian pelican, pygmy cormorant and European sea sturgeon. Rocky coastal regions in the south provide good habitat for the endangered Mediterranean monk seal (NEA, 1999)

The Mediterranean monk seal is amongst the rarest seal species and one of the six most critically endangered mammals in the world. The coasts of Greece are home to about 90% of the European population and the largest global population of the species (Hellenic Republic Ministry of Environment, Energy and Climate Change, 2010).

Italy is one of the richest countries in Europe (and the Mediterranean region) in terms of species diversity. By 2004, 6,759 species of vascular plants had been recorded (9,000 species, half of Europe's total, if non-vascular species are included). Italy also has one of the highest levels of faunal diversity in Europe, with over 57,000 species recorded (more than a third of all European fauna). Of these, 86% are land-based and14% aquatic; insects represent about two thirds of all of Italy's fauna.

9.3. Human geography

Italy has the fourth-largest population in the EU and the 23rd-largest population worldwide. At the end of 2008, the Italian population exceeded 60 million. Its eastern coastline extends to 7,600 km.

Croatia's coastline is 5,835 km in length and includes 1,246 islands and islets, of which only 47 are inhabited. Montenegro is a very small country, with a population of just over 650,000 and a coastline of 294 km. Albania is a small mountainous country, with a population of 3.2 million (UNDP Croatia, 2009) and a coastline of 316 km coastline.

In 2007, the total population of Greece was approximately 11.19 million, almost two-thirds of which live in urban areas. Greece has the longest coastline in the Mediterranean.

9.4. Economic activities

Albania is a poor country by western European standards (EUROSTAT, 2009). Its GDP *per capita* was 26% of the EU average in 2010. Agriculture is the most significant sector, employing some 58% of the labour force and generating about 21% of GDP. Albania produces significant amounts of wheat, corn, tobacco, figs (13th largest producer in the world) and olives.

The Adriatic is directly responsible for the well being of Croatians – not only those living on the coast, but also those living inland. In addition to its cultural significance, the coast is also the main area for tourism. Maritime transport, off-shore gas production, ship building, agriculture, fishing and mariculture also occur either on or near the coast, all of which are extremely important to the Croatian economy. However, urbanization, tourism and the development of agricultural land constitute major threats to Croatian coasts.

The western coasts of Greece contribute to the country's economy with several products. With good rainfall and much arable soil, the Ionian Islands produce timber, fruit, and flax and raise pigs, sheep, and goats. Their exports include currants, wine, cotton, salt, olives, and fish. Tourism is also of considerable important to both local and national economies.

In 2008, Italy was the seventh-largest economy in the world and the fourth-largest in Europe. Tourism is one of the fastest growing and most profitable sectors of the national economy. With 43.7 million international tourist arrivals and total receipts estimated at $42.7 billion per year, Italy is the fourth-highest tourism earner and the fifth most-visited country in the world. In order to satisfy the demand for fish and sea food products, aquatic organisms (e.g. mussels and oysters) are farmed in Italy.

Montenegro has a climate conducive to agriculture and tourism. However, war and sanctions in the early 1990s hit Montenegro hard, and recovery only really began after the end of the Kosovo crisis in 1999. In the years since independence, there has been a rapid growth in tourism and tourism investments, particularly along the Adriatic coast, Montenegro has been ranked as the top-growing tourist destination in the world, with growth estimated at 10% annually through to 2016. Net foreign direct investment in 2008 reached $1.223 billion, which was almost 10 times higher than in 2004, and investment *per capita* in Montenegro is one of the highest in Europe. However, investment has slowed recently, in part as a result of the global economic crisis.

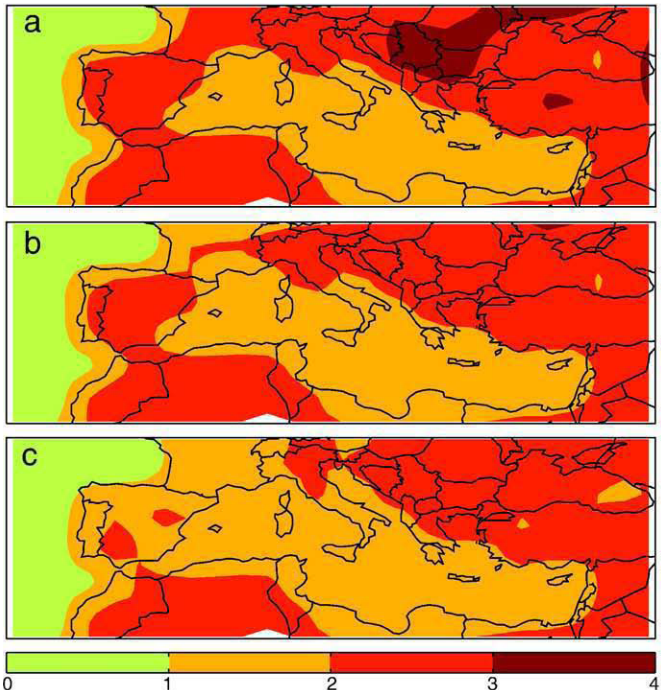
9.5. Climate change impacts

Temperature

Several studies have recorded heat waves and temperature anomalies over the last decade. The period from September 2006 to February 2007 was the warmest in Europe for more than half a millennium, with the largest surface air temperature anomalies being over Central Europe, Eastern Europe and the Balkans. Precipitation records revealed pronounced negative anomalies over the entire Mediterranean during winter 2007 (Luterbacher *et al.*, 2007).

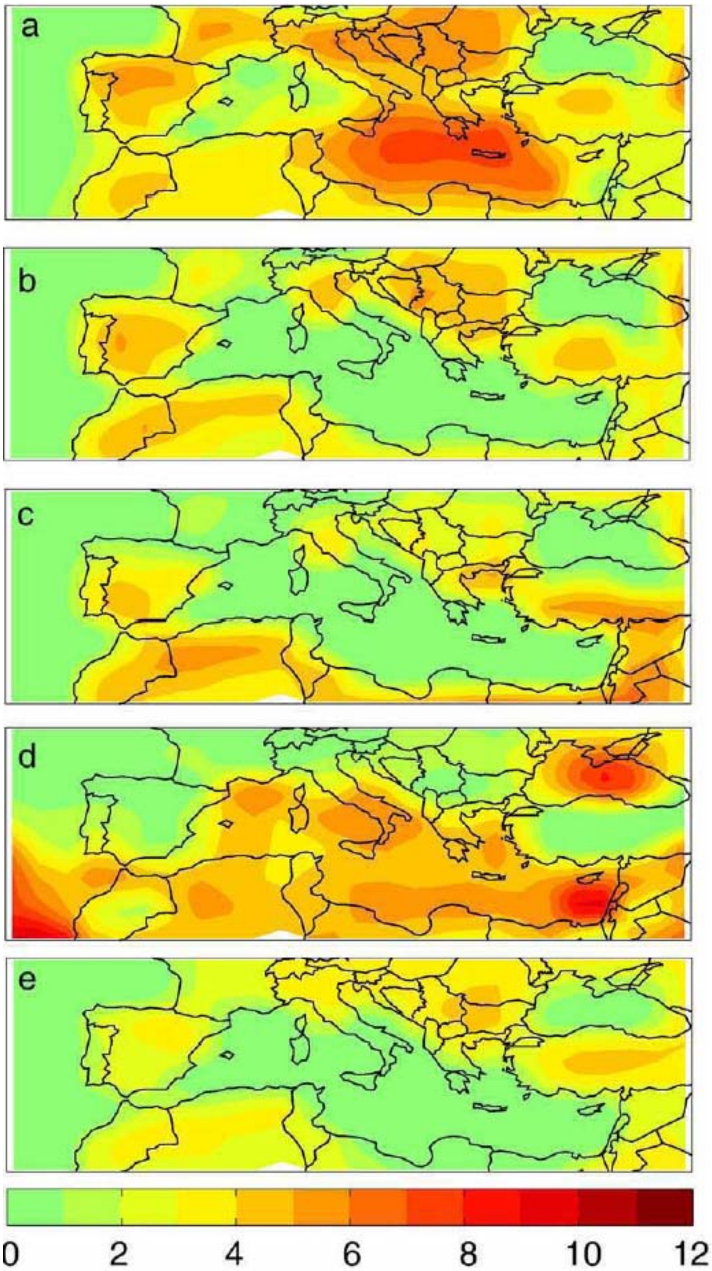
Due to the thermal inertia of the Mediterranean Sea, daily mean temperature rise (Figure 31-b), is projected to be between 1-2°C on the coast, compared to 2-3°C inland. This is likely to be slightly larger in daytime (Figure 31-a), exceeding +3 °C in the western Balkans and northern half of the Italian coast. A minimum 2°C increase in summer mean temperature is also projected. Figure 40 of the Aegean-Levantine Sea chapter (section 10) shows the projected seasonal mean temperature changes between the years 2031-2060 compared to the years 1960-1990 (Giannakopoulos *et al.*, 2009).

Figure 31 Difference in the average annual (a) maximum, (b) mean, and (c) minimum temperature (°C) between 2031–2060 and 1961–1990 (source: Giannakopoulos *et al.*, 2009).



Up to eight more weeks of summer days are expected in the Central Mediterranean Sea, from Sicily to southern Greece, and up to seven weeks in the Ionian Sea (Figure 32) (Giannakopoulos *et al.*, 2009).

Figure 32 Increase in the number of (a) summer days, (b) hot days, (c) heatwave days, and (d) tropical nights and (e) decrease in the number of frost nights between 2031–2060 and 1961–1990. Averaged annual numbers are considered and units are weeks (source: Giannakopoulos *et al.*, 2009)



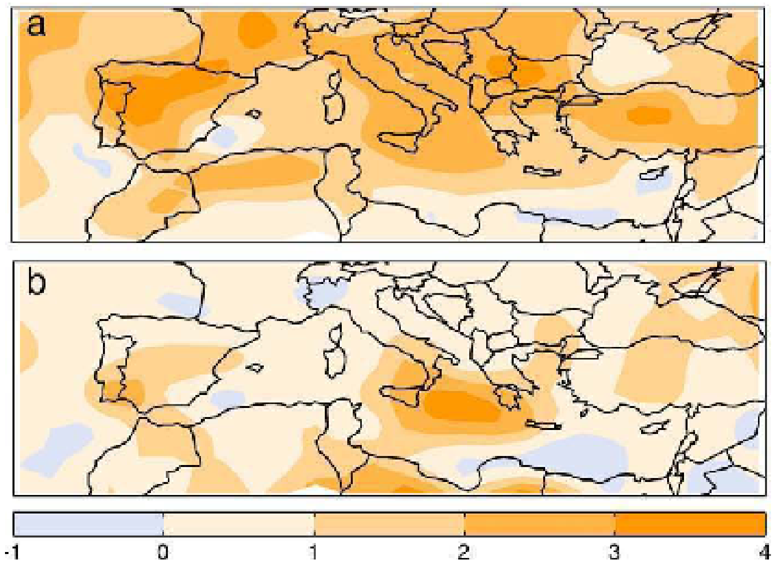
In Montenegro, the summers of 1994, 2000, 2003 and 2007 were extremely hot. Whilst the frequency of very hot days and nights was higher during the summers of 1991–2007 compared to long term averaged values (i.e. 1961-1990), there was no significant change in the frequency of minimum temperatures over maximum temperatures (REC, 2008).

In Albania, an increasing trend in minimum air temperatures has been observed over the last 15 years. However, analysis of data for the period 1961-90 showed no significant trend, although the number of days with absolute maximum temperatures over 35 °C increased and the number of days with extreme minimum temperatures of less than - 5 °C decreased. An increase in mean annual and seasonal air temperature and a decrease in mean annual and seasonal precipitation (combined with higher evaporative demand) will reduce run-off and move riverine flood risk from spring to winter (UNDP Albania, 2009).

Precipitation

Several studies show a potential decrease in precipitation in the Mediterranean and an extension of the dry season of more than three weeks in the Balkans and on Ionian Sea coasts (Giannakopoulos *et al.,* 2009). Days are qualified as dry if daily precipitation amounts to less than 0.5 mm (Hanson *et al.*, 2007). The projected number of dry days under a 2°C warming scenario is likely to increase by 1–3 weeks (±5 days) in the Adriatic and Ionian Seas (Figure 33-a) and the longest droughts lengthen by about 2-3 weeks in the Central Mediterranean (Figure 33-b).

Figure 33 Differences in annual (a) number of dry days and (b) length of longest dry spell averaged over 2031–2060 and over 1961–1990, in weeks. Right column: the corresponding 95% confidence range in weeks (source: Giannakopoulos *et al.*, 2009)



Sea water temperature

The mean sea surface temperature of the Mediterranean increased by 0.75°C between 1993 and 2003, five times more than in other seas and oceans, whereas the increase during the 1980s was 0.3°C. In the same period (1993–2003), the temperature of the Adriatic Sea increased by 0.87 °C. Scenarios developed for the periods 2030–39 and 2090–99 indicate that the average increase in annual sea surface temperature for the whole basin will be 1.1 °C for 2030–39, rising to 3.6 °C for 2090–99 (Brochier & Ramieri, 2001). This will increase thermal expansion, alongside evaporation.

Sea-level rise

A number of studies show that sea level has risen in the Central Mediterranean Sea. A rise in sea level of 1.25±0.25 m since the Roman Period is evident along the Tyrrhenian coast of Italy, 0.13±0.09 m of which has occurred since the late 19th Century or early 20th Century (beginning approximately 100±53 years before present) (Lambeck *et al.*, 2004).

Sea levels in the Mediterranean changed very little between 1960 and 2000 (Calafat & Gomis, 2009; Calafat *et al.*, 2009). This apparent stability was attributed to a rise in surface atmospheric pressure from 1961 to 1989 (Klein & Lichter, 2005) - eustatic sea level had in fact been rising, but was depressed by rising air pressure.

From 1990, most gauging stations have shown sea level rise of five to 10 times the average for the 20th Century and notably higher than the global average measured by TOPEX/POSEIDON for the same period. Impact studies mainly focus on low-lying areas, such as the Po delta (Simeoni & Corbau, 2009) or regions where risk prone city infrastructure is located.

The Adriatic coast is a tectonically and seismically active area, characterised by local uplift and subsidence, which makes monitoring changes in sea level more challenging. In Croatia, sea level is falling relative to land at a rate of -0.50 mm/year and -0.82mm/year respectively in Rovinj and Split, while sea level is rising relative to land at a rate of +0.53mm/year and +0.96mm/year respectively in Bakar and Dubrovnik (Baric *et al.*, 2008).

9.6. Climate change vulnerabilities

Climate change is likely to have socio-economic and environmental consequences for many coastlines bordering the Adriatic Sea, and Ionian Sea and Central Mediterranean Sea due increased flooding and erosion, water shortages and declines in water quality (including salt water intrusion into aquifers), and degradation or loss of biodiversity and natural ecosystems and related services.

Biodiversity and ecosystems

Climate change is likely to pose major threats to marine biodiversity. Cetaceans (marine mammals) are vulnerable as their habitat is already limited by prey availability. The additional impacts of climate change can further affect the health, physical strength and abundance of cetacean populations. This has already been observed in bottlenose dolphins of the Ionian Sea (Gambaiani *et al.*, 2008).

Climate change is also likely to encourage the spread of viruses and pathogens and may promote epizootic events like morbillivitus infections, which have been identified in the endangered Mediterranean monk seal (*Monachus monachus*). The monk seal breeds, feeds and calves in the coastal areas of Greece, where it is already vulnerable to the impacts of climate change (Hellenic Republic Ministry of Environment, Energy and Climate Change, 2010).

Several natural systems in Albania are vulnerable to sea level rise. Losses of wetlands, coastal floodplains and coastal forests are projected (Albania Second National Communication, 2009). The national parks of Kune-Vain (Lezha District) and Velipoja (Shkodra District) are located along the Drin and Buna river deltas and are particularly vulnerable.

Freshwater systems and marshes are among the most vulnerable coastal ecosystems in Croatia, particularly the Krka River, Neretva River and Vrana Lake Nature Park. Vrana Lake is the only large swamp on the Adriatic coast; it is a habitat for endangered bird species, and has immense biodiversity and unique scientific and ecological value. It is likely to be inundated if sea level rises by 0.5 m. Since the entire Croatian coast is situated on carbonate rocks and karst habitats – which are rare and extremely vulnerable to physical changes – the management of these ecosystems (which are also connected to freshwater reservoirs) is a top priority for nature protection (UNDP Croatia, 2008).

Tourism

Many coastal communities are vulnerable to sea level rise and erosion. Commercial fishing ports and fixed marinas are threatened, and beaches may be destroyed or become submerged. Historical centres of several coastal towns are just one or two metres above present sea levels. In Croatia, Zadar, Trogir, Split, Dubrovnik, Stari Grad and many others are at risk from flooding.

The tourism and recreational industry (i.e. hotels, marinas, camp sites etc) is the major source of income for local populations on the Croatian Adriatic coast and Greek Ionian coast. These areas are particularly vulnerable, and may be severely affected by flooding and erosion (e.g. the famous and popular Zlatni Rat Beach in Croatia). In Greece, increases in summer temperatures to above 40°C are projected, which are likely to lead to increased incidences of heat stress and mortality. Higher summer temperatures and heat wave frequencies, combined with water supply restrictions and increases in forest fires and urban smogs, are expected to impact the tourism sector negatively.

In Albania coastal tourism is also vulnerable to sea level rise. An increase in temperature of 2.8 to 5.6 °C during summer is likely to shift tourism away from the coast towards the mountains and lakes. Coastal tourism would become preferable at the end of spring and beginning of autumn (UNDP Albania, 2009). The increasing frequency of extreme events (e.g. heavy rains, strong winds, droughts, flooding) will also have a negative effect on settlements and tourism infrastructure.

9.7. Climate change adaptation

In addition to scientific research institutes in the countries bordering the Adriatic Sea, and the Ionian Sea and Central Mediterranean Sea, the following international institutions can contribute to the development of climate change adaptation activities in coastal zones, both in terms of increasing adaptive capacities and providing appropriate governance structures.

The Mediterranean Action Plan (MAP) was adopted by 16 Mediterranean countries and the European Community in 1975, as the first Regional Seas Programme under the aegis of UNEP. In 1976, these parties adopted the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention). Seven protocols addressing specific aspects of Mediterranean environmental conservation complete the MAP legal framework (see the Aegean-Levantine chapter, section 1 for details).

The Priority Actions Programme Regional Activity Centre (PAP/RAC) was established in Split in 1980 to assist in the implementation of the integrated planning component of the MAP.

The Blue Plan is a Regional Activity Centre (BP-RAC) of the MAP. Regional initiatives under the MAP also include the Partnership for Adriatic, which concentrates on managing Balkan coastal waters, and Adriatic Ionic Initiative, which links countries on the western and eastern coasts.

The Specially Protected Areas and Biological Diversity Protocol to the Barcelona Convention was ratified in 1995. Around 800 Specially Protected Areas have been established under it. Unfortunately, their distribution is very unequal, with only 18 % being in the eastern basin of Mediterranean.

The Coastal and Marine Union (EUCC) was founded in 1989 with the aim of promoting coastal conservation by bridging the gap between scientists, environmentalists, site managers, planners and policy makers. It has grown into the largest network of coastal practitioners and experts in Europe, with 2700 members and member organisations in 40 countries, and 15 national branches and offices in seven countries.

The South Eastern Europe Disaster Risk Mitigation and Adaptation Program (SEEDRMAP) was initiated by the World Bank and UN/ISDR and aims to reduce the vulnerability of countries in south-eastern Europe to disasters risks.

CIRCLE-MED is a geographical group in the frame of CIRCLE ERA-Net. It addresses issues of common interest to Mediterranean countries and aims to create a research community network through collaborative projects on climate change impacts research, and to bring the results of this research to policy and decision makers.

EurOcean is a focal point for information on marine science and technology in Europe. Its Internet portal aims to provide information on topics related to marine science and technology, with a priority given to two main domains: marine research infrastructures and European research, technology and development information.

The Global Climate Observing System (GCOS) developed a Regional Action Plan for Eastern and Central Europe in 2005 and a Regional Action Plan for the Mediterranean basin in 2006. These plans highlight the urgent need to reverse the degradation of observation networks, particularly in developing countries, and stress the requirement for immediate action to address critical deficiencies in climate observation and research programmes.

At the national level, most countries bordering the Adriatic Sea, and the Ionian Sea and Central Mediterranean Sea either have legislation on coastal zone management or have incorporated it in other relevant legislation. However, fewer countries have policies and/or measures targeted at adaptation.

In Croatia, coastal planning legislation incorporates basic coastal protection measures against unregulated building. A Coastal Decree (adopted in 2004; effective from end 2007) also aims to control coastal development, protect historic structures, and allow public access. Unfortunately, illegal building remains one of the key problems and pressures within protected coastal areas. There is no legislation that takes sea level rise into consideration and there is no obligation for it to be considered in coastal planning. Also, there are no cost estimates for protecting Croatian coasts or for their adaptation to climate change.

Montenegro does not yet have a national climate change policy. However, it is involved in a number of regional and trans-national adaptation initiatives. At present, the government, with financial support from international organisations and institutions, is developing a number of programmes and projects which contribute to strengthening the country's adaptive capacity and its preparedness to climate change-induced disasters. The following initiatives are currently under way:

- Developing and implementing a strategy for Integrated Coastal Zone Management. This strategy will provide a good basis for setting up a coherent policy for the management and protection of coastal areas that are particularly vulnerable to climate change. Although adopted at the national level and articulated within the National Strategy for Sustainable Development, the strategy can be used as a framework for action at the regional level (e.g. management of the Bojana delta and its catchment).

- Preparing a national overview of the vulnerability of Montenegro's coastal and marine biodiversity to climate change. The document will assess the inter-linkages between climate change and coastal/marine biodiversity and give some recommendations for future conservation adaptation activities.

- Undertaking a study of adaptation to climate change (in partnership with Egypt and Syria). In each country, the study will: (i) review available information on vulnerabilities to climate variability and extreme events; (ii) assess how relevant policies, legal frameworks, economic instruments and institutional set-ups integrate climate change concerns; (iii) review current and projected measures and actions towards adaptation; (iv) explore how adaptation could be addressed through policy measures, improved legal and institutional frameworks and appropriate economic instruments; and (v) identify key adaptation measures and opportunities for capacity building. This stocktaking exercise will be complemented by a consultation with the different stakeholders and government representatives.

In Albania, an adaptation action plan sets out general adaptation policies and identifies a range of measures. These include:

- Integrating adaptation actions into development policy and planning at every level
- Compiling an inventory of existing practices and decisions used to adapt to different climates
- Preparing disaster relief and hazard reduction programmes
- Improving monitoring/warning systems for flood and drought
- Promoting awareness of climatic variability and change
- Addressing vulnerability to climate change in the water resources, agriculture, forestry, energy and tourism sectors.

In addition to the adaptation action plan, studies to identify adaptation response measures (e.g. Drini-Mati deltas and catchments) have been supported by the Regional Environmental Centre, UNDP-GEF, World Bank and the United Nations International Strategy for Disaster Reduction.

In Greece, a number of climate change projects have been planned in the context of the National Strategic Reference Framework for the period 2007-2013. These include:

- A study of the vulnerability of Greek coastal areas and proposals for appropriate adaptation policies and measures
- A study of the impacts of climate change in each geographical prefecture
- The development of a national adaptation strategy.

The national adaptation strategy is in line with an Operational Programme on ‘Environment - Sustainable Development’, which includes a number of priorities that are related to climate change adaptation (e.g. water resource management and protection; protection of the natural environment and biodiversity).

A strategy to cope with the consequences of climate change in Greek coastal zones is already embedded in coastal planning law. The provisions of a Specific Framework Spatial Plan for Tourism include commitments to reduce the effects of climate change in coastal zones. Also, in order to promote the management of coastal zones that are exposed to particular and complex pressures, including climate change impacts, a Specific Framework Spatial Plan for Coastal Areas and Islands has been drafted and presented to the public for consultation. The draft plan includes proposals for a set-back zone of 50 to 100 m, to reduce the risk of flooding and erosion, in which building will be prohibited. To date, however, specific measures in Greece have mainly been undertaken on an *ad hoc* basis.

9.8. Case study

The Po delta and Italy’s Emiligia-Romagna region, on the western Adriatic coast, is highly vulnerable to flooding due to sea level rise and land subsidence. While rise in sea level is estimated to be 1-2 mm/year, subsidence due to the extraction of methane gas and water from quaternary deposits (e.g. Po delta, Ravenna, and Venice) is exacerbating its impacts. Subsidence rates of 250mm/year for the period 1951-1957 (Borgia *et al.*, 1982) and 37 mm/year for 1967-1974 (Bondesan & Simeoni, 1983) were estimated. Land subsidence still remains a problem today.

In Venice, sea level rose by 25cm in the 20th Century due to subsidence of anthropogenic origin and climate change. Flood frequency increased by more than seven times, causing severe impacts on the urban infrastructure (Carbognin *et al.*, 2009). It has been shown that the recently completed MOSE flood protection scheme for Venice and its lagoon is unlikely to be effective against current worst-case sea level rise projections (Umgiesser & Matticchio, 2006). The city of Venice is already highly vulnerable to modest flood events, with peak heights of 1m (Zanchettin *et al.*, 2007). A 1m rise in sea level would also affect large areas around the Po delta, if these areas remain unprotected (Figure 34). Lagoon dynamics and sea level rise impacts are complex and require detailed analyses.

Figure 34 Complete area of the Po delta risk prone in case of 1m sea-level rise (unprotected coasts) (after Kropp & Daschkeit 2008).

9.9. References

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10. Mediterranean Sea: Aegean-Levantine Sea

The Aegean-Levantine Sea is a sub-region of the Mediterranean Sea 'European Marine Region', established under the EU's Marine Strategy Framework Directive (2008/56/EC; EU, 2008) to protect the resources upon which marine-related economic and social activities depend. The Aegean-Levantine Sea borders Greece, Turkey and counties of the Middle East and North Africa, and contains the islands of Crete, Cyprus, Rhodes and a large number of smaller islands (Figure 35).

Figure 35 Location of the Aegean-Levantine Sea (source: Google Earth, 2010).

10.1. Physical geography and oceanography

The Aegean-Levantine Sea is about 0.75 million km^2 in area. It is warmer and more saline than the Western Mediterranean (Miller, 1992). Evaporation is high, causing water levels to decrease and salinity to increase eastward. Relatively cool, low-salinity surface water from the Atlantic moves eastwards across the Mediterranean, where it warms and sinks, before circulating westward at depth.

Rivers play an important role in sustaining the marine productivity of the Mediterranean. The Mediterranean is a semi-enclosed basin and has a high ratio of drainage area to surface area compared to the open ocean. River inputs are also related to the oligotrophic character (very low nutrient value) of the Mediterranean (Salihoğlu *et al.*, 1991). Because of its negative water balance and resulting water circulation, Mediterranean deep waters export large amounts of nutrient to the Atlantic Ocean (Hopkins, 1985) and are lost for internal primary production. Zones of high productivity are, therefore, mainly restricted to the coastal waters in the vicinity of major freshwater inputs (Bosc *et al.*, 2004).

The Aegean is one of the most oligotrophic seas in the world (Stergiou *et al.*, 1997). Its enclosed and semi-enclosed bays and northern waters are more eutrophic than its offshore and southern waters. This is attributed to river run-off and agricultural and municipal waste. Five major rivers, the Evros, Nestos, Strimonas, Aliakmonas and Axios, flow into the northern Aegean, which receives 93.7% of the sea's total river discharge (Therianos, 1974). The Red Sea is a major source of water for the Levantine Sea. The Red Sea is higher in altitude, more saline and nutrient-poor than the Mediterranean; the Suez Canal acts as a tidal strait that links the two seas.

There is strong evidence that river discharge into the Mediterranean has changed in recent decades. For example, the construction of the Aswan High Dam across the Nile River in the 1960s reduced the flow of freshwater into the southern Levantine Sea. The natural average river discharge before and after damming was 43 km^3/yr and 15 km^3/yr respectively (Nixon, 2003). These changes are probably more important than elsewhere in the world for two main reasons. First, fresh water resources in the Mediterranean are scarce and anthropogenic pressures on rivers are considerable. Dams and water extraction for irrigation and other purposes have rapidly developed since the 1950s (Margat & Treyer, 2004) and profoundly altered the natural functioning of rivers. Second, the Mediterranean region is strongly affected by climate change. Both climate monitoring and modelling studies have revealed a general trend toward drier and warmer conditions, which began in the last century and which are projected to intensify in the future (Gibelin & Déqué, 2003; Milly *et al.*, 2005; Norrant & Douguédroit, 2005; Christensen *et al.*, 2007; Giorgi & Lionello, 2008).

There was a decrease in average freshwater fluxes between the periods 1960-1969 and 1990-2000 (Table 14) in the Aegean-Levantine Sea. Therefore, changes in riverine input are expected to be potential drivers of long term changes in marine ecosystems.

Table 14 Average freshwater fluxes to the Aegean-Levantine Sea (source: Ludwig, 2009)

River basin	Average discharge (1960-1969) (km^3/year)	Average discharge (1991-2000) (km^3/year)
Aegean	55	48
North Levantine	24	20
South Levantine	34	16

10.2. Biodiversity and ecosystems

According to the 2007 State of Environment Report (SOER 2007) of the Turkish Ministry of Environment and Forestry, the Aegean coasts host 389 and Eastern Mediterranean coasts host 388 fish species, along the Turkish shoreline. The Sea of Marmara has been stated as the biological corridor of species, hosting over 400 pelagic fish species[4] (Ministry of Environment, 2007). However these species suffer from overfishing and water pollution.

According to World Resources Institute data, Turkey hosted 461 marine and littoral protected areas in 2003, and it is home to 8650 higher plants, 162 mammal species (year 2004), 436 bird species (year 2004), 145 reptile species (year 2004), 23 amphibian species (WRI).

Greece hosted 261 marine and littoral protected areas in 2003 (WRI, 2003), and it is also home to 4992 higher plant species, 95 mammal species, 412 bird species (year 2004), 63 reptile species, 21 amphibian species (year 2004) and 152 fish species based on the 1992-2003 data (WRI, 2003). Pinniped Seals and the Loggerhead Sea Turtle live in the seas surrounding mainland Greece, while its dense forests are home to the endangered brown bear, the lynx, the Roe Deer and the Wild Goat (Wikipedia).

Several commercial fish species in the Aegean Sea have been reported, which are: *Mullus barbatus, Spanis aurata, Sparus pagrus, Diplodus anniüaris, Scorpaena porcus, Psetta maxima, Diplodus vulgaris, Pagellus aceme, Scomber japonicus, Epinephelus aeneus, Pagellus bogaraveo, Dicentrarhus labrax, Pomatomus saltator, Chelon labrosus, Epinephelus guaza, Thunnus thynnus, Sardine pilchardus, Dentex dentex, Diplodus puntazzo, Mullus surmuletus, Pagrus ehrenbergi, Belone belone, Scomberesox saurus.* Also, the Aegean Sea hosts several octopus, oyster, lobster types together with other species, such as Sponge (*Spongia* sp.) (Ministry of Environment, 2007), which have been a major income for some local economies.

There are nine specially protected areas for the Mediterranean Monk Seal (*Monachus monachus*) and the two endangered marine turtle species (*Caretta caretta* and *Chelonia mydas*) in the Aegean-Levantine Sea (PAP/RAC, 2005). However, the SOER 2007 draws attention to the danger caused by illegal fishing by using dynamite, which lead to miscarriage and migration of Mediterranean Monk Seals.

Several Marine species are on the conservation list in Turkey, such as: *Posidonia oceanica, Cymodocea nodosa, Mesophyllum lichenoides, Cystoseira amentacea, Scyllarides latus, Palinurus elephas, Epinephelus marginatus, Charonia tritonis variegata, Lithophaga lithophaga, Pinna nobilis, Tonna galea, Centrostephanus longispinus, Paracentrotus lividus, Sciaena umbra and Umbrina cirrosa.* These are found along the Aegean coasts of Turkey (Yuksek *et al.*, 2007).

10.3. Human geography

The total population of EEA member countries with Aegean-Levantine coasts is nearly 85 million people (Table 15). Population densities are greatest in coastal zones, as these have been the major source of income for local people – historically through fisheries and agriculture, and now increasingly through tourism. The Mediterranean has become one the biggest tourist destinations in the world (Turley, 1999).

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[4] Pelagic fish live in the water column of coastal, ocean and lake waters, but not on the bottom of the sea or the lake.

Table 15 Populations of the Aegean-Levantine coastal countries

COUNTRY	POPULATON (MILLIONS)
Cyprus	0.8 * (Eurostat estimate for 2010)
Greece	11.3 (Eurostat estimate for 2010)
Turkey	72.56 (by Dec, 2009) (TurkStat, 2010)
Total 84.66	

*Includes the northern part of the island

10.4. Economic activities

Greece has a predominately service economy, which (including tourism) accounts for over 73% of GDP. Almost 9% of the world's merchant fleet is Greek-owned, making the Greek fleet the largest in the world (US Dept. of State, 2010). Greece has several ports and terminals on the Aegean-Levantine Sea. These include Alexandroupolis, Chalcis, Chios, Eleusina, Heraklion (Crete), Kavala, Laurium, Mytilene, Piraeus, Rhodes, Thessaloniki and Volos.

Turkey's economy is becoming more dependent on industry in major cities, mostly concentrated in the western provinces of the country, and less on agriculture, although traditional agriculture is still a major pillar to the economy. In 2007, the agricultural sector accounted for 8.9% of the GDP, while the industrial sector accounted for 30.8%. However, agriculture still accounted for 27.3% of employment (European Commission, 2010). The tourism sector has experienced rapid growth in the last 20 years, and constitutes an important part of the economy. Istanbul is the largest city in Turkey; it has a population of 12.8 million people, and is also the countries cultural, economic and financial centre. Turkey has 18 ports, including the Bodrum, Izmir and Kusadasi.

The Cypriot economy is prosperous and has diversified in recent years. Cyprus has been sought as a base for several offshore businesses because of its highly developed infrastructure. Main ports are situated in Limassol and Larnaca.

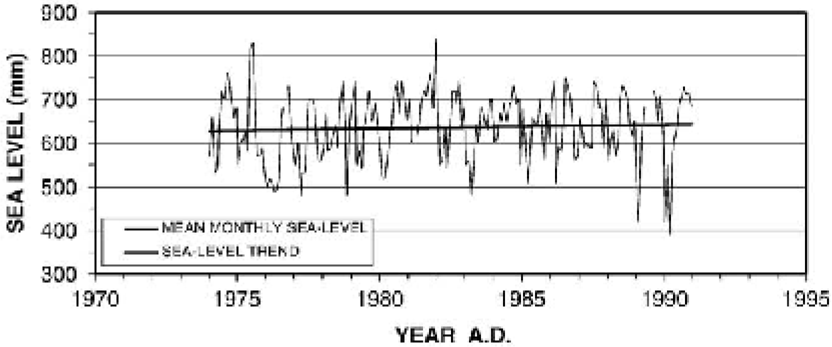
10.5. Climate change impacts

Climate change is already impacting the Aegean-Levantine Sea, with marine, coastal and terrestrial environments being affected. Rainfall has declined, periods of drought increased and sea levels risen. Extreme events have also increased, with thermal anomalies rising (summer temperatures above the seasonal norm in 1999 and 2003) on an ever-increasing geographic scale. Several studies have observed a drying and warming climate in the Mediterranean (e.g. Giorgi, 2006).

Studies of sea level rise on Aegean-Levantine coasts show that the major cause in the past was tectonic movements of crustal blocks, rather than eustatic changes (Thommeret *et al.*, 1981; Pirazzoli *et al.,* 1982). The eustatic component of sea level rise in the region did not exceed 0.5 m over the past 2000-3000 years (Flemming, 1978).

Analysis of recent mean monthly sea level values (1974–1991) from the tidal gauge on Syros Island in the Aegean Sea (Figure 36) shows a positive trend of 0.86 mm/year (Poulos *et al.*, 2009).

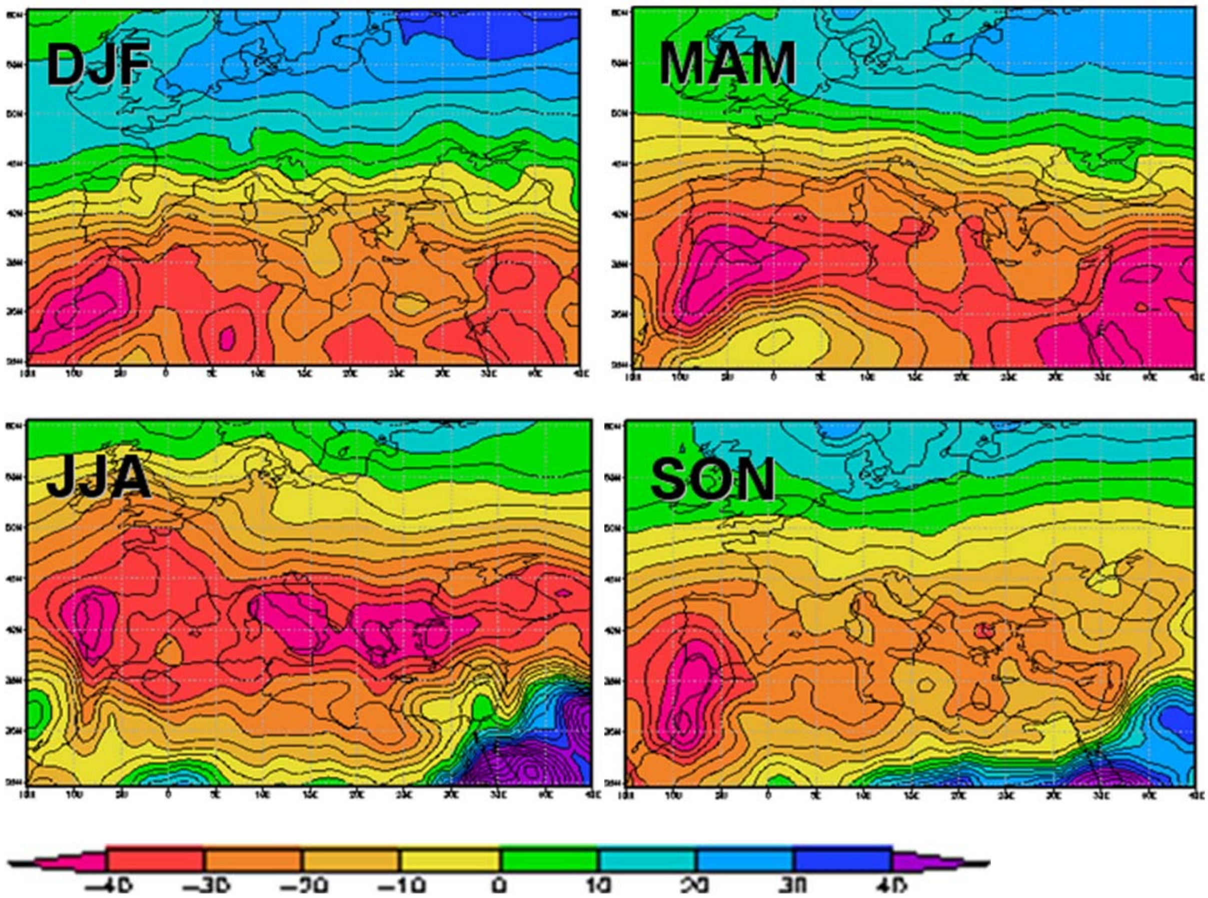
Figure 36 Mean monthly sea level fluctuation at Syros Island from 1974 to 1991, showing a positive trend of 0.86 mm/year (source: Poulos *et al.*, 2009).



It is still not possible to provide a sound assessment of sea level rise for the Aegean-Levantine Sea as a whole. The satellite monitoring conducted by the Topex/Poseidon programme on variations in the level of the Mediterranean Sea between January 1993 and June 2006 shows an obvious east-west differentiation, with a clear trend towards sea level rise in the Aegean-Levantine Sea.

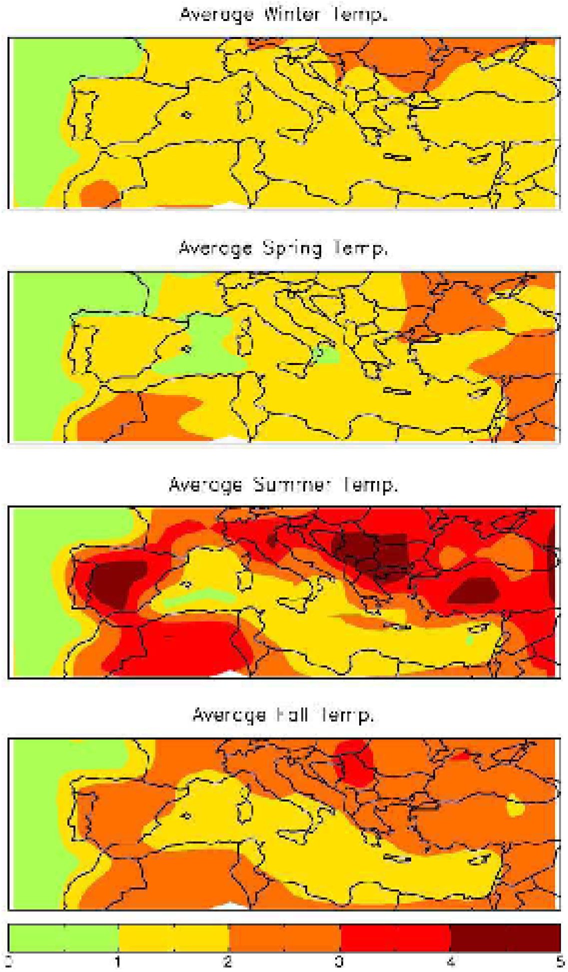
Several studies have simulated changes in precipitation. One simulation used the Multi Global Model Ensemble (MGME) and compared precipitation patterns in the period 1961-1990 with 2071-2100 (Figure 37), under IPCC’s A2 emission scenario (Giorgi & Lionello, 2008).

Figure 37 MGME ensemble average change in precipitation for the four seasons, 2071–2100 minus 1961–1990, A2 scenario. Units are % of 1961–1990 value (source: Giorgi & Lionello, 2008).



A minimum increase in mean summer temperature of 2°C has been projected for the region. Indeed, it has been argued that a 2°C rise is likely before the period 2030-2060. Figure 38 shows projected seasonal mean temperature changes between the period 2031-2060 compared to 1960-1990 (Giannakopoulos *et al*., 2009).

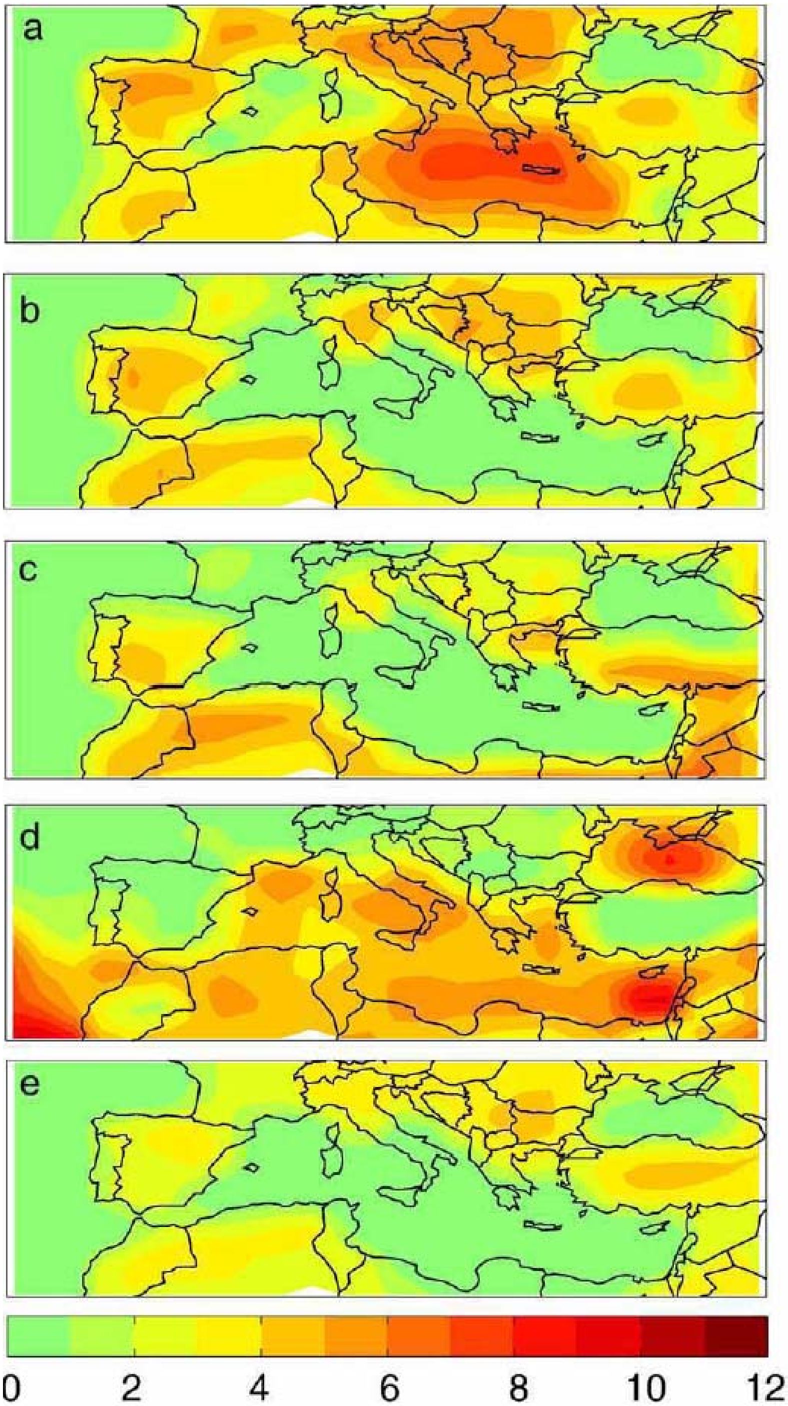
Figure 38 Difference in seasonal mean temperatures during: (a) winter, (b) spring, (c) summer, and (d) autumn between 2031–2060 and 1961–1990 (Giannakopoulos *et al.*, 2009).



The most significant temperature rise is likely in summer (June/July/August), when it could reach 4°C (±18%) inland on average. Autumn (September/October/November) is likely to have the second largest warming in absolute terms, with mean temperatures rising above 2°C (±18%). Winter (December/January/February) is likely to be warmer by 1–2°C (±25%). Spring (March/April/May) has a very similar pattern, but with slightly more warming in Turkey (Giannakopoulos *et al.*, 2009). The projections also suggest higher warming inland and less on the coast (Giorgi *et al.*, 2004; Räisänen *et al.*, 2004).

Temperature extremes and extended summer days are likely to be among the key impacts of climate change in the Aegean-Levantine region. Figure 39 shows the projected increase in the number of summer days, hot days, heat wave days and tropical nights. The largest increase in summer days and tropical nights is likely in coastal areas (Giannakopoulos *et al.*, 2009). The increase in the number of summer days is likely to be greater in Greece and on the southwest coasts of Turkey than on eastern coasts. A significant increase in tropical nights on eastern coasts is, however, expected.

Figure 39 Increase in the number of (a) summer days, (b) hot days, (c) heat wave days, (d) tropical nights, and (e) decrease in the number of frost nights between 2031–2060 and 1961–1990. Averaged annual numbers are considered and units are weeks (Giannakopoulos *et al.*, 2009).



In general, the northern part of the Mediterranean is likely to see an increase of more than a month of summer and two weeks of tropical nights, while the southern and easternmost parts are likely to see about one extra month of summer and more than a month of tropical nights (Giannakopoulos *et al.*, 2009).

These simulations give a collective picture of a substantial drying and warming of the region, especially in the warm season where declining precipitation exceeds −25 to 30% and warming exceeds 4–5 °C (Giorgi & Lionello, 2008). An increase in dry days of more than three weeks is likely in Turkey and up to three weeks on Aegean Sea coasts (Giannakopoulos *et al.*, 2009).

Severe future climate change impacts have been projected for the region and it has been identified as a significant 'hot-spot', with possible seasonal extremes (Giorgi, 2006; Giorgi & Lionello, 2008). Temperature extremes are likely to cause impacts on natural systems and human infrastructure, and increase the risk of forest fires and increase peak energy demand in summer. Marine biodiversity is likely to be threatened with invasive species entering the Levantine Sea from the Red Sea, through the Suez Canal.

10.6. Climate change vulnerabilities

The Mediterranean sits between the arid climate of North Africa and the temperate climate of Central Europe and is, therefore, affected by interactions between mid-latitude and tropical processes. Studies show that, as a result of these conditions, even relatively small changes in atmospheric circulation can lead to substantial changes in climate. This makes the Mediterranean a highly vulnerable region to climate change, with large climatic shifts having already occurred in the past (Lionello *et al.*, 2006; Ulbrich *et al.*, 2006; Luterbacher *et al.*, 2006).

Many Aegean-Levantine coastal regions are expected to be exposed to an increasing risk of flooding and erosion. Low-lying coasts are particularly vulnerable, notably delta areas, lagoon coasts, tidelands and some islands. Additionally, cliffs and beaches are vulnerable to erosion, estuaries are vulnerable to increased salination, and coastal groundwater aquifers are vulnerable to shrinkage and saltwater intrusion.

Although sea level rise in the Mediterranean Sea is not expected to be as high as in the oceans, low-lying areas and estuaries, which are the most productive agricultural areas, the location of key urban centres and the focus for tourism, are none-the-less threatened. In Turkey, coastal areas at high risk of inundation (elevations of 1 m) include: the coastal plains of Seyhan and Ceyhan rivers, Akyatan Lagoon and Tuzla (Adana), and Goksu Delta (Mersin) on the Levantine coast; Gulluk and Dalaman (Mugla), Didim (Aydin), Selcuk and Gediz Delta (Izmir) on the Aegean coast; and Dalyan Lake (Bursa) on the Marmara coast (Demirkesen, 2007). Many 'flagship' cultural sites are also expected to be damaged or destroyed by sea level rise and increased wave activity (e.g. the ancient cities Phaselis and Patara). Other historical sites could be buried by active sand dunes; indeed, the ancient city of Pompeipolis [Viransehir] has already lost (UNDP Turkey, 2007).

Several alien plant and animal species have already been introduced to the Levantine Sea from the Red Sea through the Suez Canal. Known as the Lessepsian migration or Erythrean invasion, the impacts of some of these species has been considerable as they are replacing native species (Galil & Zenetos, 2002). A rapid reduction in abundance of the herbivorous sparid (*Salpa salpa)*, a common species throughout the Mediterranean, *has* occurred in the Levantine Sea. It is being replaced with a competitor, *Siganus rivulatus*, which was first recorded in the Levantine in the early 1990s (Baric *et al.,* 2008). Red mullet *Mullus barbatus* and hake *Merluccius merluccius* have also been replaced by Red Sea competitors (Por, 1978). More species are expected to migrate from the Adriatic and Black Sea.

Over the last decade, the seaweed *Caulerpa taxifolia,* known as the 'killer algae', has spread over much of the Mediterranean coast, causing a major threat to local biodiversity. A cold-tolerant strain was inadvertently introduced into the Mediterranean in waste water from the Oceanographic Museum at Monaco, where it has now spread over more than 13,000 hectares of seabed. Although exact reasons have not been yet identified, investigations have shown a general tendency of biodiversity loss at sites where *Caulerpa taxifolia* has been established (Bartoli *et al*., 1997)**.** The existence of this invasive species has been reported in Antalya Bay, on the Levantine coast of Turkey.

Agriculture is likely to be among the most vulnerable sectors in Aegean-Levantine coastal areas. Vulnerabilities in southern areas are expected to be more severe than in northern temperate areas. Studies suggest that increases in CO_2 concentrations in southern areas may help reduce (but not completely recover) the loss of agricultural yield arising from warmer and drier conditions. In cooler northern areas, CO_2 increases may have little net positive effect on most crops, provided that the increase in water demand can be met (Giannakopoulos *et al.*, 2009). Rain-fed crops are likely to be most vulnerable to climate change and summer crops are likely to be more vulnerable than winter crops due to longer dry seasons. In Turkey, the negative impacts of climate change on the agriculture sector are expected to cause an increase in migration from rural areas to big cities (e.g. Istanbul, Ankara and Izmir).

10.7. Climate change adaptation

In addition to national scientific research institutes in Greece and Turkey, a number of international institutions can contribute to the development of climate change adaptation activities in coastal zones, both in terms of increasing adaptive capacities and providing appropriate governance structures (see chapter on the Adriatic Sea, and the Ionian Sea and Central Mediterranean Sea for details).

At the national level, the countries bordering the Aegean-Levantine Sea are addressing the impacts of climate change in the coastal zone.

In Greece, a strategy to cope with the consequences of climate change in coastal zones is already embedded in coastal planning law. The provisions of a Specific Framework Spatial Plan for Tourism include commitments to reduce the effects of climate change in coastal zones. Also, in order to promote the management of coastal zones that are exposed to particular and complex pressures, including climate change impacts, a Specific Framework Spatial Plan for Coastal Areas and Islands has been drafted and presented to the public for consultation. The draft plan includes proposals for a set-back zone of 50 to 100 m, to reduce the risk of flooding and erosion, in which building will be prohibited. To date, however, specific measures in Greece have mainly been undertaken on an *ad hoc* basis.

In Turkey, the Ministry of Environment is planning to establish a coastal zone department. The Authority for the Protection of Special Areas has declared several protection areas in coastal zones (e.g. Fethiye-Gocek, Gokova, Patara, Kekova, Foca, Datca-Bozburun and Belek) and has been developing special environmental programmes.

A number of research projects and adaptation studies have been carried out in the countries bordering the Aegean-Levantine Sea. Among them there are the following;

- The Disaster Risk Mitigation and Adaptation (AL-DRMAP) project was financed by a number of stakeholders, including the World Bank and Global Facility for Disaster Reduction and Recovery, to reduce the region's vulnerability - in accordance with the Hyogo Framework for Action.
- The *Global Climate Observing System* (GCOS) developed a Regional Action Plan for the Mediterranean basin in 2006. The plan highlights the urgent need to reverse the degradation of observation networks and stresses the requirement for immediate action to address critical deficiencies in climate observation and research programmes.

A number of key issues have been identified to address problems of coastal zone management associated with climate change and anthropogenic pressures in countries bordering the Aegean-Levantine Sea (Hallegatte, 2009). These include:

1. Information exchange and technology transfer
   a. Share information, knowledge, experience and best practice relating to adaptation measures in coastal zones
   b. Raise awareness of the need to protect coastal areas from damage caused by climate change impacts (e.g. flooding, erosion and storms).

2. Additional research
   a. Assess potential impacts of sea level rise and integrate into strategic planning
   b. Assess impacts of climate change on marine ecosystems, fisheries, ground water etc
   c. Develop and transfer adaptation technologies.

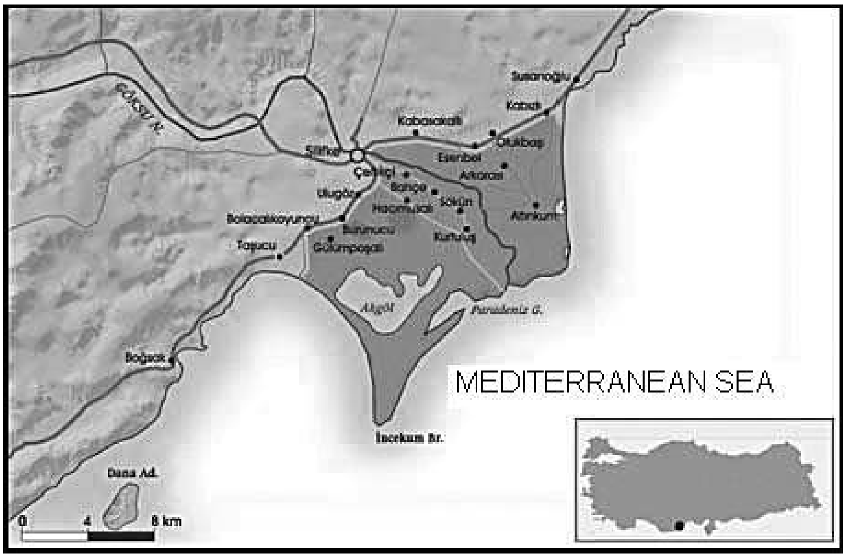
3. Other needs:
   a. Build/upgrade monitoring/warning systems to assess vulnerabilities of coastal zones
   b. Create integrated impact scenarios for coastal areas.

10.8. Case study

Göksu Delta, Turkey

The Göksu Delta is located to the south of Mersin in Turkey, where the Göksu River enters the sea. The river has a 10,000 km^2 catchment area and the delta is bounded by the Taurus Mountains to the north and northeast. There are two shallow lakes (Paradeniz and Akgöl) to the east and the west respectively (Figure 40).

Figure 40 Göksu Delta, Mersin, Turkey



The Göksu Delta is important for its biodiversity, which led to Specially Protected Area status being designated in 1991. In 1994, its wetlands were included in the Ramsar list of Wetlands of International Importance. Since the implementation of an irrigation scheme in 1968, the delta has become an important agricultural area, leading to rapid socio-economic development. There are also five municipalities and seven villages in the area. The economic, physical and ecological properties of the delta demonstrate the importance of this low-lying coastal area to the local population and to Turkey itself. The delta has an average elevation of 2 m above sea level, so any rise in sea level will have adverse impacts at various levels (Özyurt & Başeren, 2008).

The coastal slope of the delta is very shallow; it experiences significant wave heights of 5.5-6 m and, as a result, coastal erosion has already been observed. Regulation projects on the Göksu River, including dam construction and irrigation channels, have contributed to this erosion. The river itself has also exacerbated coastal erosion and the overall vulnerability of the delta. A recent vulnerability assessment (funded by the UK's Department for Environment, Food and Rural Affairs) revealed high vulnerability of the whole system to sea level rise. Moreover, freshwater resources are threatened by the demand from activities such as agriculture (Ozyurt & Ergin, 2009).

The study also showed that the infrastructure systems located on the coastal fringe of the region are not as vulnerable. This is a protected area with strictly controlled human activities in terms of settlements and land use. However, economic and social development of the delta region is vulnerable. The main income of the local population is agriculture, which is considered to be highly vulnerable to sea level rise. The irrigation scheme shifted the economic base from a variety of sectors (e.g. animal husbandry, fishing etc.) to intensive agriculture (Ozyurt & Ergin, 2009).

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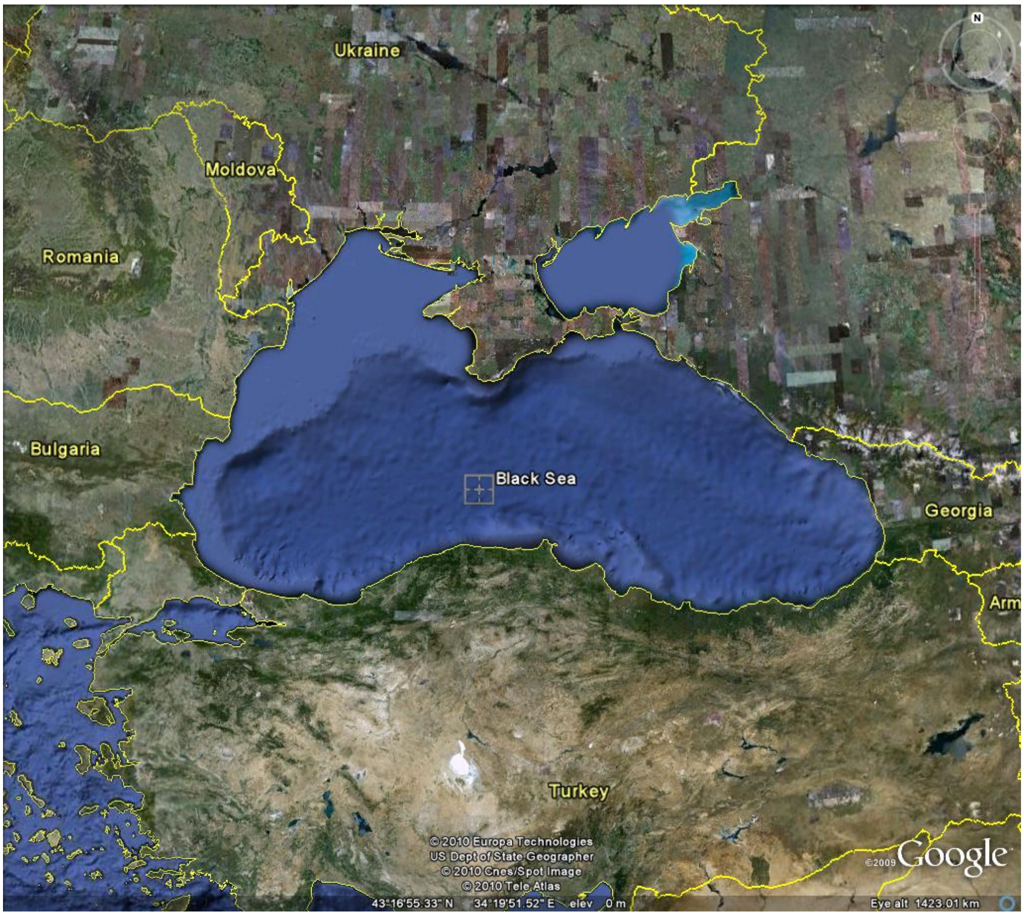
11. Black Sea

The Black Sea is a 'European Marine Region', established under the EU's Marine Strategy Framework Directive (2008/56/EC; EU, 2008) to protect the resources upon which marine-related economic and social activities depend. The Black Sea is one of the world's most isolated seas (FAO, 2010). It is linked with the Mediterranean through the Bosporus Strait, the Sea of Marmara and the Dardanelle, and is surrounded by Bulgaria, Romania, Ukraine, Russia, Georgia and Turkey. The Black Sea Catchment is internationally known as one of ecologically unsustainable development and inadequate resource management, which has led to severe environmental, social and economic problems (Figure 41).

Figure 41 Location of the Black Sea (source: Google Earth, 2010)



11.1. Physical geography and oceanography

The Black Sea's link to the Mediterranean, the Bosphorus, is essentially a narrow elongated shallow channel approximately 31 km long, with a width varying between 0.7-3.5 km and a depth of 39 to 100 m. (BSC, 2008). The channel has a two layer flow, carrying about 300 km^3 of seawater to the Black Sea from the Mediterranean along the bottom layer and returning a mixture of seawater and freshwater with twice this volume in the upper layer (BSC, 2008).

The seabed is divided into the shelf, the continental slope and the deep sea depression. The shelf occupies a large area in the north-western part of the Black Sea, where it is over 200 km wide and has a depth ranging from 0 to 160 m (BSC, 2008). In other parts of the sea, the shelf has a depth of less than 100 m and a width of 2.2 to 15 km. Near the Caucasian and Anatolian coasts, the shelf is only a narrow intermittent strip. The deep sea depression is over 2,200 m deep, and 87% of the Black Sea water is naturally anoxic, which again makes it highly sensitive to anthropogenic impacts (BSC, 2008). Only its thin surface layer contains oxygen, and it is here where almost all of its marine life dwells.

The ratio of its catchment area to its surface exceeds six, which causes the Black Sea to be very vulnerable to pressure from land-based human activity, and its health to be equally dependent from the coastal and non-coastal states of its basin. Every year, the Black Sea receives about 350 km^3 of river water, from a 1.9 million km^2 basin covering about one third of the area of continental Europe (BSC, 2008).

Europe's second, third and fourth largest rivers, the Danube, Dnieper and Don flow to the Black Sea (*via* the Sea of Azov), as well as several other major rivers (e.g. Rioni, Kodori and Inguri Chorokh (Coruh), Kizilirmak, Yesilirmak, Sakarya, Southern Bug and Dniester) (Figure 42 & Table 16).

Figure 42 The Black Sea river catchment area (source: BSC, 2008)

Table 16 Water flux and basin area of the major Black Sea rivers (source: UNECE, 2010)

River Mean	**water flux (m^3/s)**	**River basin area (km^2)**
Danube	6573.8	801,463
Dniester	376.6	72,100
Dnieper	1488.1	504,000
Don	670.9	422,000
Chorokh (Coruh)	N/A	22,100
Southern Bug	110.5	46,200
Rioni	408.5	13,330

11.2. Biodiversity and ecosystems

The Black Sea is home to hundreds of species of plants and animals, which depend upon its state of health. Some of these species are already rare or endangered. The thin upper layer of marine water (up to 150 m) supports the unique biological life of the Black Sea ecosystem (BSC, 2008). The deeper and denser water layers are saturated with hydrogen sulphide that, over thousands of years, accumulated from decaying organic matter in the Black Sea. Due to its unique geomorphological structure and specific hydrochemical conditions, specific organisms (protozoa, bacteria, and some multi-cellular invertebrates) inhabit these deep waters. Knowledge about these life forms is very limited. However, disturbance of the natural balance between the two layers could trigger irreversible damage to the people and ecosystem of the Black Sea (BSC, 2008).

Isolation from the flushing effects of the open ocean, coupled with its huge catchment, has made the Black Sea particularly susceptible to eutrophication. This has led to radical changes in its ecosystem in the past three decades, with a major transboundary impact on biological diversity and human use of the sea, including fisheries and recreation (BSC, GEF, UNDP, UNOPS, 2007).

Around 125 protected areas have been designated bordering the Black Sea coast (World Protected Areas Data Base, 2008). These vary in size from tiny scientific reserves of 1 ha up to the newly designated Zernov's Phyllophora Field in the north west shelf of the Ukraine (402,500 ha) to the several thousand hectare areas listed below (Black Sea SCENE, 2010). According to the research by the “Black Sea SCENE” Project, there is no clear information in the database on whether or not the coastal zones are involved in these protected areas, and the list provided should be treated with care. At present, it appears that some 1.1 million ha of coastal/marine protected areas have been designated by Black Sea countries, with about half of this represented by the Danube Delta Biosphere Reserve in Romania alone. The most significant sites that certainly include a marine zone proper are (World Protected Areas Data Base, 2008):

- Danube Delta Biosphere Reserve (Romania) which has a marine buffer zone extending out to a depth of 20 m and covering 103,000 ha
- Mai: Vama Veche (Romania) is entirely marine, covering 5,000 ha

- Zernov's Phyllophora Field Botanical Reserve (Ukraine), established in November 2008, which is entirely marine and covers 402,500 ha
- Chernomorskiy Biosphere Reserve (Ukraine) includes Tendrivsky and Yagorlitsky Bays which cover 74,971 ha (84%) of the area
- Bolshoi Utrish (Russia) has 2,530 ha of marine area up to 40 m deep extending 2 km offshore
- Kholketi National Park (Georgia) has an adjacent marine reserve that comprises a shelf extending 6 - 8 km from the coastline and covers 15,742 ha.

11.3. Human geography

Although the Black Sea is surrounded by the above mentioned six countries, its catchment includes significant areas of 18 countries: Austria, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Georgia, Germany, Hungary, Moldova, Slovakia, Slovenia, Romania, Russia, Turkey, Serbia, and Ukraine. The catchment area is inhabited by around 160 million people (BSEI, 2005) and includes some of Europe’s major population and industrial centres: western and southern Ukraine, Russia (Rostov on Don, Krasnodar, Smolensk), Turkey (Istanbul), Austria (Vienna), and Slovakia (Bratislava).

11.4. Economic activities

Inhabitants of the Black Sea region have traditionally taken advantage of a wealth of rich natural resources, and continue to do so. Goods and services provided by these resources range from natural gas and energy to transportation routes. Development of neighbouring countries (Bulgaria, Romania, Ukraine, Russia, Georgia and Turkey) is closely linked to the natural environment. However, these countries still need time following the collapse of centrally planned systems to make socio-economic progress.

The largest ports on the Black Sea are: Varna (Bulgaria), Constanta (Romania), Odessa and Sevastopol (Ukraine), Novorossiysk (Russia), Batumi, Poti and Sokhumi (Georgia), and Istanbul (Turkey).

Agriculture is among the major economic sectors in all countries bordering the Black Sea. In the northern countries (Bulgaria, Romania and Russia), grain, wheat, sugar beets, sunflower seeds, vegetables, potatoes, and fruits are grown in abundance. In Georgia and Turkey, tea, citrus fruit, hazelnuts, and grapes are grown in agricultural areas on the coast. Also cattle breeding and the dairy industry are important to the region. Fishing and tourism are also important sectors in the region. The sea has also become an important transit corridor for energy supplies from east to west.

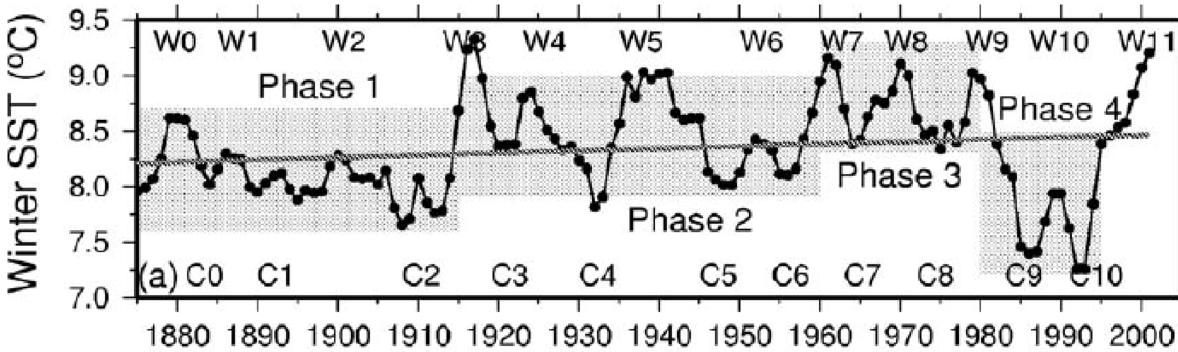
Annual per capita GDP in the region is low compared to the European Union, ranging from Georgia’s $4,280 to Russia’s $16,139 (World Bank, 2008). Unemployment rates in 2008were: Bulgaria 5.6%, Romania 5.8%, Ukraine 6.4%, Russian Federation 6.3%, Georgia 16.5%, and Turkey 9.8% (World Bank, 2008). Black and grey economies and poverty are also widespread throughout the region, while other problems include gender inequality, social exclusion and lack of public participation.

11.5. Climate change impacts

Climate change is having several impacts on the Black Sea. Apart from sea-level rise and erosion, it is also suffering from water acidification, and surface and deep water temperature increase. The vulnerability of the unique environment and ecosystem in each region of the Black Sea varies.

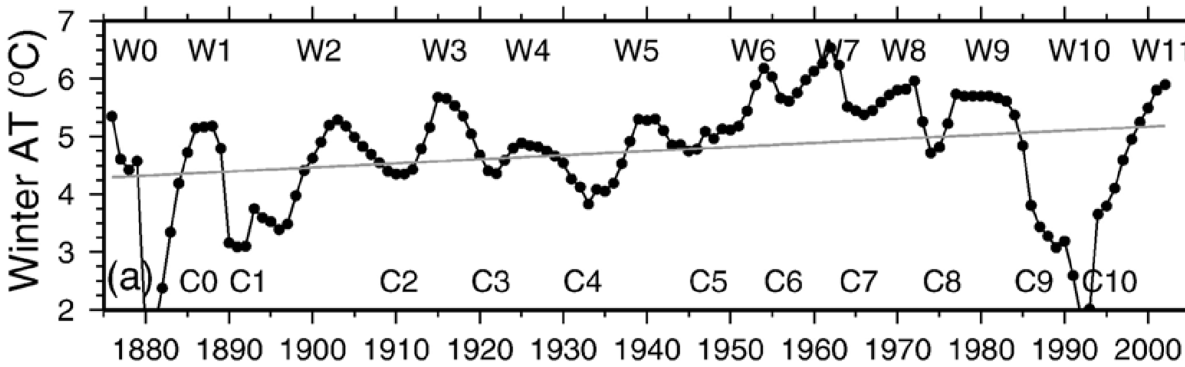
Increasing water temperature is considered as the most pervasive of present day impacts of climate change on marine systems. A warming trend of 0.25 °C during the last century occurred in the Black Sea (Figure 43). The period from the early 1960s to the 1980s was the most significant warming phase, dominated by persistently positive winter shallow sea temperature anomalies above the long term mean (Oguz, Dippner & Kaymaz, 2006).

Figure 43 Long term variations of the winter (December–March) mean sea surface temperature (°C) averaged over the interior basin with depths greater than 1500 m (source: Oguz, Dippner & Kaymaz, 2006).



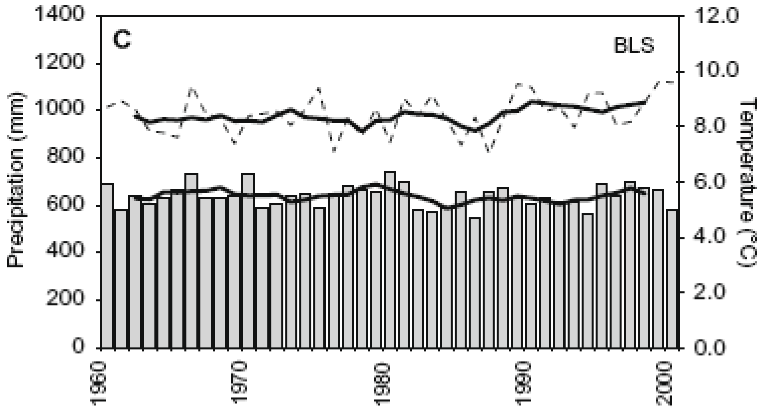
Other impacts include increasing mean temperature (Figure 44), wind velocity and storm frequency, and changes in ocean circulation, vertical structure and nutrient loads. Because the oceanic and atmospheric gas concentrations tend towards equilibrium, increasing CO_2 in the atmosphere drives more CO_2 into the ocean, where it dissolves forming carbonic acid (H_2CO_3) and thus increases ocean acidity (Brierley & Kingsford, 2009). Ocean pH has dropped by 0.1 in the last 200 years (The Royal Society, 2005).

Figure 44 Long term variations of (a) winter (December–March) mean air temperature (°C) measured at the meteorological station near the Kerch Strait, on the north coast of the Black Sea (source: Oguz, Dippner & Kaymaz, 2006).



The river catchments of the Black Sea do not show clear trends in precipitation patterns (Ludwig *et al*., 2009). There is only a slight increase in the mean temperature of their drainage basins due to the climate change between 1960 and 2000 (Figure 45).

Figure 45 Evolutions of precipitation (grey bars) and temperature in the drainage basins of the Black Sea (source: Ludwig, *et al*., 2009).



Salinity is increasing in the low-lying coastal areas of the Black Sea. This is mainly caused by periodic flooding due to storm surges and leads to the degradation of agricultural lands. The Burgas region of Bulgaria is also affected by salinisation of ground water. Specific actions to counteract this problem have not yet been undertaken. The altitude of many coastal areas makes the risk of coastal flooding less severe.

According to observations over the last 85 years, the average sea-level rise in the Black Sea is about 2.5–2.8mm/year, while the global mean increase rate is about 3.3 mm/year (Belokopytov & Goryachkin, 1999). Considering various other parameters, such as surface freshwater flux, changes in river run-off and surface pressure and subsidence of surrounding land, it was concluded that around two thirds of the long term increase in sea-level in the last century was due to an increase of water volume (Tsimplis, 2004). Sea-level rise in the Black Sea is already threatening numerous ports and towns along the Ukrainian, Russian and Georgian coasts.

Coastal erosion and ground water salinisation are the most important impacts of sea-level rise in the Black Sea. High levels of human activity place a significant amount of stress on coastal areas, especially coastal lowland plains. Many coastal areas have deteriorated as a result of erosion and uncontrolled urban and industrial development (BSC, 2009). The Romanian coast, for example, has been subject to serious beach erosion problems for several decades. In the last 35 years, the northern shoreline has retreated inland by 180-300 m and 80 ha/year of the beach has been lost (EC, 2009). Similar losses have also been noted in the southern management unit, where important economic activities such as tourism are more widespread. Coastal erosion does not only threaten the tourism sector, but residential buildings and public welfare as well. Similarly in Bulgaria, erosion poses the greatest threat to the coastal zones, with almost half of the coastline being subject to erosion (EC, 2009).

The future impacts of climate change on several parameters (water temperature, precipitation, sea-level rise, etc.) for the Black Sea have been studied. However, data regarding models and scenarios for projected impacts and vulnerabilities are still limited or not available.

11.6. Climate change vulnerabilities

The intensity of physical impacts of climate change is unique in many geographical areas of the Black Sea, therefore the vulnerabilities, resistance and resilience of organisms and ecosystems is highly variable too. Changes in sea-level, sea water pH and the extent of oxygen-deficient ‘dead zones’, together with other factors acting together, create negative synergistic effects to which organisms and ecosystems may have little resistance (Jackson, 2008). In addition, vulnerabilities of coastal ecosystems are exacerbated by human activities. Given the essential roles that oceans play in planetary function and provision of human sustenance, the challenge is to intervene before tipping points are reached (Brierley & Kingsford, 2009).

Intertidal habitats and ecosystems on the Black Sea coast are vulnerable to sea-level rise due to their low tidal range and limited scope for on-shore migration (Alpar, 2009). Coastal plains with elevations of up to 1.0 m are at high risk of inundation. Examples include the Danube delta (Romania) and Terkos Lake (Istanbul) and Kizilirmak delta-Bafra (Samsun) on the Turkish coast (Demirkesen *et al.*, 2007). However, the risk of flooding due to sea-level rise is expected to be modest; tides are also non-existent and currents are very weak. Heavy rain storms and rivers draining into low-lying coastal areas are the main factors affecting coastal flood risk (EC, 2009).

The Black Sea’s coastal areas are expected to become increasingly vulnerable to the effects of erosion, partly due to climate change and sea-level rise, but largely due to the lack of effective coastal planning regulations. Although erosion is a serious problem along the Romanian coastline, flash floods as well as droughts and desertification are the most serious climate change threats to the country as a whole.

Fish stocks are vulnerable to the direct and indirect impacts of climate change. Direct impacts act on physiology and behaviour, and alter growth, reproductive capacity, mortality and distribution. Indirect impacts alter the productivity, structure and composition of the ecosystems on which fish depend. Increased rates of exploitation also reduce stock levels and increase their variability. Fishing communities whose markets are based on just a few species are vulnerable to fluctuations in stocks, whether due to overfishing, climate change or other causes.

11.7. Climate change adaptation

Prior to the 1990s, relatively little action had been taken to protect the Black Sea. In 1992, the Black Sea countries signed the Bucharest Convention, followed closely by the first Black Sea Ministerial Declaration (the Odessa Declaration) in 1993. This inspired the GEF and other donors, particularly the European Union, to provide more than US$17,000,000 support to the region to help implement the Odessa Declaration and to formulate the longer-term Black Sea Strategic Action Programme.

The Black Sea Environmental Programme was launched in June 1993 and formed the basis of the Black Sea Strategic Action Plan, signed in October 1993 at a Ministerial Conference in Istanbul.

Following signature of the Action Plan, GEF funding was secured to enable countries to complete National Black Sea Strategic Action Plans and to establish the Secretariat for the Black Sea Commission, which became operational in October 2000.

Further GEF funding was secured in 2002 with the commencement of the Black Sea Ecosystem Recovery Project. The project supported regional aspects of the Black Sea Partnership for Nutrient Control and assisted and strengthened the role of the Black Sea Commission. Additionally, the project ensured the provision of a suite of harmonized legal and policy instruments for tackling the problem of eutrophication and release of certain hazardous substances, and to facilitate ecosystem recovery. An important feature of the project was its encouragement of broad stakeholder participation.

A cornerstone of this project was the revision of the Black Sea Transboundary Diagnostic Analysis (originally published in 1996). This document is an objective, non-negotiated analysis using best available verified scientific evidence to examine the state of the environment and the root causes for its degradation. It provided the factual basis for a new Black Sea Strategic Action Programme, which embodies specific actions (policy, legal, institutional reforms and investments) that can be adopted nationally, usually within a harmonized multinational context, to address major priority transboundary problems and, in the longer-term, enable the sustainable development and environmental protection of the Black Sea.

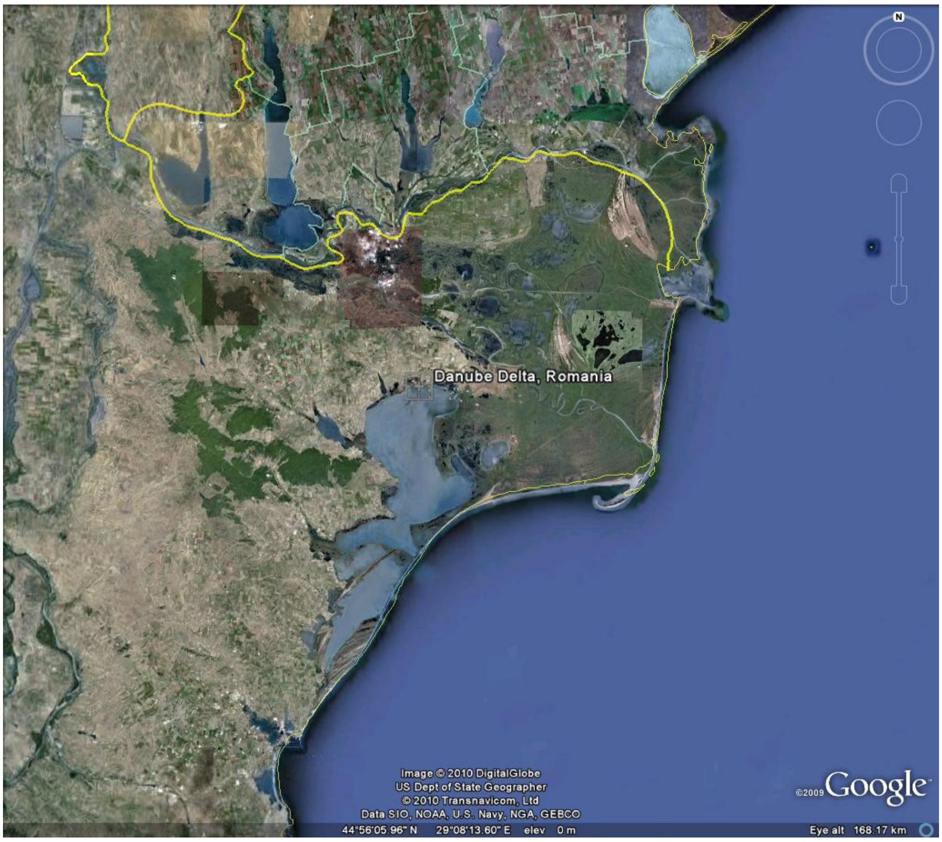
The Black Sea Commission’s only involvement in climate change matters was in October 2008, when it organised a conference aimed at understanding and dealing with the consequences by using science, information technology and policy.

At national level, institutional, political and financial constraints are among the main handicaps towards taking effective adaptation measures. There is also a significant lack of data regarding the costs and benefits of adaptation, and uncertainty surrounding future climate impacts. However, projects to protect coastal areas from erosion are being undertaken in Bulgaria and Romania, although coastal strategies/legislation does not exist in either country. Also in Romania, the Danube Delta Biosphere Reserve Authority published a master plan for its protection in 2005. In addition, the International Commission for the Protection of the Danube River, which was established to implement the Danube River Protection Convention, works to ensure the sustainable and equitable use of waters and freshwater resources in the Danube River basin.

11.8. Case studies

Deltaic coastal zone between the Sulina and Sf. Gheorghe Danube River mouths (Romania) (Figure 46)

Figure 46 Location of Danube delta, Romania (source: Google Earth, 2010).



Human activities have drastically changed the natural evolution of the coastal strip between Sulina and Sf. Gheorghe Danube mouths, where the highest erosion and substantial accumulation rates can be observed compared to the entire Romanian Black Sea coast. Anthropogenic influences are the most important factors controlling coastal evolution in recent decades (Stănică and Panin, 2009).

The construction of embankments along the Danube River and its tributaries, in addition to dam construction for hydroelectric purposes, has contributed to a decrease in sediment discharge (mainly as bed load) (Panin, 1976, 1998; Giosan *et al.,* 1997; Ungureanu and Stãnicã, 2000). Also jetties constructed along the Sulina shoreline have strongly affected the circulation of near-shore currents and related sediment transport, as they interrupt the local dominant southward direction of the long-shore current, which transports sediments originating from the various secondary mouths of the Chilia tributary (Stănică and Panin, 2009).

As a result of the operation of the dams and the extension of the Sulina Canal, dramatic changes (both accumulation and erosion) have occurred. Thus, along the coastal zone between the Sulina and Sf. Gheorghe Danube River mouths, rapid shoreline retreat from 5 to 25 m/year has occurred (Panin, 1999). In addition, various scenarios for the rate of sea-level rise suggest a general coastline retreat ranging from 1.5 to 2 m/year as a result climate change.

This means that, in addition to the present day trend in shoreline evolution, a 35 to 50 m retreat could be added by 2030 as a result of changes in global climate (Stănică and Panin, 2009).

Kizilirmak river delta (Turkey) (Figure 47)

Figure 47 Location of the Kizilirmak river delta (Source: Google Earth, 2010).

The rocky and steep northern coasts of Turkey are less vulnerable to sea-level rise than those of other Black Sea countries. However, the Kizilirmak River delta is an exception, where coastal erosion is an environmental threat that increases inundation and leads to land loss. Coastal retreat along the eastern side of the delta is between 2.5–5.0 m/year and is mostly attributed to decreasing sediment supply, resulting from the construction of dams for electricity generation (Alpar, 2009).

The Kizilirmak is the largest Turkish river flowing into the Black Sea, with a catchment area of 78,646 km^2 and total runoff of 5.9 km^3/year. The delta plain is sandy at the coast, gradually turning into silt, clay and organic soil inland (Özesmi, 1999). The sediments supplied by the river feed the coastal barriers along the eastern margin of the delta. A group of lagoons lie along the shoreline, whose barriers enclose 15,000 ha of wetland and lagoon habitat that gives way to agriculture inland. Erosion and retreat of the delta are likely to result in a gradual loss of the lagoon barriers. The construction of dams, together with intensive agriculture and illegal sand extraction, reduce the amount of sediment reaching the coast and increase the vulnerability of the coastal zone to sea-level rise (Alpar, 2009).

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Annexes

Annex 1: Current state of knowledge from the European Commission's report - ***The economics of climate change adaptation in EU coastal areas***

Annex 2: State of knowledge about sea-level rise

Annex 3: Relevant coastal climate change impacts, vulnerability and adaptation research projects

Annex 1: Current state of kno wledge from the European Commission's report - *The economics of climate change adaptation in EU coastal areas*

General issues on the economics of climate change adaptation in EU coastal areas

The report by DG MARE (EC, 2009) discusses very briefly and from general perspective the vulnerability of European coastal areas to climate change. Key actors are identified, levels of responsibility and national/sub-national adaptation plans and practices reviewed, and Member State investments in coastal protection for the period 1998 to 2015 summarised. DIVA simulations were performed to estimate the cost of climate related damage and adaptation. The results of the DG Mare study were compared with the PESETA study. The PESETA study focussed on certain sectors (i.e. health, tourism, agriculture), but included a study of coastal systems using the DIVA tool (Ciscar, 2009). Whilst the DIVA tool makes cost estimates that are comprehensible to most stakeholders, it must be remembered that model projections/calculations of this type include a lot of uncertainties.

The DIVA tool

The EU financed several studies that applied the Dynamic Interactive Vulnerability Assessment tool (DIVA tool)) (Hinkel & Klein, 2009; Costa *et al.*, 2009). DIVA is a product of the DINASCOAST project[5] (2001-2004) and can assist in the assessment of coastal vulnerability in relation to sea-level rise. DIVA does not provide an integrated vulnerability indicator at the end of a simulation, but several indicators (e.g. people at risk, damage and adaptation costs, land loss) for the coastal area under examination. DIVA offers a more comprehensive approach than the SimCLIM model, but it still has certain shortcomings and problems. It is too coarse to be used as a decision support tool, but should be regarded as a system that supports discussion about sea-level rise and related impacts (Hinkel & Klein, 2009).

Static and averaging components

The DIVA tool uses land use outputs from the IMAGE model[6]; a dynamic development has not yet been considered. It is assumed that the current coastal land use pattern is maintained, with new coastal residents and infrastructure inflating the current pattern. With regard to coastal morphology, coastlines are considered as a traverse, with each part of them characterized by specific features (McFadden, 2007).

Regarding information on population, DIVA uses results from the implementation of the SRES scenarios on IMAGE 2.2 across 17 world regions (Nakicenovic & Swart, 2000). The regional growth rates are assumed to apply homogenously to the countries within the region. *Per capita* income is also extracted from the same model. The regional growth rates are assumed to apply homogenously to the countries within the region, with the exception of rich countries in poor regions. The exception is valid for Hong Kong, Singapore, Macau, Taiwan and several Caribbean countries. Following Tol (1995), the number of people forced to migrate is calculated as the coastal area permanently flooded times the population density in that area. The value per migrant is three times the *per capita* income. Agricultural land values are used to value the loss of drylands occupied by humans. The reason for this lies in the

[5] **D**ynamic and **IN**teractive **AS**sessment of National, Regional and Global Vulnerability of **COAST**al Zones to Climate Change and Sea-Level Rise, www.dinas-coast.net/

[6] http://www.pbl.nl/en/themasites/image/model_details/index.html

assumption that agricultural land has the lowest value and, if land for housing or industry is permanently inundated, then those activities would expand elsewhere at the expense of agriculture or nature.

Sea-level scenarios

The major climate change factor in DIVA is sea-level rise. The sea-level scenarios are not endogenously calculated in DIVA, but are based on runs of the CLIMber-2 model, forced by certain IPCC forcing scenarios. In its origin, CLIMber-2 is a climate model of intermediate complexity with a rather coarse resolution (5°). For the different IPCC forcings, uniform (sea-level rise is the same all over the world) and non-uniform scenarios were calculated based on the resolution of the model. These scenarios were readjusted *via* a regionalisation of the thermal expansion component (based on the Peltier 2002 model). Natural subsidence is considered to a certain extent, although human induced subsidence is not considered. Future flooding is calculated by assuming that all other climate factors remain constant, including existing tracks, frequency and intensity of storms. Surge elevation is simply displaced upwards by sea-level rise.

The impact valuation and cost assessment for adaptation

The economic assessment module is based on Tol (1995) and uses simple econometric approaches calibrated with empirical data. The impacts valued by the DIVA tool are:

- Land lost to erosion and flooding.
- Wetland lost.
- Flood risks.
- Salinity intrusion.
- Forced migration.

Adaptation costs include aspects such as building sea and river dykes, beach nourishment and wetland nourishment. Decisions on adaptation can be based on cost-benefit analysis, pre-selected adaptation options or on user-defined levels of adaptation. A direct impact such as erosion is calculated with the Bruun rule (Cooper & Pilkey, 2004, Section 2.4.4), modified to include beach nourishment. DIVA assumes erosion to be a linear function of sea-level rise (in detail, erosion is 100 times the rise in relative sea-level) and beach nourishment. This implies that the marginal benefits of beach nourishment are constant: for every cubic metre of additional sand supplied, the value of land is considered to be constant. The costs of beach nourishment are also linear in the amount of sand supplied, so that the marginal costs of beach nourishment are constant. If the costs of beach nourishment are greater than the marginal benefit, then no nourishment will take place. If the costs are less than the benefit, then nourishment will fully offset erosion. Nourishment costs are assumed to be the same in all countries.

In DIVA the number of people displaced is calculated as the coastal area permanently flooded times the population density in that area; the economic impacts per migrant is assumed to be three times the *per capita* income.

Criticism of DIVA approach with regard to local decision-making

DIVA has certain shortcomings that have to be taken into account in policy/decision-making. The developers of DIVA did not plan for it to be used as a decision support tool (Hinkel & Klein, 2009). Nevertheless, this was the case in the DG Mare study. Therefore, the benefits and limitations of DIVA have to be clarified. It was noted in the DG Mare report that coastal adaptation policies across the EU are elaborated at different administrative levels and set in place by both public and private actors. In the UK, for example, coastal protection is seen as a matter for national authorities and coastal policies are decided at the national level. In Germany, each individual coastal state drafts its own coastal plan and decides on scenarios and strategies, while in Denmark coastal protection measures have to be initiated, financed and implemented by local landowners or within municipalities. So far, any cost categories calculated and provided by DIVA are not yet available for regions, but summed up for the national level. Therefore, it is difficult to use results provided by DIVA, as these may not be aggregated in a scale relevant for decision-makers across all coastal European countries.

Furthermore, the administrative scale where decisions are taken seems to vary (from coarse national level to local communities) and the spatial scales regarding analysis of impacts and projections seem to be unique among all the actors. Despite of this, it should be noted that DIVA has recently been applied in several studies (Costa *et al.*, 2009) and it is currently the only tool that allows global assessment of sea-level rise impacts.

There are three basic responses to sea-level rise: protect, retreat or accommodate. DIVA already explores protection and accommodation, but further refinements of assumptions are possible in order to bring it more close to reality.

One of the characteristics of DIVA is that, if protection is to take place, the model will assume that the entire coastal segment will be protected, independent of its length. For some specific regions, this may lead to misleading results, since actual impacts might be over-estimated due to the existence of large coastal segments. Accommodation options for open spaces are considered in DIVA (e.g. beach and wetland nourishment), although options for built environment are disregarded. Further development is needed here, as managing the existing and future built environment at the coast has large implications for the costs of storm surges - whose height is influenced by sea-level rise.

Further development is also necessary to enable the tool to assess the costs and benefits of so-called soft adaptation. Beach and wetland nourishment are already considered, but the opportunities for adaptation go beyond these limited options.

Changes in land use planning, build construction and occupancy regulations are examples of meaningful soft adaptation measures related to sea-level rise that are currently lacking in the DIVA analysis. Retreat is not an option in DIVA and, of all options, this is the least popular among decisions-makers, if not impossible in some situations.

Furthermore, the DIVA tools use modules that rely on outdated assumptions. A matter of intense discussion focuses on the Bruun rule (e.g. Cooper & Pilkey, 2004). The Bruun rule is a simple 2D model allowing an assessment of shoreline response to rising sea-level. The model has seen near global application since its original formulation in 1954. Criticism with regard to this model has to do with the fact that this concept has been superseded by numerous subsequent findings and is now invalid. Several assumptions behind the Bruun rule are known to be false and nowhere has it been adequately proven; indeed, several studies disprove it in the field. No universally applicable model of shoreline retreat under sea-level rise has yet been developed. Despite this, the Bruun rule is in widespread contemporary use at a global scale, both as a management tool and as a scientific concept (Cooper & Pilkey, 2004, and the references therein). Storm surge characteristics (e.g. in terms of return level) are simply projected into the future by only considering sea-level uplift. This is a rather simple assumption, which cannot be supported by recent scientific results.

A final critisism, which cannot be fully explained yet, is concerned with cost assessment in general. Performing different scenario runs and keeping starting parameters constant for these runs can simulate higher costs for more sustainable scenarios (e.g. B1) than simulations based on (for example) A2 forcing.

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Annex 2: State of knowledge about sea-level rise

Components of sea-level rise

Two climate-related components have to be considered in the context of sea-level rise. Firstly, so-called eustatic sea-level rise considers the mass of water in the oceans and the impacts of melting ice masses and surface run-off from land. Secondly, the steric component considers the thermal expansion of water due to warming stimuli.

As the ocean warms, its density and volume increase and its mass remain constant. Due to the high heat capacity of surface waters, the propagation of warming stimuli to deeper layers is delayed. This implies that it is possible to estimate a sea-level response time following a shift in temperature. Siddall *et al.* (2009) estimate this to be 2,900 years, whereas Hansen *et al.* (2007) suggest ~2,500 years, based on sea-level rise data from the Holocene. Grinsted *et al.* (2009) state that the response time that applies today, however, may be very different from that which governed sea-level rise throughout most of the Holocene. They conclude that the response time for present day sea-level rise is 200 to 300 years. If this holds to be true, future sea-level rise is likely to be under-estimated. Nevertheless, sea-level rise will be a problem for many centuries and cannot be halted, in particular when a warming stimulus is introduced into the system.

A number of additional factors influence sea-level. Tectonic effects such as vertical land movements have to be considered when calculating relative sea-level rise (Rasmussen, 2004). Ocean currents and/or mass imbalances could also have a regional impact on sea-level. Levermann *et al.* (2005) showed that thermo-haline circulation strength affects sea-level in North America and Europe. Further, Tsimplis & Shaw (2009) indicate that North Atlantic Oscillation patterns could have an impact on regional and seasonal sea-level rise.

Clearly, sea-level rise is not uniformly distributed globally and none of the drivers are understood completely (Figure 1). Current empirical observations are not yet sufficient to develop a precise assessment of the causes of sea-level rise, let alone projections of future rise. Therefore, an improvement in estimates of the spatial variability in future sea-level change is an important research target in coming years (Milne *et al.*, 2009). The best available evidence should be used in estimates, including high precision assessments based on satellite, gravity and altimetry measurements.

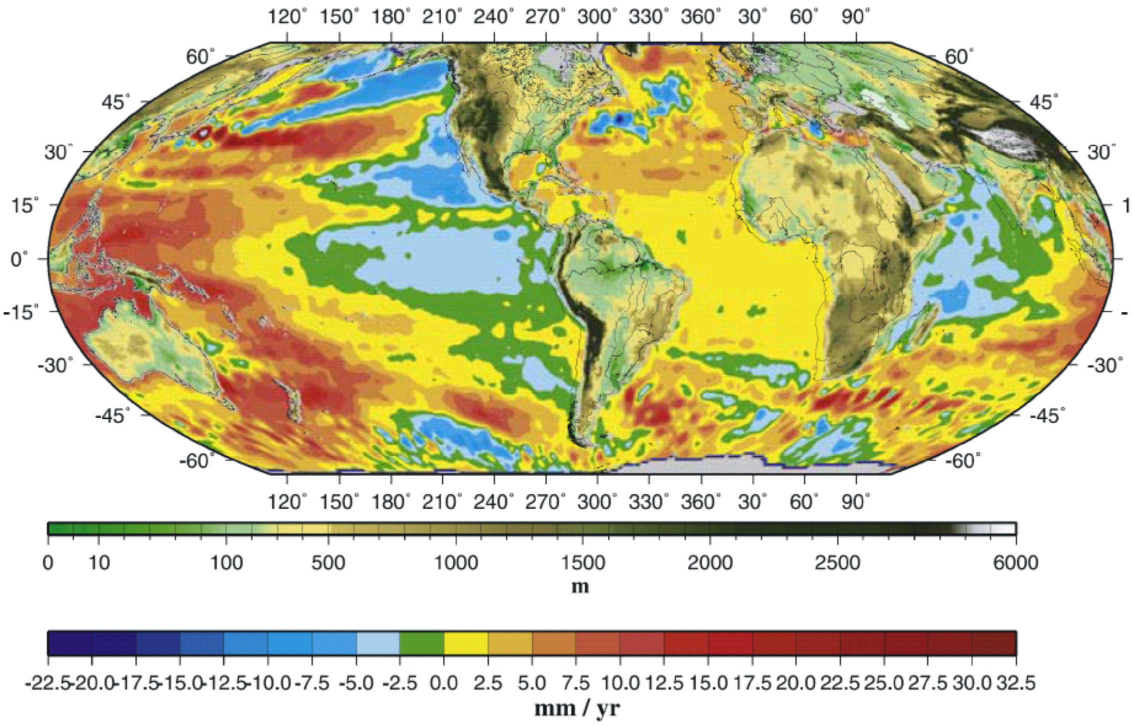


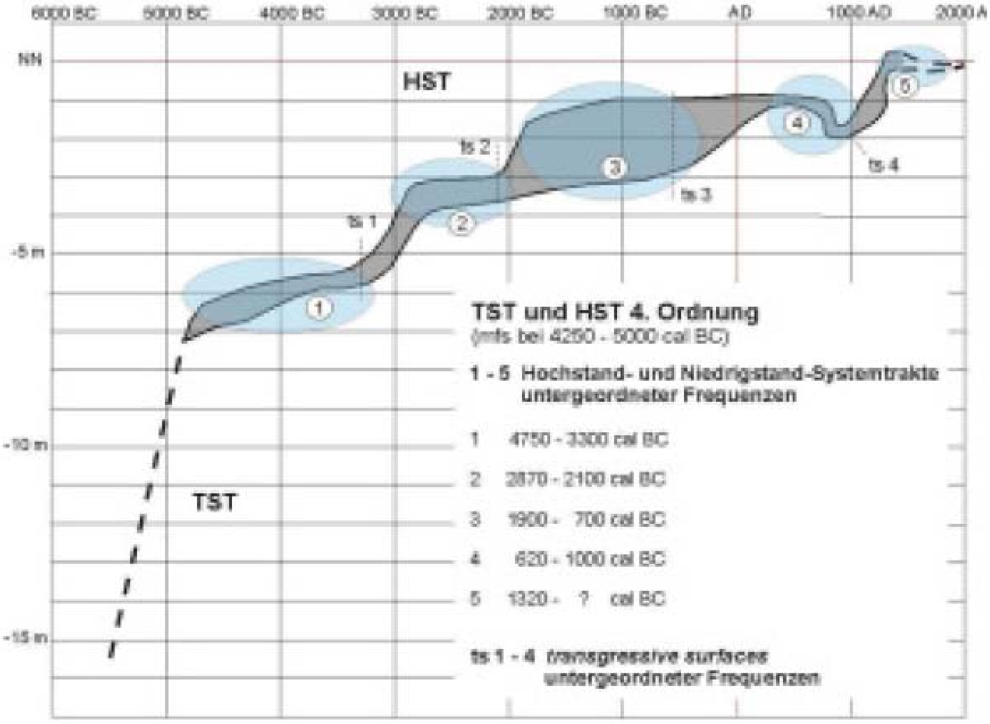
Figure 1: Sea-level rise trends (1993-2003) after the TOPEX/Poseidon satellite mission. This figure illustrates how different sea-level rise was during this decade. The global average amounts to 2.8mm/yr, after Cavenaze & Nerem (2004).

Geo-historic data and sea-level rise of the 20th Century

In general, spatial sampling of historic data is poor compared with the distribution of tide gauges measurements during the last century. The majority of these data span parts of the Holocene period only (10,000 years ago to present), with a distinct paucity of data before the last glacial maximum around 25,000 years ago. From the end of the last glacial maximum (20,000 years ago) until 8,000 years ago, sea-level increased by approx 120m (~10mm/yr). Nonetheless, yearly growth rates could be misleading, in particular for long time spans, because they are averaging out sudden jumps (Fig. 2a). Increases of 50mm/yr were documented around 19,000 years ago (Clark *et al.*, 2004). Behre (2004) estimated increases of 12.5mm/yr 9,000 to 7,000 years ago. Similar observations were made for the last interglacial (Rohling *et al.*, 2009). During this era, analyses show that the Greenland ice sheet melted completely within a time span of 400 years, corresponding to a sea-level rise of 16mm/yr (Rohling *et al.*, 2009).

During the last 6,000 years, sea-level rise slowed down. For central Europe (East Frisian coast), Bungenstock (2005) estimated sea-level rise of 1mm/yr on the basis of sediment stratigraphy, pollen analyses and radiocarbon dating. Further it was found that sea-level during this time span did not rise continuously, but showed several rapid positive (and negative jumps) which could be correlated with climatic changes.

Figure 2: Upper (a) – Sea-level curve for the East Frisean coast based on sequence stratigraphic analyses (after Bungenstock, 2005). Lower (b) - Overlay of global palaeo-climatic data and the sea-level rise curve, with phases of so-called rapid climate change shown as columns; these time spans were cooling phases in Europe (after Bungenstock, 2005).


6000 BC
5000 BC
4000 BC
3000 BC
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AD
1000 AD
NN
-5 m
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HST
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ts 1
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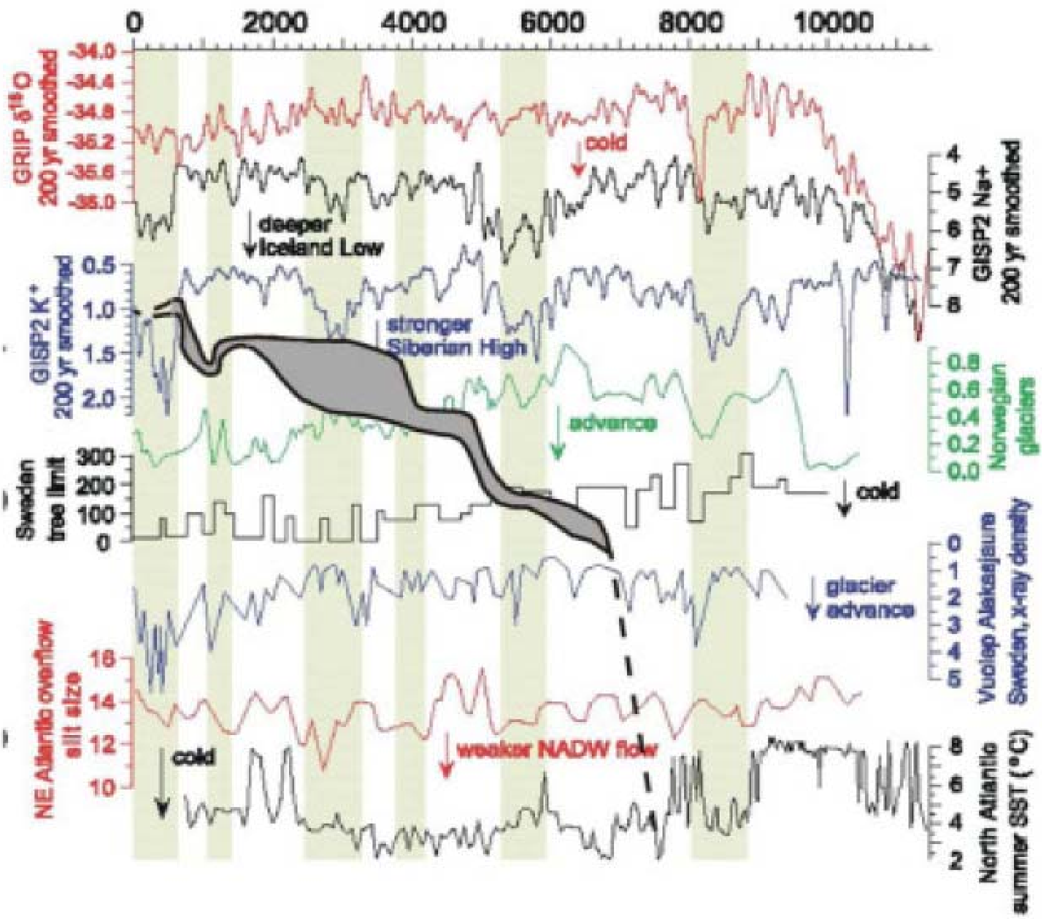
ts 3
ts 4
TST und HST 4. Ordnung
(mfs bei 4250 - 5000 cal BC)
1 - 5 Hochstand- und Niedrigstand-Systemtrakte untergeordneter Frequenzen
1 4750 - 3300 cal BC
2 2870 - 2100 cal BC
3 1900 - 700 cal BC
4 620 - 1000 cal BC
5 1320 - ? cal BC
ts 1 - 4 transgressive surfaces untergeordneter Frequenzen


0
2000
4000
6000
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GRIP δ18O 200 yr smoothed
cold
deeper Iceland Low
GISP2 Na+ 200 yr smoothed
GISP2 K+ 200 yr smoothed
stronger Siberian High
advance
Norwegian glaciers
Sweden tree limit
cold
glacier advance
Vuolep Alakasjaure Sweden, x-ray density
NE Atlantic overflow silt size
cold
weaker NADW flow
North Atlantic summer SST (°C)

Between 700 and 900 AD, Bungenstock (2005) found a decrease of approximately 1m, while from 900 to 1300 AD a rapid increase of up to 2m was estimated. The most significant result was that several periods in the last 6.000 years showed rapid increases and decreases, as well as and long periods of stabilization. Therefore, estimates of sea-level rise strongly depend on the observed time scale (e.g. for the last 6.000 years 1.2mm/yr; for the last 1,000 years ~1.7mm/yr; approximately 4.4mm/yr during 900 to1300 AD. Due to the fact that Bungenstock (2005) could correlate rapid increase with cooler and warmer periods in the past (Figure 2b), there is a clear indication that response time of the hydrosphere might be much shorter than estimated. However, it is still a matter of debate as to whether the steric or eustatic component is most prominent in recent and future sea-level rise. It is commonly agreed that the steric component was most relevant for the observed sea-level rise during the 20^{th} Century. However, many researchers believe that, in the 21st Century, eustatic increase will become the most relevant because of accelerated melting of inland glaciers (Meier *et al.*, 2007). In this regard, a component of major concern is the Greenland ice sheet. Vinther *et al.* (2009) found that ice mass losses in Greenland are underestimated and a temperature increase of only a few degrees will result in a contribution to sea-level larger than previously projected.

What is not considered in model projections?

Singular events with low probability, but with high impacts are normally not included in model projections of sea-level rise. One prominent example of this is the discussion on the instability of the West Antarctic Ice Sheet, which could cause an additional 5 to 6m sea-level rise if it collapses (Vaughn & Spouge, 2002). Paleo-climatic evidence (e.g. corals on tectonically stable coasts from the last interglacial period about 130,000 years ago) and ice core records show strong hints that the West Antarctic Ice Sheet could respond very sensitively to a global temperature rise of about 2 degrees above pre-industrial levels. Two mechanisms were discussed: (i) the high speed of sea-level rise due to melting of the Greenland ice sheet, which could possibly push destabilization of the ice shelves surrounding the West Antarctic Ice Sheet; and (ii) shallow ocean warming around and under the ice shelves surrounding the West Antarctic Ice Sheet, causing a weakening and thinning from below (Overpeck *et al.*, 2006). Examinations on the basis of empirical data further support this scenario. Clark *et al.* (2004) show that such events have occurred in the past (e.g. 19,000 years ago, when an abrupt sea-level rise of 10 to15m within a time span of approximately 1,500 years occurred). However, the sea-level rise effect on an unstable West Antarctic Ice Sheet is still a matter of debate. In a recent study, Bamber *et al.* (2009) estimated the pulse effect of a collapse of the West Antarctic Ice Sheet. The authors found that eustatic sea-level rise - caused by such an event - will be only 3.3m (average), which is less than identified by other studies. Bamber *et al.* (2009) also estimated the regional effects of such a pulse and showed the highest values on the Pacific and Atlantic coasts of Northern America. The pace of a potential collapse of the West Antarctic Ice Sheet is unknown. If it were rather fast (e.g. melting over 500 years), it would add about 6.5mm/yr to sea-level rise – about twice the current rate due to all sources. For Europe, this would imply a rise of 2.5 to 3.5m, although on a longer time scale.

How much will sea-level rise in the 21st Century?

Assessing sea-level rise for the coming 100 years is difficult. Due to model simulations having problems with singular events like rapid movement of Antarctic ice masses, any attempt to project sea-level rise for the 21st Century must be based on more fundamental processes and knowledge obtained from the examinations of palaeo-data.

Besides the total amount of annual increase in sea-level, questions surround the very long response times of continental ice masses and the hydrosphere to warming stimuli. While sea-level rise accelerated during recent decades, the impacts of sudden events like rapid ice movements (e.g. in Antarctica) are possibly over-estimated (Bamber *et al.*, 2009). Considering all these effects, statistical or regression approaches seem to be suitable to estimate future sea-level rise.

Rahmstorf (2006), for example, used a simple regression model to suggest that sea-level rise could reach 0.5 to 1.4m above 1990 levels by 2100 (4.6-12.7mm/yr). Grinsted *et al.*, (2009) used a four-parameter linear response equation and estimated sea-level rise for the A1B scenario to 0.9 to 1.4m (14mm/yr maximum) by 2100. A more recent study estimated sea-level rise of approximately 190cm (~17mm/yr) by 2100 (Vermeer & Rahmstorf, 2009). Considering the evidence collected during recent decades, such an increase might be possible, although current rates are towards the lower figure (Peltier, 2009). This situation could change rapidly with an accelerated melting of the Greenland ice sheet (Vinther *et al.*, 2009; Richardson *et al.*, 2009). Recent model outputs, while being the subject of continuing debate, are nonetheless suggesting that sea-level rise estimates cited in IPCC AR4 (IPCC, 2007) are too low (WBGU, 2006) (Figure 3).

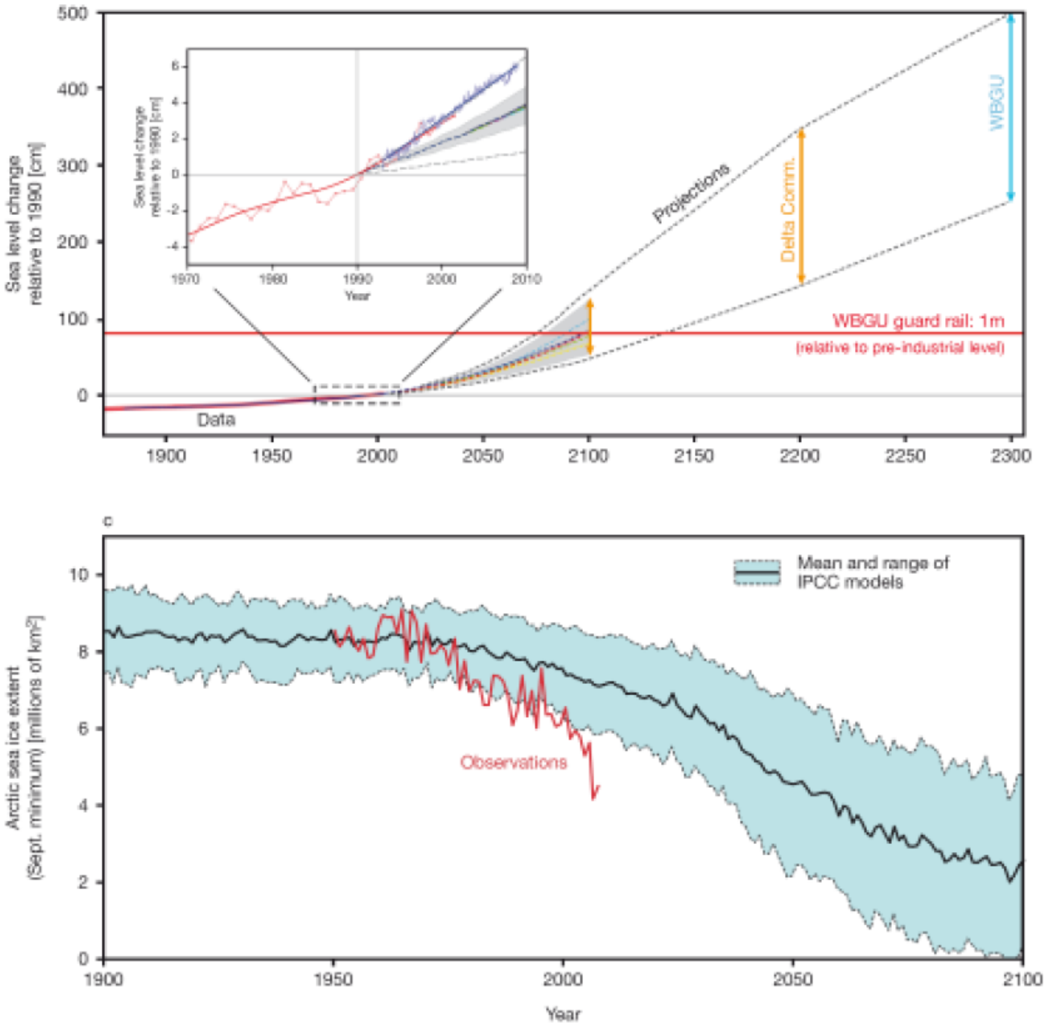

Figure 3: Projections of future sea-level rise and comparison with recent satellite measurements (upper panel, inset). It is clearly shown that the current sea-level rise is much faster than assessed in IPCC AR4. In the lower panel the velocity of melting sea ice is shown.

Although this does not contribute to sea-level rise, it supports the argument of an accelerated melting of glaciers in the polar hemisphere (after WBGU, 2009).

Other effects influencing sea-level rise

The effect of land waters on regional sea-level variation is not yet well understood, but could either accelerate or decelerate sea-level rise. Lettenmeier & Milly (2009) stated that a number of mechanisms could reduce continental water mass, causing a higher inflow into the oceans (e.g. reductions of water storage, urbanization suppressing groundwater recharge, extraction of groundwater reducing aquifer storage). On the other hand, mechanisms exist which allow land to gain water. For example, the sequestration of water in reservoirs in the middle of the 20th Century depressed rates of sea-level rise by more than 0.5 mm/yr on a decadal timescale – although this effect slowed down during the last decades.

Tools for assessing sea-level rise impacts – advantages and shortcomings

<u>Global Vulnerability Analysis</u>

Despite its age, the Global Vulnerability Analysis (GVA) is still the most quoted approach for assessing coastal vulnerability. The model was developed by Hoozemans *et al.* (1993). It considers changes in flooding caused by storm surges, expressed in terms of the number of people at risk of flooding on average per year, and the loss of coastal wetlands. Assessments are at national level, thus parameters needed to be determined on a country basis. GVA provided the first compilation of quantitative information on coastal vulnerability to sea-level rise. The results of this work have been widely used as the basis for international policy analysis and in integrated assessments, including those running under the IPCC. However, constraints include obsolete data, a static one-scenario approach to sea-level change as the only driving variable, and arbitrary assumptions on socio-economic development and adaptation. A restricted set of model approaches are now available that allow regional/local vulnerability assessments.

<u>The DIVA tool</u>

The Dynamical Interactive Vulnerability Assessment tool (DIVA) is a kind of a geographic information system consisting of seven modules (Figure 4) (Hinkel & Klein, 2009). The strategy of the approach is to divide the global coast into 12,148 coastal segments with similar characteristics (McFadden *et al.*, 2007). On the basis of these segments the analyses will be performed.

Module Name	Author	Description
River Effect	Rob Maaten	Calculates the distance from the river mouth over which variations in sea level are noticeable.
Wetland Change	Loraine McFadden	Calculates area change in km^2 due to sea-level rise for seven types of wetlands.
Flooding	Robert Nicholls	Calculates flooding due to sea-level rise and storm surges.
Wetland Valuation	Luke Brander	Calculates the value of different wetland types as a function of GDP, population density and wetland area.
Indirect Erosion	Luc Bijsterbosch, Zheng Bing Wang	This is a reduced version of the Delft Hydraulics ASMITA model. It calculates the loss of land, the loss of sand and the demand for nourishment due to indirect erosion in tidal basins.
Total Erosion	Robert Nicholls	Calculates direct erosion based on the Bruun rule. Adds up direct erosion and indirect erosion in tidal basins.
Adaptation	Richard Tol	Calculates socio-economic impacts of the geodynamic effects, taking into account preset and/or user-defined adaptation options.

Figure 4: The seven modules of the DIVA approach.

For each segment, DIVA provides a multitude of parameters such as population density, wetland area, frequency and height of storm surges and area flooded. The tool enables the analysis of a range of mitigation and adaptation scenarios for the time frame 2005 to 2100 (in 5 year steps). DIVA is specifically designed to explore the vulnerability of coastal areas to sea-level rise. It comprises a global database of natural system and socio-economic factors, relevant scenarios, a set of impact-adaptation algorithms and a customized graphical-user interface. For site-specific applications, the model must be modified because local features are not yet included.

The SimCLIM model

The Simulator of Climate Change Risks and Adaptation Initiatives (SimCLIM) open framework software system is part of an ongoing effort to design tools to aid decision-making under changing climate conditions (Warrick *et al.*, 2005). SimCLIM enables examination of potential erosion and flooding in response to future climate scenarios, including sea-level rise due to climate change, as well as changes resulting from local land movements. The method features a separate sea-level generator to calculate sea-level change due to climate change, in association with that resulting from local land movements. SimCLIM also includes a set of impact modules (e.g. allowing small-scale economic assessments). For the coastal zone, the focus is on erosion and flooding, taking into account storm effects, local sea-level trends and lag effects, in order to provide time-dependent responses of the shoreline to sea-level rise at selected sites. The coastal flood model is spatial and allows the user to examine changes in the areas of potential inundation from the combined effects of sea-level rise and extreme storm events. One of the distinct advantages of using the generator is that it allows rapid generation of place-based sea-level scenarios, which accounts for some uncertainties associated with emissions scenarios. By comparison with DIVA, its resolution is finer which allows it to perform impact assessments, for example, at city level. The model *per se* is 'data rich', implying that, in addition to background data, a lot of data has to be collected before a regional assessment study can be performed. Also, SimCLIM uses the Bruun rule as a module to calculate coastal erosion.

The FUND model

The Climate Framework for Uncertainty, Negotiation and Distribution model (FUND) is an integrated assessment model for climate change impacts and adaptation analyses with a number of linked modules. The coastal module of FUND examines the potential dry land and wetland losses as a result of sea-level rise, and then applies an economic optimum assessment of the benefits of coastal defence (Nicholls *et al.*, 2005). FUND projections are for 16 world regions; population change and *per capita* growth are assumed to be uniform for all countries within a region and are extended post-2100. Results are better seen as 'what if' analyses, rather than conventional analyses. While integrated assessment models such as FUND are powerful tools for thinking about the future, the resulting metrics need to be interpreted with great caution.

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Annex 3: Relevant coastal climate change impacts, vulnerability and adaptation research projects

The following table shows list of some of the relevant coastal climate change impacts, vulnerability and adaptation research projects in Europe.

Ref.	Research project title and objectives	Carried out by	European marine basins covered	Interreg project	Dates
NORTH-EAST ATLANTIC: EUROPEAN PROJECTS					
1	**THESEUS** Innovative coastal technologies for safer European coasts in a changing climate will develop a systematic approach to delivering both a low-risk coast for human use and healthy habitats for evolving coastal zones subject to multiple change factors.	Alma Mater Studiorum-Universita Di Bologna	North-east Atlantic	✓	2009-2013
2	**EPOCA** European project on ocean acidification will determine the sensitivity of marine organisms, communities and ecosystems to ocean acidification. Molecular to biochemical, physiological and ecological approaches will be combined with laboratory and field-based perturbation experiments to quantify biological responses to ocean acidification, assess the potential for adaptation, and determine the consequences for biogeochemical cycling.	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (CNRS)	North-east Atlantic	✓	2008-2012
3	**Ranking port cities with high exposure and vulnerability to climate extremes – exposure limits** looked at population and asset value exposed now and in 2100 for major cities like Amsterdam, Rotterdam, Hamburg, London and Glasgow. For these cities, the exposed population rise from 2.3 million to 4.0 million, and the exposed assets from $360 to $2220 billion.	Organisation for Economic Co-operation and Development/ Organisation de Coopération et de Développement Economiques (OECD/OCDE)	All - global		2008
4	**BRANCH** Biodiversity Requires Adaptation in Northwest Europe under a CHanging climate advocated the need for changes in spatial planning and land-use systems in North-West Europe to allow wildlife to adapt to climate change. This included the impacts of sea level rise on the coast at different geographical scales along the North Sea coast, from individual sites to entire stretches of coastline.	BRANCH partners (Alterra, Conservatoire du Littoral, Environment Agency, Environmental Change Institute, Hampshire County Council, Kent County Council, Natural England, Provincie Limburg, Tyndall Centre for Climate Change Research)	North-east Atlantic	✓	2005-2007
5	**DINAS** Dynamic and INteractive ASsessment of National, Regional and Global Vulnerability of COASTal Zones to Climate Change and Sea-Level Rise is an integrated modelling project that combines science and data from a range of different disciplines to help policymakers interpret and evaluate coastal vulnerability. An integrated methodology/assessment tool called DIVA has been developed to assess the consequences of a range of mitigation and	Potsdam Institute for Climate Impact Research (PIK), Flood Hazard Research Centre (FHRC), WL|Delft Hydraulics, Institute of Environmental Studies (IVM), Centre for Marine and Atmospheric Sciences (ZMAW), Cambridge Coastal Research Unit (CCRU), Neotectonics Research Centre, DEMIS b.v.	North-east Atlantic	✓	2001-2005

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	adaptation scenarios.				
6	**MACIS** project (Minimisation of and Adaptation to Climate change Impacts on Biodiversity) summarized the impacts of climate change on biodiversity, developed methods to assess the potential impacts in the future and assessed policy measures to stop biodiversity loss. The project showed, for example, that 1.5% of considered species could lose all suitable climate space by 2100; 2.8% could lose >90%.	Helmholtz Centre for Environmental Research - UFZ; Centre de la Recherche Scientifique Laboratory of Alpine Ecology; University of Lund; University of Oxford; Université de Lausanne; Pensoft Publishers; Consejo Superior de Investigaciones Científicas; University of Turin; University of Edinburgh; Helsingin Yliopisto, Helsinki; South African National Botanical Institute; Oxford Brookes University	North-east Atlantic	✓	2007 - 2009
7	**SAFECOAST** project involved gaining and sharing knowledge and information on coastal flood and erosion risk management between coastal management authorities in Denmark, Germany, Netherlands, Belgium and United Kingdom. An important finding of the project was the confirmation of the similarities in coastal problems and possible solutions, and the commonality in methodological approaches, among the various North Sea countries.	Ministry of Transport, Public Works and Water Management VenW [NL]; Ministry of the Interior of the Land Schleswig-Holstein [D]; Schleswig-Holstein State Ministry for Agriculture, Environment and Rural Areas [D]; Danish Coastal Authority [DK]; Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency / NLWKN [D]; Flemish Ministry of Transport and Public Works [B]; Environment Agency [UK]	North-east Atlantic	✓	2005 – 2008
8	**BLAST** Bringing Land and Sea Together aims to deliver, through co-operation and participation of all North-Sea facing countries processes and solutions addressing technical and scientific problems including climate change. The project deals with, for example, data exchange and harmonization and with presenting findings as a series of cases for testing across various multiple communities. These solutions should support EU policies affecting the North Sea Region (e.g. Maritime Policy, Marine Strategy, Water Framework Directive, INSPIRE Directive).	Norwegian Hydrographic Service (lead partner); Norwegian Coastal Administration; National Survey and Cadastre; Danish Coastal Authority; Local Government Denmark; National Space Institute; Aalborg University; Federal Maritime & Hydrographic Agency; Jeppesen GmbH; T-Kartor AB; Malardalen University; Natural Environment Research Council; Seazone Solutions Ltd.; UK Hydrographic Office; Agency for Maritime and Coastal Services; Coastal Division division of Agency for Maritime and Coastal Services); Flemish Hydrography (division of Agency for Maritime and Coastal Services); Shipping Assistance Division (division of Agency for Maritime and Coastal Services); Delft University of Technology, Faculty of Aerospace Engineering - the Netherlands.	North-east Atlantic	✓	2009-2012
9	**CLIWAT** aims to evaluate the effects of climate change on water quantity and quality in coastal areas of the North Sea region and provides approaches for adapting and risks reduction to society and nature, including new standards for e.g. engineering of drainage and sewer systems, dikes, roads and buildings. The project also aims to increasing the public awareness by making the website easily accessible by, for example, showing simulation results in the form of maps.	Geological Survey of the Netherlands-Deltares/NL, VITENS/NL, Provincie Fryslan/NL, Wetterskip Frysland/NL, Ghent University/B, LIAG/Germany, BGR/D, LANU/D, Seecon/D, Region Syddanmark/DK, Environment Centre Aarhus/DK, Environment Centre Ribe/DK, Aarhus University/DK, Municipality of Horsens/DK and GEUS/DK Lead Beneficiary: Region Midtjylland, Horsens, Denmark	North-east Atlantic	✓	2008 – 2011
10	**CPA** Climate Proof Areas aims to create a portfolio of climate adaption strategies for the North Sea Region. This will be done by	Province of Zeeland; Municipality of Schouwen-Duiveland; Deltares Unit Subsurface and Groundwater; University of	North-east Atlantic	✓	2008 – 2011

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	carrying out multi-focused pilot projects across the region in order to analyse the impacts of climate changes as a first step. Subsequently, diverse climate adaptation strategies will be developed, implemented and tested. In addition, the project will foster political support established by a Memorandum of Understanding (MoU) of the North Sea Commission, triggering future investments on a transnational level.	Oldenburg; Swedish Geotechnical Institute (SGI); Arvika kommun; County Administrative Board of Värmland; Administrative Board Västra Götalands län; Swedish Meteorological and Hydrological Institute; Ghent University – Centre for Mobility and Physical Planning; National Trust; RSPB; Wildlife Trust NCPB			
11	**DiPol** project on the Impact of Climate Change on the quality of urban and coastal waters aims to assess impacts and suggesting measures to reduce the adverse consequences of climate change that affect the quality of urban and coastal waters. A tool will be developed and implemented to illustrate the impacts of climate changes on water quality.	Beneficiaries: Institute of Environmental Technology and Energy Economics at Hamburg University of Technology; Hamburg Authority for Urban Development and the Environment; University of Applied Sciences Lubeck (FHL); Norwegian Geotechnical Institute (NGI); VU University Amsterdam; Deltares; Swedish Geotechnical Institute; University of Gothenburg; Albertslund Municipality; Technical University of Denmark; University of Copenhagen Sub-partners: University of Applied Sciences Hamburg; Grammar School Kirchdorf; Wilhelmsburg; Elvebakken VG school; Hvidovre Forsyning A/S (Utilities); Copenhagen Municipality vej og Park; Glostrup Municipality Natur og milj; Norweigan Climate and Pollution Agency	North-east Atlantic	✓	2009-2011
12	**Mare** Managing Adaptive Responses focuses on developing a transnational methodology to implement urban Flood Risk Management (FRM) in four countries. The project will thereby support national policy making related to the European Floods Directive. The main result will be a transnational methodology for FRM planning applicable in urban environments.	Gemeente Dordrecht; Waterschap Hollandse Delta; Rijkswaterstaat Zuid-Holland; Provincie Zuid-Holland; UNESCO-IHE; Ministerie van Verkeer en Waterstaat; Dura Vermeer Business Development b.v; Sheffield City Council; The University of Sheffield; Rotherham Metropolitan Borough Council; City of Hannover, Civil Engineering division; Leibniz University of Hannover, Faculty of Architecture and Landscape Sciences; Hannover Region Environment Department; Technical University Hamburg-Hamburg; Bergen	North-east Atlantic	✓	2009 – 2011
13	**Interreg Nor th S ea Region Prog ramme** initiated *cooperation* between European regions that are relevant for the North Sea area. This programme also includes projects with a focus on adaptation to climate change.	Multiple	North-east Atlantic	✓	2007 – 2013
NORTH-EAST ATLANTIC: MEMBER STATE PROJECTS					
14	**Denmark -** **COADAPT** is funded by the Danish Council for Strategic Research. The main objective of the COADAPT project is to develop shoreline management tools to meeting the additional threats for the coastal areas due to sea level rise, changes in storminess. As	DHI; University of Copenhagen; Danish Coastal Authority	North East Atlantic: Greater North Sea		2009 – 2013

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	part of this, the project aims to (i) better understand impacts of climate change on coastal environments (e.g. flooding, erosion, degradation); (ii) to develop coastal protection techniques and systems; (iii) to develop new shoreline management practices, legislation etc.				
15	**Germany - KRIM** Climate Change and Preventive Risk and Coastal Protection Management on the German North Sea Coast, has the goal of providing orientation and action know-how for the future task of society entailing "risk management in coastal protection under conditions of uncertainty". The project has two major research questions: • What are the potential impacts of a climate change and adaptation measures? • What are possible consequences for risk management in coastal protection?	GKSS Research Centre; University of Hannover; University of Bremen; Programme Group "Humans, Environment, Technology" (MUT); BioConsult; INFRAM; Research Institute for Knowledge Systems BV (RIKS)	North-east Atlantic		Unknown
16	The Institute for Chemistry and Biology of the Marine Environment, University of Oldenburg, Germany, leads a number of projects that deal with observing, modelling and GIS of the Germany North Sea area. These projects include: • The set up of an observation system to monitor changes in physical, geochemical und ecological characteristics. • The development of a model to evaluate the consequences of new wind parks. • The development of a GIS tool to assess the ecosystem goods and services in the North Sea area. • The development of a WEB portal that contains data on North Sea habitats, both based on observations and modelling. • Database development to combine the aforementioned information.	Institute for Chemistry and Biology of the Marine Environment, University of Oldenburg, Germany	North-east Atlantic		Ongoing
17	**The Neth erlands - Climate changes Spatial Planning** focuses to enhance joint-learning between those to communities and people in practice within spatial planning. Its mission is to get climate change and climate variability one of the guiding principles for spatial planning in the Netherlands.	The development of the programme and management is coordinated by Wageningen UR, VU University Amsterdam, MNP and KNMI.	North-east Atlantic		2004-2009
18	**The Neth erlands - Knowledge for Climate programme** is a research programme for the development of knowledge and services that makes it possible to climate proof the Netherlands. Governmental	Wageningen University and Research Centre and the University of Utrecht have jointly founded the Knowledge for Climate Foundation.	North-east Atlantic		2008 – 2013

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	organisations (central government, provinces, municipalities and water boards) and businesses, actively participate in research programming through the input of additional resources (matching).The programme is partially funded using resources from FES (Economic Structure Enhancing Fund). As part of the projects adaptation measures in the hydrological system of the Netherlands are compared. Considered measures deal with increased dike heights to prevent river and coastal flooding; (ii) additional pumping station; (iii) new "geometry" of the coast; (iv) adaptive building regulation. **Climate ch ange effe cts on res toration of es tuarine d ynamics within the Delta region** : changes in the Southwest delta of the Netherlands will result in changes in habitat availability and species composition. Species that presently are important in the ecological functioning might disappear and new species might colonise. Within the project effects of climate change scenarios on environmental conditions and subsequently estuarine habitats and species will be calculated. In addition to this, we will make an inventory of species that may become invasive due to climate change.	Together with the co-initiators of the Programme, Knowledge for Climate is implemented by VU University, the Royal Dutch Meteorological Institute (KNMI) and the Netherlands Organisation for Applied Scientific Research (TNO).			
MEDITERRANEAN PROJECTS					
19	**EMWIS** (Euro-Mediterranean water information system) is funded by INTERREG IVb. The project deals with problems of water scarcity in the Mediterranean region.	European Environment Agency (EEA); CIFME - Minister of Energy and Water, Lebanese Republic; INBO - MENBO; GWP; MED-EUWI; IME; World Water Council (WWC); SMAP - RMSU; europa-jaratouna; lambassade-de-leau	Mediterranean	✓	
20	**PEGASO** (People for Ecosystem-based Governance in Assessing Sustainable development of Ocean and coast) is building on existing capacities and develop common novel approaches to support integrated policies for the coastal, marine and maritime realms of the Mediterranean and Black Sea Basins in ways that are consistent with and relevant to the implementation of the ICZM Protocol for the Mediterranean.	The project is coordinated by Universitat Autonoma de Barcelona and includes 25 partners from 16 countries: Universidad Pablo de Olavide (ES) Université de Genève (CH) Plan Bleu – Regional Activity Centre (FR), Hellenic Centre for Marine Research (HCMR) (GR), Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), (FR), Mediterranean Coastal Foundation (MEDCOAST) (TR), ACRI-EC (MA), Danube Delta National Institute (DDNI) (RO), Université Mohammed V Agda l (MA), Priority Action Programme / Regional Activity Centre (PAP/RAC) (HR), AREA-ED (DZ), International Union for Conservation of Nature, National Institute of Oceanography and Fisheries (NIOF) (EG), Centre for Environmental Management (CEM) - University of Nottingham (UK), University of Balamand (LE), Flanders Marine Institute (VLIZ) (BE), Marine Hydro-physical Institute (UA), Università Ca' Foscari di Venezia – IDEAS (IT), La Tour	Black Sea (and Mediterranean)		2010-2013

Ref.	Research project title and objectives	Carried out by	European marine basins covered	Interreg project	Dates
		du Valat (FR), Joint Research Centre (JRC) (EU), National Authority for Remote Sensing and Space Sciences (NARSS) (EG), Institut National des Sciences et Technologies de la Mer (INSTM) (TN), The Commission on the Protection of the Black Sea Against Pollution - Permanent Secretariat			
WESTERN MEDITERRANEAN PROJECTS					
21	ADIOS is partially funded by the European Commission programme 'Energy, Environment and Sustainable Development'. The project examines atmospheric deposition and the impact of pollutants, key elements and nutrients on the open Mediterranean.	Centre de Formation et de Recherche sur l'Environnement Marin, Perpignan; Centre de Recherche et d'Enseignement en Geosciences de l'Environnement (CEREGE), Aix-Marseille; Laboratoire d'Oceanographie et de Biogeochimie (LOB), Marseille; Laboratoire de Microbiologie Marine (LMM), Marseille; Laboratoire d'Etudes en Geophysique et Oceanographie Spatiale (LEGOS), Toulouse; Ecole Normale Superieure &emdash; Laboratoire d'Ecologie, Montrouge; Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Gif sur Yvette; Laboratoire de Physique et Chimie Marine (LPCM), Villefranche-sur-Mer; Laboratoire de Physique et Chimie Marines, Universite Pierre et Marie Curie (UPMC), Paris; University of Barcelona - Departament d'Estratigrafia i Paleaontologia, Facultat de Geologia, Barcelona; Universitat Autonoma de Barcelona, Barcelona; Istituto Talassografico di Trieste, Trieste; Istituto di Fisica dell'Atmosfera, Roma; University of Ancona Local Research Units (ULR) of CoNISMa National Consortium for Marine Science, Ancona; Istituto Nazionale di Oceanografia e di Geofisico Sperimentale (OGS), Trieste; National Centre for Marine Research, Athens; National and Kapodistrian University of Athens, Athens; Research Unit of the University of Aegean, Mytilene; Institute of Marine Biology of Crete, Heraklion; Environmental Chemical Processes Laboratory, University of Crete, Heraklion; Department of Environmental Science, Lancaster University, Lancaster; University of Edinburgh, Department of Geology and Geophysics, Edinburgh; Institut de Geologie, LIMNOCEANE, Universite de Neuchatel, Neuchatel	Mediterranean: Western Mediterranean		2001-2004
22	CIESM-SUB is aimed at investigating the effect of recent climate change in the deep Mediterranean. Using a multidisciplinary sampling strategy, the participating scientists from different Mediterranean countries were able to document the influence of westward fluxes on the nutrient dynamics, plankton size distribution and hydrological structure of the sampled area. Coming decades will determine	No information available	Mediterranean: Western Mediterranean		Not available

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	whether this pattern cascades further into the western basin and, if so, how it will be reflected in the macro-biota. Another key finding was the evidence of a persistent anticyclonic eddy, close to the Vavilov Seamount, likely of remote northwestern Mediterranean origin.				
23	**HERMES** Hotspot ecosystem research on Europe's deep ocean margin was funded by the European Commission and brought together expertise in biodiversity, geology, sedimentology, physical oceanography, microbiology and biogeochemistry so to better understand the relationships between biodiversity and ecosystem functioning.	The HERMES consortium comprised 50 partners including 9 small companies, from 17 European and neighbouring countries. The partners included small and large institutions and both universities and government laboratories. Project Co-ordinators are NERC/National Oceanography Centre Southampton, UK.	Mediterranean: Western Mediterranean		2005-2009
24	**ORFOIS** examines the origin and fate of biogenic particle fluxes in the ocean and their interaction with the atmospheric CO2 concentration as well as the marine sediment. The main scientific objectives of project ORFOIS are to: identify and quantify globally the mechanisms underlying the transformation of biogenic particles to dissolved substances within the ocean water column in order to predict correctly surface ocean carbon dioxide sources and sinks; develop a refined particle flux model for operational use in ocean general circulation models which realistically describes particle dynamics in the water column, deposition of material to the sediment, and the interaction with the carbon dioxide partial pressure pCO_2; provide a global closed carbon and nutrient budget for modern (preindustrial) conditions including the water column sediment interaction; estimate the changes in CO_2 sea surface source sink patterns and vertical redistributions of carbon as well as nutrients for future global change, climate change as well as carbon sequestration scenarios including the associated potential economic impacts.	University of Bergen; Danmarks Miljøundersøgelser National Environmental Research Institute; Laboratoire des Sciences du Climat et de l'Environnement; Institut Universitaire Européen de la Mer; Max-Planck-Institut für Meteorologie; Institute for Marine Environmental Sciences Universität Bremen; Forschungsstelle Nachhaltige Umweltentwicklung Zentrum für Meeres- und Klimaforschung Universität Hamburg; Institute of Oceanography Hellenic Center for Marine Research; Centre for Estuarine and Coastal Ecology Netherlands Institute of Ecology; School of Environmental Sciences University of East Anglia.	Mediterranean: Western Mediterranean		Not available
25	The general scientific objectives of SESAME IP (Southern European seas: assessing and modelling ecosystem changes), supported by the European Commission, are to assess and predict changes in the Mediterranean and Black Sea ecosystems as well as changes in the ability of these ecosystems to provide goods and services. SESAME will create a platform for disseminating the research results to all levels of society. It will stimulate and strengthen international cooperation in the Mediterranean and Black Sea regions through the participation of research organizations from Member States, Associated States, Associated Candidate countries, non-EU Mediterranean and NIS countries as well as international organizations.	Hellenic Centre for Marine Research**,** HCMR, GREECE; Centre National de la Recherche Scientifique; P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences; ORTA DOGU TEKNIK UNIVERSITESI Institute of Marine Sciences, Middle East Technical University**;** University of Liege, MARE Interfacultary Research Centre, UNIVERSITE DE LIEGE; Consejo Superior de Investigaciones Cientificas**;** Consorzio Nazionale Interuniversitario per le Scienze de Mare; Panepistimion Aigaiou; Institute of Oceanology, Bulgarian Academy of Sciences; Israel Oceanographic & Limnological Research Limited; Athens University of Economics and Business - Research Center**;** Bogazici Universitesi; National Council for scientific research; Consiglio Nazionale delle Ricerche; Sofiiski	Mediterranean: Western Mediterranean		Not available

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
		Universitet "Sveti Kliment Ohridski", Department of Meteorology and Geophysics, University of Sofia; Ente per le Nuove Tecnologie, l'Energia e l'Ambiente; Fondazione Eni Enrico Mattei; National Institute of Marine Geology and Geo-Ecology; Institut Français de Recherche pour l'Exploration de la Mer; Institute of Biology of Southern Seas A.O.Kovalevsky Institute of Biology of the Southern Seas; Institute of Oceanography and Fisheries Institut za Oceanografiju I ribarstvo; Istituto Centrale per la Ricerca scientifica e tecnologica Applicata al Mare, ICRAM, ITALY; Istituto Nazionale di Oceanografia e di Geofisica Sperimentale; Fondazione IMC-Centro Marino Internazional-ONLUS; Commission of the European Communities, Directorate General Joint Research Centre; Institut National des Sciences et Techniques de la mer; Marine Hydrophysical Institute Ukrainian National Academy of Science			
26	MEDOCC part of the Western Mediterranean Basin INTERREG IIIb Programme supports trans-national cooperation projects on territorial development in Western Mediterranean countries (Spain, France, Italy, Portugal and the United Kingdom - Gibraltar). The programme's objectives included the promotion of the environment.	Ministerio de Economía y Hacienda, Espagne; Préfecture de Région Provence-Alpes-Côte d'Azur, France; Ministère de l'Economie et des Finances, Grece; Ministero delle Infrastrutture e dei Trasporti, Italie; Planning and Priorities Coordination Directorate, Malte; Ministério das Finanças, Portugal; Department of trade, industry and telecommunications, Gibraltar	Mediterranean: Western Mediterranean	✓	2000-2006
27	GENMEDOC recognises and defends the need to adopt shared guidelines for the management and conservation of Mediterranean biodiversity. The project brings together initiatives dealing with the conservation and valuation of biodiversity - one of the EU's environmental priorities and one of the priorities of the MEDOCC programme. Valuation, protection and management of the natural heritage lies at the core of this project, which includes the development of ecological networks (in support of Natura 2000)	GENERALITAT VALENCIANA - Conselleria de Territori i Habitatge Centre d'Investigació i Experiències Forestals (CIEF) Banc de Llavors Forestals; : UNIVERSITAT DE VALÈNCIA; : CONSEJERÍA DE AGRICULTURA, AGUA Y MEDIO AMBIENTE; FUNDACIÓ JARDÍ BOTÀNIC DE SÓLLER; Institut des Régions Arides; Università di Catania; MEDITERRANEAN AGRONOMIC INSTITUTE OF CHANIA (MAICh); UNIVERSITA' DEGLI STUDI DI CAGLIARI; CONSERVATOIRE BOTANIQUE NATIONAL MEDITERRANEEN DE PORQUEROLLES; Institut Botànic de Barcelona	Mediterranean: Western Mediterranean	✓	2003-2004

Ref.	Research project title and objectives	Carried out by	European marine basins covered	Interreg project	Dates
28	**BEACHMED** defined the technical, environmental and economic issues connected with the extraction of marine borrow sand, essential for the reconstruction and conservation of erosive coasts in Western Mediterranean countries.	9 Main Partners: Regione Lazio (Italy) Direzione Regionale Ambiente e Cooperazione tra i Popoli, Leader Partner; Conseil Général de l'Hérault (France); Generalitat Catalunya (Spain); Regione Liguria (Italy); Regione Toscana (Italy); Regione Emilia-Romagna (Italy); Crete Region (Greece); Direction Régionale de l'Equipement Languedoc-Roussillon (France); East Macedonia and Thrace Region (Greece) 11 Observer Partners	Mediterranean: Western Mediterranean	✓	Ended 2008
EASTERN MEDITERRANEAN PROJECTS					
29	**Identification and implementation of adaptation response measures in Drini-Mati rivers deltas** aims to assist Albania in beginning a process by which strategies to moderate, cope with, and take advantage of the consequences of climate change are enhanced, developed, and implemented. A system for monitoring climate change and its impacts on the Drini-Mati River Deltas ecosystem is now in place. Local government institutions already have the capacity to analyze data on climate variability and associated ecological impacts and integrate this into decision making. Community capacities were trained by UNDP to understand the impacts of climate fluctuations and expected changes on natural ecosystems and local livelihoods are developed. UNDP helps to integrate adaptation measures, with involvement of local community, local authorities, NGOs, conservation groups, scientists and other stakeholders. The project is financed by GEF through UNDP.	Ministry of Environment, Forests and Water Administration (Climate Change Unit);Institute of Hydrometeorology, Regional Environmental Centre	Mediterranean: Aegean-Levantine Sea (Eastern Mediterranean)		2008-2012
30	**AL-DRMAP** Disaster risk mitigation and adaptation has been financed by a number of stakeholders including World Bank and Global Facility for Disaster Reduction and Recovery in reduce the regions vulnerability in accordance with Hyogo Framework for Action.	European Commission; Swedish International Development Agency; Italian Cooperation	Mediterranean: Adriatic, Ionian and Central Mediterranean		2006-2011
31	**Global Climate Observation System (GCOS) Regional Action Plan for the Mediterranean basin** stresses the necessity to upgrade and properly maintain the observation equipment systems, especially in the developing countries.		Mediterranean Basin		2006
32	**Adricosm-Star** (ADRIatic Sea Integrated Coastal areas and River Basin Management System – Montenegro Coastal Area and Bojana River Catchment) aims at developing an integrated coastal and river water management and modelling system which covers the area of Bojana River Delta (managed jointly by Albania and Montenegro)	CMCC (Centro Euro-Mediterraneo per i Cambiamenti Climatici, Lecce - Italy); INGV (Istituto Nazionale di Geofisica e Vulcanologia, Bologna - Italy); SGI (Studio Galli Ingegneria Spa, Padua - Italy); CNR-ISAC (CNR - Istituto per le Scienze dell'Atmosfera e del Clima, Sezione di Roma, Rome - Italy);	Mediterranean: Adriatic, Ionian and Central Mediterranean		2007-2010

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	and the whole Montenegrian Adriatic coast.	CNR-ISMAR-AN (CNR - Istituto per le Scienze del MARe, Sezione di Ancona - Italy); CNR-ISMAR-BO (CNR - Istituto per le Scienze del MARe, Sezione di Bologna - Italy); ENEA (Centro ricerche Lerici, La Spezia - Italy); OGS (Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste - Italy); CIRSA (Centro Interdipartimentale per le Ricerche di Scienze Ambientali, Università di Bologna, Ravenna - Italy); UNITUS (Dipartimento di Ecologia e Sviluppo Economico Sostenibile, Università della Tuscia, Viterbo - Italy); E&Y (Ernst &Young, Milan - Italy); CLU (CLU srl, Modena – Italy); ISPRA - ex APAT (Istituto Superiore per la Protezione e la Ricerca Ambientale, Rome - Italy); CETI (Centre for Ecotoxicological Research of Montenegro, Podgorica - Republic of Montenegro) HI-M (Hydrometeorological Institute of Montenegro, Podgorica - Republic of Montenegro); IMB (Institute of Marine Biology of Montenegro, Kotor - Republic of Montenegro); BU (Physical Faculty of Belgrad University, Belgrad - Serbia); SEWA (South Environment and Weather Agency, Belgrad - Serbia); IEWE (Institute of energy, water and environment - Albania)			
BALTIC SEA					
33	**Coastal Sustainability as a C hallenge** aims towards strengthened co-operation and information exchange within and between the protected areas in the Baltic Sea Region. The goal is to develop models for co-operation and communication with the aim to better integrate coastal protected areas into the surrounding local communities based on a survey, existing models and local pilot activities. The work will be documented in distance education materials and a coastal communication tool box.	18 partners of National Parks and Biosphere Reserves involved from Finland, Estonia, Latvia, Lithuania and Germany.	North-east Atlantic – Greater North Sea; Baltic Sea	✓	2005-2007
34	**BONUS-169 Baltic Sea Science Plan** (EU FP6) has been developed to create prudent, long-term, holistic multidisciplinary solutions involving sustainable use of the sea by understanding and quantifying the role of climate change and variability and its implications for the dynamics of the region's ecosystem; understanding the physical, chemical and biological functioning of marine ecosystems and understanding and quantifying human impacts; and developing the scientific basis for sustainable use and protection of the marine environment and its associated biodiversity.	The ERA-NET BONUS programme is composed of a total of 12 partners: 11 research funding organizations and one intergovernmental organization (ICES) connected with the coordination of marine science in the Baltic Sea region. In addition, BONUS links six funding organizations as Observers, thereby increasing the number of involved organizations to 18.	Baltic Sea	✓	2004-2007
35	**Baltic Sea Region** INTERREG III B Neighbourhood Programme is a community initiative involving trans-national co-operation on spatial	Various	Baltic Sea	✓	2000-2006

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	planning and regional development for the Baltic Sea region. The Programme was prepared in close consultation with Member States' ministries. The European Commission approved the programme in 2001. Since then, eight different calls for applications were launched and 126 projects in eight sectors (agriculture, education, energy, fisheries, forestry, industry, tourism and transport) were approved. Some of the most relevant sub-projects are listed in the following rows.				
36	BaltCoast is supported by the European Regional Development Fund (ERDF) as well as national, regional and local co-financing. This Interreg III B Project supported concrete Integrated Coastal Zone Management (ICZM) pilot projects in the Baltic Region and developed recommendations how to link spatial planning and ICZM.	German Ministry for Transport, Building and Regional Development of Mecklenburg-Vorpommern	Baltic Sea	✓	2002-2005
37	SEAREG focuses on the socio-economic and environmental assessment of climate change in the Baltic Sea region (BSR) specially the sea level rise and the changing runoff patterns of rivers. These can both lead to major flooding events having severe impacts on the spatial development of cities and regions as well as sustainable development of entire BSR.	Geological Survey of Finland (GTK); Centre for Urban and Regional Studies (CURS/YTK); Swedish Meteorological and Hydrological Survey (SMHI); University of Greifswald; Regional Council of Itä-Uusimaa	Baltic Sea	✓	2002-2005
38	ASTRA (Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region) further developed the successful results of the BSR Interreg IIIB SEAREG project. SEAREG assessed the impacts of future sea level rise in several case study areas in the BSR. Focussing on the Baltic Sea Region (BSR), the project "Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region" (ASTRA) assesses regional impacts of the ongoing global change in climate. Its aim is to develop adequate climate change adaptation strategies and policies, together with relevant stakeholders, such as planners and decision makers.	Geological Survey of Finland; GTK: Lead partner; YTK; The Potsdam Institute for Climate Impact Research (PIK); University of Latvia, Riga, Department of Geography and Earth Sciences; Tallinn University, Institute of Ecology; Geological Survey Of Estonia (EKG); Environmental Centre for Administration and Technology (ECAT); Vilnius University, Department of Hydrology and Climatology; Polish Geological Institute (PGI), Gdansk; Baltic Sea Research Institute Warnemünde (IOW); Institute of Geology & Geography, Vilnius; Klaipeda city municipality; TuTech Innovation GmbH; City of Espoo; Pirkanmaa Regional Environment Centre; Regional Council of Uusimaa; The Association of Finnish Local and Regional Authorities; City of Kokkola	Baltic Sea	✓	Ended 2007
39	BALANCE "Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning", is an INTERREG III B co-funded project aimed towards development of informed marine management tools for the Baltic Sea based on spatial planning and cross-sectoral and transnational co-operation.	A BALANCE Secretariat is located at the premises of the Lead Partner, which is the Danish Forest and Nature Agency in Denmark. The secretariat has been established in order to co-ordinate the work within the BALANCE project and to ensure an efficient strategic and operational management of the project.	Baltic Sea	✓	2005-2007
40	AGORA is part-financed by the European Union (European Regional Development Fund) within the BSR Interreg IIIB Neighbourhood Programme. Usually the methodologies and experiences are hard to	44 Partners from 10 Baltic Sea States including Russia and Belarus.	Baltic Sea	✓	2005-2007

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	find or not accessible at all after the projects terminated. Thus the lead partners of the tourism sector of BALTIC21 with its existing network prepared the project Agora. Agora tries not to invent everything new but it starts on existing results, knowledge and experience of other projects. Agora compiles tools and information concerning sustainable tourism and makes them accessible for interested users. The source for this information are the Agora partners representing all three dimensions of sustainability, all levels of administration and tourism management and different thematic interests, projects, actors and stakeholders of tourism.	Lead Partner - Ernst Moritz Arndt-University of Greifswald			
41	**WATERSKETCH** aims to develop strategies for sustainable river basin management in order to do justice to different economic, ecological and social functions. Case studies in the partner countries will cover the most relevant challenges. The results of Watersketch will support decision-making of spatial planners. A final web-based toolbox will make the results available to others.	Lead partner: SKYE. Other partners: TuTech Innovation GmbH; National Environmental Research Institute; Country of North Jutland; Lodz Technical University Faculty of Process and Environmental Engineering; Kaunas University of Technologie; Coastal Research and Planning Institute; State Ministry of Environment, Free and Hanseatic City of Hamburg; North Ostrobothnia Regional Environment Centre; Kainuu Regional Environment Centre; University of Turku, Satakunta Environmental Research Institute; Regional Council of Satakunta; Northern Environmental Research Network; Council of Oulu Region; Regional Council of Kainuu	Baltic Sea	✓	2004-2007
42	**COASTMAN** aims to demonstrate the conditions under which spatial conflict resolution in Coastal Zone Management (CZM) can be handled in a bottom-up perspective starting from practical case studies covering the numerous dimensions and different cultures around the Baltic Sea. It also aims to promote long-term capacity building in Coastal Zone Management with a focus on methods for conflict resolution through the development of a network and joint educational program for CZM in the Baltic Sea Region.	Royal Institute of Technology (KTH)- Leadpartner; Stockholm City Planning Administration; TuTech Innovation GmbH; Hamburg Ministry for Urban Development and the Environment; Southeast Finland Regional Environment Centre; Municipal Government of Haapsalu; Tallinn University of Technology; Klaipeda Regional Environmental Protection Department; Klaipeda State Seaport Authority; Klaipeda University; University of Latvia; Ventspils City Council; Committee on Natural Resources and Environmental Protection of Leningrad Region; Administration of the Primorsk Local Municipality; St.Petersburg State Polytechnical University; Russian State Hydrometeorological University; Green Polytechnic non-profit making partnership.	Baltic Sea	✓	2004-2007
43	**BalticMaster** is an international project which aims to improve maritime safety by integrating local and regional perspectives. The focus is on the Baltic Sea Region and issues concerning pollution prevention, coastal zone management and on land response capacity to an oil spill at sea. The project Baltic Master II is recognized as a flagship project in the Baltic Sea Strategy of the European Union. The	Baltic Master II includes partners from 9 different countries around the Baltic Sea. The fact that all Baltic Sea countries are represented in the project gives it a particular strength when carrying out its activities on maritime safety. 30 partners and 18 associated partners are involved in the project. The project partners range from local, regional and national authorities to	Baltic Sea	✓	2009-2012

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	project is part financed by the European Union (European Regional and Development Fund) under the Baltic Sea Region Programme 2007-2013.	research institutes, pan-Baltic organisations and universities.			
44	**The Baltic Sea Region (BSR) INTERREG IVB Programme (2007-2013)** was designed under the European Community's territorial cooperation objective. It built on the experience of its two predecessor programmes supporting trans-national cooperation in the Baltic Sea region under the community initiatives INTERREG IIC (1997-1999) and INTERREG IIIB Neighbourhood Programme (2000-2006). The overarching strategic objective of the programme is to strengthen the development of a sustainable, competitive and territorially integrated Baltic Sea region by connecting potentials over borders. As part of Europe, the Baltic Sea region is expected to become a better place for its citizens to invest, work and live. The programme is thus addressing the EU's Lisbon and Gothenburg strategies in order to boost knowledge-based socio-economic competitiveness of the region and its further territorial cohesion. The eligible area includes the whole territory of Denmark, Estonia, Finland, Latvia, Lithuania, Poland and Sweden, and Northern parts of Germany as EU Member States. Also the neighbouring countries of Norway (whole country), Russia (north-western regions) and Belarus (whole country) belong to the programme area. Some of the most relevant sub-projects are listed below.	Various – see below	Baltic Sea	✓	
45	**BaltCICA**: the overall goals of the Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region project are to: • Assess impacts of climate change on the living environment. • Test and implement concrete plans for adaption in close collaboration with local and regional authorities. • Assess the costs of climate change and the increased risk of flooding on a regional level. • Develop a concept for managing the process of reduction and adaptation to climate change. The project is part financed by the European Regional Development Fund and the Baltic Sea Region Programme.	Geological Survey of Finland; Helsinki University of Technology; Hanko Water and Wastewater Works; Union of the Baltic Cities – Commission on Environment; Helsinki Region Environmental Services Authority; City of Helsinki; City of Tampere; Geological Survey of Estonia; University of Latvia; North Vidseme Biosphere Reserve; Municipality of Klaidpeda; Environmental Centre for Administration and Technology; Vilnius University; Lithuanian Geological Survey; Kalundborg Municipality; Danish Board of Technology; Geological Survey of Denmark and Finland; Nordic Centre for Spatial Development; Norwegian Institute for Urban and Regional Research; Leibniz Institute for Baltic Sea Research Warnemünde; HafenCity University/Institute for Urban-, Regional- and Environmental Planning; EUCC – The Coastal Union Germany; Potsdam Institute for Climate Impact Research.	Baltic Sea	✓	2009-2011
46	**BalticClimate** (Baltic Challenges and Chances for local and regional development generated by Climate Change) will enable BSR municipalities, regions and other actors to deal with climate change in	Academy for Spatial Research and Planning, Hannover; Environmental Projects State Ltd.	Baltic Sea	✓	2007-2010

Ref.	Research project title and objectives	Carried out by	European marin e basins covered	Interreg project	Dates
	a cooperative, integrative and sustainable way. Through regionalized climate change information, impact and vulnerability assessments, and tested integrative planning approaches in target areas, an easy to use toolkit will be elaborated.				
47	**Eco-Region** (The Baltic 21 Eco Region Project) will contribute to the aim of Baltic 21 to develop the BSR into the world's first EcoRegion, where economic growth goes hand in hand with environmental integrity and social justice.	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety; Deutsche Gesellschaft für technische Zusammenarbeit (GTZ)	Baltic Sea	✓	2008-2012
48	**Baltic green belt** will create a global symbol for trans-boundary co-operation in nature conservation and sustainable development. Activities are usually rooted in the former border regions: people previously separated by the iron curtain now co-operate to form economically and ecologically sustainable landscapes. One key factor is the preservation of the green heritage of 40 years of the iron curtain.	University of Kiel	Baltic Sea	✓	2007-2013
49	**BaltSeaPlan** (Planning the future of the Baltic Sea) aims to develop integrated and national maritime planning schemes. Not directly addressed to sea-level rise, but it has to be considered, because shore protection plays an important role.	German Federal Maritime and Hydrographic Agency (BSH); World Wide Fund For Nature (WWF) Germany; Ministry of Transport, Building and Regional Development Mecklenburg-Vorpommern; Maritime Office in Szczecin; Maritime Office in Gdynia; Maritime Institute in Gdańsk; National Environmental Research Institute (NERI); Royal Institute of Technology (KTH); Swedish Environmental Agency (SEPA); Estonian Marine Institute of University of Tartu; Baltic Environmental Forum (BEF) Estonia; Coastal Research and Planning Institute (CORPI); Baltic Environmental Forum (BEF) Lithuania; Baltic Environmental Forum (BEF) Latvia	Baltic Sea	✓	2009-2012
50	**WATERPRAXIS** works from theory and plans to eco-efficient and sustainable practices to improve the status of the Baltic Sea. Although not directly addressing sea-level rise issues, it does focus on river systems, including those at the coast.	Finnish Environment Institute (SYKE); North Ostrobothnia Regional Environment Centre; Hamburg University of Applied Sciences (HAW Hamburg); National Environmental Research Institute, Aarhus University; Municipality of Naestved; Danish Ministry of the Environment; Lodz Technical University; Kaunas University of Technology; Charity and Support Fund Sesupe Euroregion, Sakiai Office; Luleå University of Technology; Rezekne Higher Education Institution; Kaliningrad State Technical University; Voivodship Board of Land Melioration; County Administrative Board of Norbotten; Aalborg University	Baltic Sea	✓	2007-2013
51	**SPICOSA** (Science and Policy Integration for Coastal System Assessment) is developing self-evolving, holistic research approach and support tools for the assessment of policy options for sustainable	The SPICOSA partnership embraces 54 partners: 53 universities, SMEs, and research institutes (including the JRC of the European	Baltic Sea	✓	2007-2011

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	management through a balanced consideration of the ecological, social and economic aspects of coastal zone systems.	Commission) and EUCC (a network of coastal experts, practitioners and policy makers) in 21 countries. The Scientific Coordination is under the responsibility of the University of Western Brittany (Brest, France) and the Institute of Coastal Marine Environment of CNR (Naples, Italy), while the Administrative Coordination lies with the French National Institute of Marine Research (IFREMER).			
52	RA:dOst (Regional adaptation strategies for the German Baltic Sea coast) is developing strategies for adaptation to climate change impacts on the Baltic Sea coast in a dialogue involving science.	There is a core team of 17 partners which includes several Federal State authorities and one non-governmental organisation. Furthermore, the project involves a multitude of network partners. At the time of proposal submission, the RADOST network included around 60 partners; it will expand continuously throughout the course of the project.	Baltic Sea	✓	2009-2014
53	PEGASO (People for Ecosystem-based Governance in Assessing Sustainable development of Ocean and coast) is building on existing capacities and develop common novel approaches to support integrated policies for the coastal, marine and maritime realms of the Mediterranean and Black Sea Basins in ways that are consistent with and relevant to the implementation of the ICZM Protocol for the Mediterranean.	The project is coordinated by Universitat Autonoma de Barcelona and includes 25 partners from 16 countries: Universidad Pablo de Olavide (ES) Université de Genève (CH) Plan Bleu – Regional Activity Centre (FR), Hellenic Centre for Marine Research (HCMR) (GR), Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), (FR), Mediterranean Coastal Foundation (MEDCOAST) (TR), ACRI-EC (MA), Danube Delta National Institute (DDNI) (RO), Université Mohammed V Agda l (MA), Priority Action Programme / Regional Activity Centre (PAP/RAC) (HR), AREA-ED (DZ), International Union for Conservation of Nature, National Institute of Oceanography and Fisheries (NIOF) (EG), Centre for Environmental Management (CEM) - University of Nottingham (UK), University of Balamand (LE), Flanders Marine Institute (VLIZ) (BE), Marine Hydro-physical Institute (UA), Università Ca' Foscari di Venezia – IDEAS (IT), La Tour du Valat (FR), Joint Research Centre (JRC) (EU), National Authority for Remote Sensing and Space Sciences (NARSS) (EG), Institut National des Sciences et Technologies de la Mer (INSTM) (TN), The Commission on the Protection of the Black Sea Against Pollution - Permanent Secretariat	Black Sea (and Mediterranean)		2010-2013