Vulnerability and adaptation to climate change in Europe

ISSN 1725-2237

European Environment Agency

X

Vulnerability and adaptation to climate change in Europe

European Environment Agency

Cover design: EEA
Layout: Scanprint A/S, EEA

Luxembourg: Office for Official Publications of the European Communities, 2006

ISBN 92-9167-814-7
ISSN 1725-2237

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99
Web: www.eea.eu.int
Enquiries: www.eea.eu.int/enquiries

Contents

Acknowledgements

The European Environment Agency's European Topic Centre for Air and Climate Change (ETC/ACC) provided input to this report. The coordinating input from the ETC was provided by Xianfu Lu (Tyndall Centre, the United Kingdom).

Contributors included, in alphabetical order:

Alison Colls (Tyndall Centre, the United Kingdom);

Markus Erhard (IMK-IFU, Forschungszentrum Karlsruhe, Germany);

Uta Fritsch (Potsdam Institute for Climate Impact Research);

Jelle van Minnen (Netherlands Environmental Assessment Agency, the Netherlands);

Thomas Voigt (Umweltbundesamt, Germany).

The EEA project manager was André Jol.

EEA acknowledges the comments received on the draft report from the National Focal Points of EEA member countries and the European Commission (DG Environment), which have been included in the final version of the report as far as practically feasible.

Executive summary

Significant changes in climate and their impacts are already visible globally, and are expected to become more pronounced. In Europe, mountain regions, coastal zones, wetlands and the Mediterranean region are particularly vulnerable. Although there are some positive effects, many impacts are adverse. Existing adaptive measures are concentrated in flood defence, so there is considerable scope for adaptation planning and implementation in other areas, such as public health, water resources and management of ecosystems.

The need for adaptation

Projections for 2100 suggest that temperature in Europe will have risen by between 2 to 6.3 °C above 1990 levels. The sea level is projected to rise, and a greater frequency and intensity of extreme weather events are expected. Even if emissions of greenhouse gases stop today, these changes would continue for many decades and in the case of sea level for centuries. This is due to the historical build up of the gases in the atmosphere and time lags in the response of climatic and oceanic systems to changes in the atmospheric concentration of the gases.

The Environment Council of the European Union has recently confirmed the EU indicative target of a maximum of 2 °C global temperature increase above pre-industrial levels in order to avoid severe adverse impacts of climate change. Achieving such a target will require substantial reductions of global GHG emissions over and above those already agreed under the Kyoto Protocol. There is also growing recognition that Europe must adapt to the climate change impacts that inevitably will occur.

Vulnerability

Vulnerability refers to the risk of adverse impacts from climate change, including extreme weather events and sea level rise, on both natural and human systems.

Regional vulnerability

Regions: South-eastern Europe, the Mediterranean and central European regions are the most vulnerable to climate change. Here, considerable adverse impacts are projected to occur on natural and human systems that are already under pressure from changes in land use, for example. Northern and some western regions of Europe, on the other hand, may experience beneficial impacts, particularly within agriculture, for some period of time.

Mountains and sub-arctic areas: Impacts of temperature rise on snow cover, glaciers and permafrost are likely to have adverse impacts on winter tourism. There could also be an increased risk of natural hazards, and loss of plant species and habitats. Mountainous regions, like the Alps, are particularly vulnerable to climate change and are already suffering from higher than average increases in temperature.

Coastal zones: Climate change could have profound impacts on coastal zones due to sea level rise and changes in frequency and/or intensity of storms. This would result in threats to ecosystems, infrastructure and settlements, the tourism industry and human health. Habitats and coastal ecosystems on the Baltic, Mediterranean and Black Seas in particular are at high risk. It is projected that the Mediterranean and Baltic coasts will experience considerable loss of wetlands.

Vulnerability by issue

Ecosystems and biodiversity: Observed temperature rises and changes in precipitation patterns already affect various aspects of Europe's natural systems. The most vulnerable ecosystems are the European arctic and mountains, coastal wetlands and ecosystems in the Mediterranean region. Projected climate change is expected to lead to considerable losses of species and habitats throughout Europe.

Agriculture and fisheries: Climate change and increased CO_2 concentration could have a beneficial impact on agriculture and livestock systems in northern Europe through longer growing seasons and increasing plant productivity. However, in the south and parts of eastern Europe the impact is likely to be negative. In fisheries, changes in fish migration patterns are expected to occur. However, resource over-exploitation is currently a more important factor threatening the sustainability of commercial fisheries in Europe.

Forestry: Climate change will probably result in yield increases in commercial forests in northern Europe. However, Mediterranean regions and continental Europe will experience decreases in yield due to more frequent droughts. In addition, increased risks of fire are likely in southern Europe.

Water resources: Temperature rise and changing precipitation patterns are expected to exacerbate the already acute water shortage problem in southern and south-eastern regions. Changes in frequency and intensity of droughts and floods are projected, which could cause significant financial and human loss throughout Europe.

Tourism: Unreliable snow cover resulting from temperature rise is likely to lead to a loss in winter tourism. Water shortage, water quality problems, and more frequent and intense heat waves in southern Europe could cause notable reductions in summer tourism. However, new opportunities for tourism may arise in other areas.

Human health: Changes in frequency and intensity of extreme weather and climate events could pose a serious threat to human health. These threats may either be direct, such as heat waves and flooding, or indirect, for example by the spread of tick-borne diseases. Particularly vulnerable sections of the population are elderly people with limited access to health care services.

Energy: Temperature rise is likely to increase energy demand for air conditioning in the summer, particularly in southern Europe. Such extra power demand, compounded by climate change induced reduction in hydro-production and problems with cooling water availability could cause disruption to energy supplies.

Adaptation

Strategies and policies

Adaptation refers to policies, practices and projects which can either moderate damage and/or realise opportunities associated with climate change.

At global level, the 2004 UN Framework Convention on Climate Change conference agreed to develop a five year, structured programme of work on the scientific, technical and socio-economic aspects of impacts, vulnerability and adaptation to climate change.

So far, the integration of climate change considerations into key EU environmental policies, such as the EU Biodiversity Strategy, the Habitats Directive and the Water Framework Directive, has not yet taken place to any great extent. Neither has such integration occurred in other relevant EU policy areas, such as the common agricultural policy (CAP).

At EU and national level, a number of research programmes assessing the implications of potential climate change impacts have been planned or are about to commence. Research started more recently in support of planning of national and international adaptation measures. In 2004, the European Commission initiated the development of a European action programme on flood risk management, including a possible future Floods Directive. In this context, climate change has been mentioned as a key issue. Then, in October 2005, the Commission launched the second phase of the European Climate Change Programme. This programme is primarily aimed at identifying additional measures to reduce greenhouse gas emissions in order to achieve the Kyoto Protocol targets. Here, for the first time, it was agreed to address adaptation issues.

A consultation process with stakeholders will be held in 2006 to discuss the EU role in climate change adaptation policies. The aim is to integrate adaptation into relevant European policy areas in order to identify good, cost-effective practice in the development of adaptation policy, and to foster learning. The Commission aims to publish a green paper by the end of 2006.

At national level, strategies are currently under preparation in Denmark, Finland and the United Kingdom. In many EEA member countries adaptation measures are either planned or taking place in the context of natural hazard prevention, environment protection and sustainable resource management.

Examples of actual or planned measures are:

- Austria: natural hazards and tourism in the Alps;
- Belgium: river flood risk management;
- Finland: hydropower generation, infrastructure (transport, buildings) and forestry;

- France: health sector and forestry;
- Italy: coastal zone management and tourism in the Alps;
- Norway : infrastructure (buildings) and forestry;
- the Netherlands: river flood risk management and coastal zone flood defence;
- Spain: agriculture (droughts);
- Sweden: forestry;
- Switzerland: hydropower generation, ecosystems and tourism in the Alps;
- the United Kingdom: river flood risk management, coastal zone flood defence and insurance.

Adaptation challenges

Development and implementation of adaptation measures is a relatively new issue. Existing adaptive measures are very much concentrated in flood defence, which has enjoyed a long tradition of dealing with weather extremes. Concrete adaptation policies, measures and practices outside this area are still scarce. Therefore, there is considerable scope for advancing adaptation planning and implementation in areas such as public health, water resources and management of ecosystems. There are a number of challenges which should be addressed to make progress on climate change adaptation. These include:

- improving climate models and scenarios at detailed regional level, especially for extreme weather events, to reduce the high level of uncertainty;
- advancing understanding on 'good practice' in adaptation measures through exchange and information sharing on feasibility, costs and benefits;
- involving the public and private sector, and the general public at both local and national level;
- enhancing coordination and collaboration both within and between countries to ensure the coherence of adaptation measures with other policy objectives, and the allocation of appropriate resources.

1 Introduction

1.1 Background

Atmospheric build-up of greenhouse gases has altered the energy balance within the Earth's climate system and has resulted in significant changes in important aspects of our climate. The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (hereafter referred to as the IPCC) concluded that '*an increasing body of observations gives a collective picture of a warming world*' with '*new and stronger evidence that most of the warming observed in the past 50 years is attributable to human activities*'. Without drastic changes in the current production and consumption patterns, the trend in global emissions of greenhouse gases will continue. By 2100, global surface temperature is projected to warm by 1.4 to 5.8 °C, and global-mean sea-level to rise by 9 to 88 cm in relation to the 1990 levels (IPCC, 2001). In line with this global climate trend, climate in Europe has been changing and has had a wide range of impacts on the natural environment and human society in the Region. During the 21st century, temperature in Europe is projected to rise by 2.0 to 6.3 °C (Parry, 2000). Temperature and other changes in the climate system are likely to induce profound changes in the functioning and services of European's natural and human systems (EEA, 2004a).

In recognition of the significance of combating climate change, countries have under the United Nations, initiated actions to reduce greenhouse gas emissions, and hence to mitigate global climate change. The ultimate objective of the United Nations Framework Convention on Climate Change (hereafter referred to as the UNFCCC) ([1]) (Article 2) is to '*stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*'. Although there are scientific and political uncertainties on the determination of concentration levels below which this condition can be considered fulfilled, it is generally recognized that substantial further emission reductions are needed beyond the reductions required by the Kyoto Protocol ([2]) of the UNFCCC. Without further policies and measures to reduce greenhouse gas emissions global emissions of carbon dioxide (the most important greenhouse gas) are projected to rise by 60 % by 2030 above the 1990 level (IEA, 2004). Discussions started in 2005 under the UNFCCC process on possible future (post-2012) emission targets, guided by the ultimate objective of the UNFCCC. In line with the UNFCCC's underlying principles of common but differentiated responsibilities and respective capabilities, developed countries and (some) newly industrialized countries could be expected to further reduce their emissions while developing countries may be allowed an increase for some period.

Even if emissions of greenhouse gases stop today, these changes would continue for many decades and in the case of sea level for centuries. This is due to the historical build up of the gases in the atmosphere and time lags in the response of climatic and oceanic systems to changes in the atmospheric concentration of the gases (Wigley, 2005).

Therefore, in addition to emission reduction (mitigation) measures, it is essential that natural as well as human systems also develop adequate adaptive responses to avoid the risks posed by, and to take advantage of the opportunities arising from global climate change. The Conference of the Parties to the UNFCCC (COP-10, Buenos Aires, 2004) formally requested its Subsidiary Body for Scientific and Technological Advice (SBSTA) to develop a structured five-year programme of work on the scientific, technical and socio-economic aspects of impacts, vulnerability and adaptation to climate change. This programme is to address issues related to methodologies, data and modelling; vulnerability assessments; adaptation planning, measures and actions; and integration of climate change concerns into sustainable development ([3]). Information presented in this report could be of assistance as

([1]) Full text of the Convention is available at http://unfccc.int/resource/docs/convkp/conveng.pdf.
([2]) Full text of the Protocol is available at http://unfccc.int/resource/docs/convkp/kpeng.pdf.
([3]) Source: Decision 1/CP.10 of the UNFCCC (http://unfccc.int/resource/docs/cop10/10a01.pdf#page=2).

the European Union (hereafter referred to as the EU)'s contribution to the development of this Work Programme.

As a region of industrialized countries, Europe has been focusing its climate policy on mitigation. However, as the impacts of climate change become more evident also for Europe and scientific studies reveal more reasons for concerns under a changing climate, countries in Europe have started to plan for and implement measures to adapt to projected climate change and their impacts. The EU Environment Council meeting in December 2004 and subsequent meetings in 2005 highlighted the need to prepare for and adapt to the consequences of some inevitable climate change. By documenting the wide ranging impacts of climate change, the European Environment Agency (EEA) also called for adaptive responses to climate change in Europe (EEA, 2004a). Several EU Member States have already developed national adaptation strategies.

1.2 Objectives of the report

This report is prepared with the following objectives:

- to provide information on vulnerability in Europe, highlighting the need for adaptation;
- to facilitate information sharing among EEA member countries and learning from 'best practices in vulnerability assessments and adaptation planning';
- to contribute to the discussion on adaptation strategies and policies at EU and national level;
- to identify current and future information needs, towards which the EEA and other organizations might be able to contribute.

1.3 Definitions of vulnerability and adaptation

With the rapid growth of literature on climate change vulnerability and adaptation, concepts of vulnerability and adaptation have been re-defined. In particular, the process of bringing climate change into mainstream strategies and policies has re-introduced some of the broader definitions of vulnerability and adaptation (Downing and Patwardhan, 2005).

The literature on risk, hazards, poverty and development is concerned with underdevelopment and exposure to climate variability, among other pressures and threats. Within this context, vulnerability is a function of the state of development. It is often manifested in some aspect of human condition, such as ill health and poverty. Adaptation, in this regard, is to focus on building or enhancing adaptive capacity to reduce vulnerability (Figure 1).

Within the context of climate change, the IPCC defines vulnerability in climate change terms: the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. Adaptation is defined as adjustment in

Figure 1 Definitions of vulnerability and adaptation

Hazard literature

Vulnerability = *f* *(state of* **development**)
Adaptation: *building/enhancing/***adaptive capacity** *to reduce* **vulnerability**

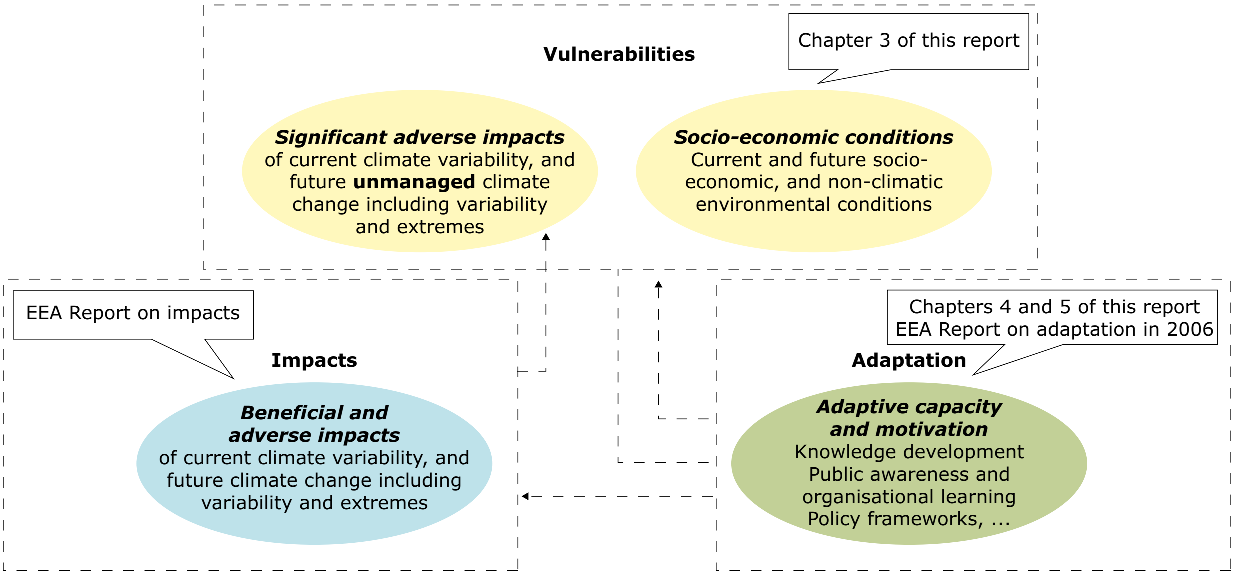
Climate change (IPCC)

Vulnerability = *Adverse* **impacts = adaptation**
Adaptation: *moderating damages, and/or realising opportunities to reduce* **vulnerability**

This report

Vulnerability = *Adverse* **impacts**
Adaptation: policies, practices, projects *for moderating damages, and/or realising opportunities*

Figure 2 Major components of this report in relation to the key subjects of climate change impacts, vulnerability and adaptation



natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities associated with climate change ([4]). Hence, vulnerability is seen as the residual impacts of climate change after adaptation measures have been implemented (see Figure 1).

Therefore, both vulnerability and adaptation depend on context and scale. There are no universal definitions for vulnerability and adaptation. Different meanings of vulnerability are surveyed in literature (Downing and Patwardhan, 2005). It is suggested that broader definitions of vulnerability are most useful when addressing adaptation policy needs but, when the term is used, care should be taken to explicitly specify its derivation and meaning.

The uncertainty surrounding climate change, its impacts and adaptive processes is so formidable that very little can be said yet with confidence about adaptive capacity and adaptation, and therefore also about vulnerability to long-term climate change by the IPCC definition. Therefore, throughout this report, vulnerability is defined as *'a state induced from adverse impacts of climate change, including variability and extremes, and sea level rise, of both natural and human systems.'* In other words, vulnerability of natural and human systems to unmanaged climate change is presented and discussed. Adaptation refers to *'policies, practices, and projects with the effect of moderating damages and/or realising opportunities associated with climate change'*, including climate variability and extremes and sea level rise (see Figure 1).

Readers are referred to literature (Downing and Patwardhan, 2005) for more extensive discussions on different definitions of vulnerability and the determinants of vulnerability and adaptive capacity (Brooks *et al.*, 2005).

1.4 Scope of the report

This report aims to provide an overview of key vulnerabilities to, and ongoing activities for adapting to the impacts of climate change, including climate variability and sea level rise, in EEA member countries. The aim is also to identify challenges for climate change adaptation strategies and measures in Europe. This report is a follow-up of the EEA report on climate change impacts (EEA, 2004a), and should also be considered in connection with other EEA reports (e.g. on water, coastal zone management, biodiversity). Since this is the first EEA report on vulnerability and adaptation to climate change, it should be regarded as a scoping study. A more detailed analysis of adaptation practices in Europe is planned for a subsequent EEA report due to be finalized in 2006. Further, the IPCC Fourth Assessment Report (AR4) due to be published in 2007, will include a volume treating the

([4]) Source: the glossary of the Third Assessment Report of the IPCC, http://www.ipcc.ch/pub/syrgloss.pdf.

issues of climate change impacts, vulnerability and adaptation, with one chapter on Europe. The OECD has recently started a project on adaptation in OECD countries which should also be considered by any related EEA work in the future. Figure 2 illustrates the major components of this report in relation to the key subjects of climate change impacts, vulnerability, and adaptation.

1.5 Sources of information

This study used a combination of methods to collect and analyse information:

- A large body of literature on climate change impacts, vulnerability and adaptation in Europe was reviewed (e.g. IPCC reports, relevant chapters of national communications to the UNFCCC, publications of EU-funded research projects, national assessment reports, and research journal articles);
- A questionnaire was developed to elicit first-hand and up-to-date information on national vulnerability assessment, adaptation strategies, policies and measures in EEA member countries

1.6 Outline of the report

Climate change vulnerability and adaptation in Europe within the context of EU policy frameworks is briefly reviewed in Section 2. Section 3 then introduces the scientific overview of sectoral vulnerability in Europe. Adaptation policies and practices are discussed with a country perspective in Section 4. Section 5 highlights the challenges to adaptation to climate change in Europe. Finally, the conclusions are summarised in Section 6. Three case studies with in-depth information on vulnerability issues in Europe are presented in Appendix 1.

2 EU policy frameworks

2.1 Climate change policies

By ratifying the UNFCCC and its Kyoto Protocol, the EU committed itself to the ultimate goal of the Convention. The objective is to stabilise greenhouse gases at levels sufficient to prevent dangerous anthropogenic climate change so that food security is maintained, economic development is sustainable and ecosystems are able to adapt naturally. The EU has implemented a number of common and coordinated policies and measures to reduce greenhouse gas (GHG) emissions. A key measure, among other initiatives, is the EU-wide carbon trading scheme which started in 2005 (European Commission, 2004a).

EU climate policy has mainly focused on mitigation over the past decade. In comparison, adaptation to the potential impacts of climate change, including climate variability and sea level rise, has not yet been given much attention. However, under the UNFCCC process, the need for adaptation has been a recurrent focus at the recent Conferences of Parties to the Convention. In view of the high level of vulnerability and limited adaptive capacity in developing countries, three international funds were created under the Convention and its Kyoto Protocol: a Special Climate Change (SCC) Fund to support adaptation and technology transfer; a Least Developed Countries (LDCs) Fund to support the preparation of National Adaptation Programmes of Action (NAPAs) (Burton *et al.*, 2002); a Kyoto Protocol Adaptation Fund to support adaptation projects and programmes in participating developing countries (Adger *et al.*, 2003; Dessai and Schipper, 2003; Huq, 2002; Huq and Burton, 2003). Although all such initiatives are developing country oriented, industrialised countries including the EU countries are requested to make voluntary contributions towards these funds, to enable the implementation of adaptation measures in vulnerable developing countries. The EU and many of its member countries have provided extensive financial and technical assistances to help developing countries in their adaptation efforts. This is also reflected in the EU Action Plan on Climate Change and Development adopted in 2004 ([5]).

Within the EU, there is growing public awareness for the likely changes in natural and human systems under a changing climate, and recognition of the need for taking proactive measures to adapt to such changes. At their meeting in December 2004, the EU Environment Council concluded that there is a need to prepare for and adapt to the consequences of some inevitable climate change. In addition, the Council mentioned the importance of incorporating the consideration of climate risks into poverty reduction strategies, national strategies for sustainable development, and the need to limit climate change effects in order to help achieve the Millennium Development Goals and the Johannesburg Plan of Implementation goals and targets, and the importance of the EU Action Plan on climate change in the context of development cooperation, adopted by the Council ([5]).

Furthermore, the European Commission in its proposals for a post-2012 climate change strategy mentioned the need for a European approach to climate change (European Commission, 2005). This communication (and the associated staff working paper) also underlined the impacts on biodiversity and ecosystems of varying degrees of global temperature rise. The communication as well as various Environment Councils (December 2004, March 2005) reaffirmed the proposed EU target of 2 °C global temperature increase above pre-industrial levels. This would help to avoid serious adverse effects to, for example, water resources, ecosystems, biodiversity and human health.

2.2 Integration in other policies

In order to maintain a high level of biodiversity in general, the EU adopted its European Biodiversity Strategy in February 1998, as part

([5]) Details of the Action Plan are included in the Annex to the EU Council Conclusion 'Climate change in the context of development cooperation (7523/03 DEVEN 195 ENV 586).

of its implementation of the UN Convention on Biodiversity. This strategy aims to anticipate, prevent and eradicate the causes of significant reduction or loss of biodiversity at the source. Climate change is mentioned in various parts of the strategy text, including the context of climate change impact on biodiversity. The strategy was discussed at the Malahide Conference in 2004 ([6]). This conference proposed, among others, that habitats and species most at risk from climate change need to be assessed by 2007, and appropriate management plans subsequently prepared. To achieve objectives, the Nature Conservation European Directives (Birds, 79/409/CE, and Habitat, 92/43/CE) and their subsequent implementation network of sites, the Natura 2000 (N2K), can be helpful instruments. However, the development of specific strategies and policies to address the effects of climate change on biodiversity has not yet taken place at the EU level. Some measures, such as developing ecological corridors, have been undertaken by some countries to allow ecosystems to connect better and also to adapt to changing climate conditions.

Climate change and its impacts on water bodies in the EU are expected to affect the ecological quality of the surface and groundwater resources in Europe. Some efforts are being made to explore the implications of climate change and its impacts on the implementation of the Water Framework Directive (WFD) (2000/60/EC). The Directive itself does however not include specific provisions to address climate change impacts. Furthermore, upon the request by the EU Member States, an extensive assessment on potential impacts of climate change on Europe's water dimension was carried out (Eisenreich, 2005). It is important for any impact assessment of climate change in the water sector to adopt the same scheme with relation to the river basin districts and bodies of water identified, and the quantitative and qualitative aspect of the 'surface water status' and 'groundwater status', as defined in WFD. Furthermore, upon the request by the EU Environment Ministers, the European Commission will develop a proposal for an EU flood prevention and management action plan in 2006, including a possible future Floods Directive. The plan will make provision for an early warning system, integrated flood basin and flooding management plans, and the development of flood risk maps ([7]). In this context, climate change has been mentioned as a key issue.

The declaration of the EU's Fourth Ministerial Conference on Environment and Health ([8]) recognised that climate is already changing. It also recognised that changes in the intensity and frequency of extreme weather events, such as floods, heat-waves and cold spells, will pose additional challenges to health risk management. The Declaration calls for proactive and multidisciplinary approach by governments, agencies and international organisations and improved interaction at all levels. In particular, the ministers decided to take action to reduce the current burden of disease due to extreme weather and climate events. It also called for further efforts to identify, prevent and adapt to the health impacts of climate change and other global environmental changes to the greatest extent possible.

Other EU policies, such as the common agricultural policy (CAP), do not yet include strategies or policies to explicitly address the current and future (potential) impacts of climate change.

Under the second phase of the European Climate Change Programme, the European Commission has in October 2005 started a consultation process with a wide range of stakeholders to discuss and prepare the further development of the EU's climate policy. For the first time a working group on adaptation has been established. This working group will discuss the EU role in adaptation policies with the aim to integrate adaptation fully into relevant European policy areas, to identify good, cost-effective practice in the development of adaptation policy and to foster learning. The Commission aims to publish a green paper by the end of 2006.

([6]) http://europa.eu.int/comm/environment/nature/biodiversity/develop_biodiversity_policy/malahide_conference/index_en.htm.
([7]) Source: http://www.europa.eu.int/comm/enivornment/water/flood_risk/index.htm.
([8]) http://www.euro.who.int/budapest2004/20040701_4.

3 Vulnerability in Europe — sectoral perspectives

Since the early 1980s, scientific studies have generated a wealth body of knowledge on the potential impacts of a changing climatic regime on Europe's natural environment and on society. This section summarises information from literature, and puts a specific focus on the potential adverse impacts of projected climate change and sea level rise within the natural and socio-economic context of Europe. Regional variations in vulnerability to projected climate change are highlighted with a view to identifying priority areas where adaptation actions are most needed.

Section 3.1 discusses vulnerability of Europe's natural environment and associated services, while Section 3.2 focuses on the vulnerability of other socio-economic sectors. Section 3.3 draws conclusions on regional variations in vulnerability across Europe and hence identifies priority areas for adaptation. In addition, three case studies have been conducted as examples. These studies present in-depth information on how vulnerability is identified and what adaptation measures are required, planned or implemented. The case studies address natural ecosystems, a region (the Alps), and a sector (water resources). These case studies are included in Appendix 1 of the Report.

3.1 Vulnerability of natural environment and associated services

3.1.1 Natural ecosystems and biodiversity

The natural environment and human wellbeing in the world, including Europe, largely depends on Earth ecosystems and the services they provide. Such services include food and water supply, climate regulation, and species preservation. Ecosystems have always been influenced by man. Over the last 50 years, however, humans have used ecosystems more intensively than in any comparable period of time in human history (MA, 2005). Furthermore, most ecosystems and the biodiversity within them became exposed to multiple pressures, such as habitat destruction, fragmentation, air pollution, and more recently climate change. As a result of both intense exploitation and multiple stresses, ecosystems and their services have been degraded in

Box 1 Key messages from the Millennium Ecosystem Assessment

- Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. This is due largely to their needs to meet rapidly growing demands for food, fresh water, timber, fibre and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.
- The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of nonlinear changes and the exacerbation of poverty for some groups of people. These problems, unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems.
- The degradation of ecosystem services could grow significantly worse during the first half of this century and is a barrier to achieving the Millennium Development Goals.
- The challenge of reversing the degradation of ecosystems while meeting increasing demands for their services can be partially met under some scenarios that the MA has considered but these involve significant changes in policies, institutions and practices, which are not currently under way. Many options exist to conserve or enhance specific ecosystem services in ways that reduce negative tradeoffs or that provide positive synergies with other ecosystem services.

Source: MA, 2005.

many parts of the world. Species composition within the ecosystems has undergone significant changes. Species have become extinct at rates 100–1 000 times greater than what is considered to be normal; and the diversity of life on Earth has substantially, and largely irreversibly, decreased (Hare, 2003; MA, 2005). Box 1 summarises the key findings from the Millennium Ecosystem Assessment, an international work programme which assessed trends in ecosystem services and how changes in ecosystems services affect human well being now and in the future.

Climate change has been a recent addition to the list of environmental pressures that affect ecosystems and their services. Climatic conditions determine, to a large extent, whether a species can exist in a certain area. They directly govern the potential distribution, because species can often only reproduce and live within specific climatic conditions. Indirectly climatic conditions affect the potential distribution because they are closely linked to ecosystem disturbances like forest fires and changes in nutrient supply through changes in soil decomposition. Such changes in climatic conditions affect the functioning and distribution of ecosystems. There is compelling evidence that the extent and rate of climate change observed has affected species and ecosystems already. These observations and scientific theory clearly suggest that natural ecosystems are generally vulnerable to climate change (Smith and Hitz, 2003). Relatively small changes in climate (e.g. global warming of less than 1 °C) already have effects on ecological hotspots, whereas significant effects in many places of the world can be expected if the warming exceeds 2 °C.

For Europe, observed temperature increase and precipitation decrease already affect various aspects of the natural ecosystems. For example, arctic mammals already suffer from the warmer conditions and related change in sea ice extent. Vast losses of habitats (50 % or more) are projected for global temperature rises of 2–3 °C. For the arctic, such global temperature rise would imply a warming of up to 7 °C. Some substantial declines in previously stable species are reported in the United Kingdom (RSPB *et al.*, 2005). Climate change is identified as a major factor. WBGU (2003) identified four regions with highly vulnerable ecosystems: The arctic region (including parts of Scandinavia and Greenland), mountain regions, various coastal zones across Europe, especially in the Baltic and various parts of the Mediterranean. The vulnerability of these regions is discussed in more details in Appendix 1.

A modelling exercise projects that by 2050, 80 % of the 2 000 (1 350 plants, 157 mammals, 108 reptiles and 383 breeding birds) surveyed current species across Europe would be lost under high greenhouse gas emissions and climate change scenarios (Schröter *et al.*, 2004). The detailed examination of the projections for plants in 2050 under the full range of scenarios suggests that 5 % of these species would lose all available habitats (Schröter *et al.*, 2004).

3.1.2 Agriculture

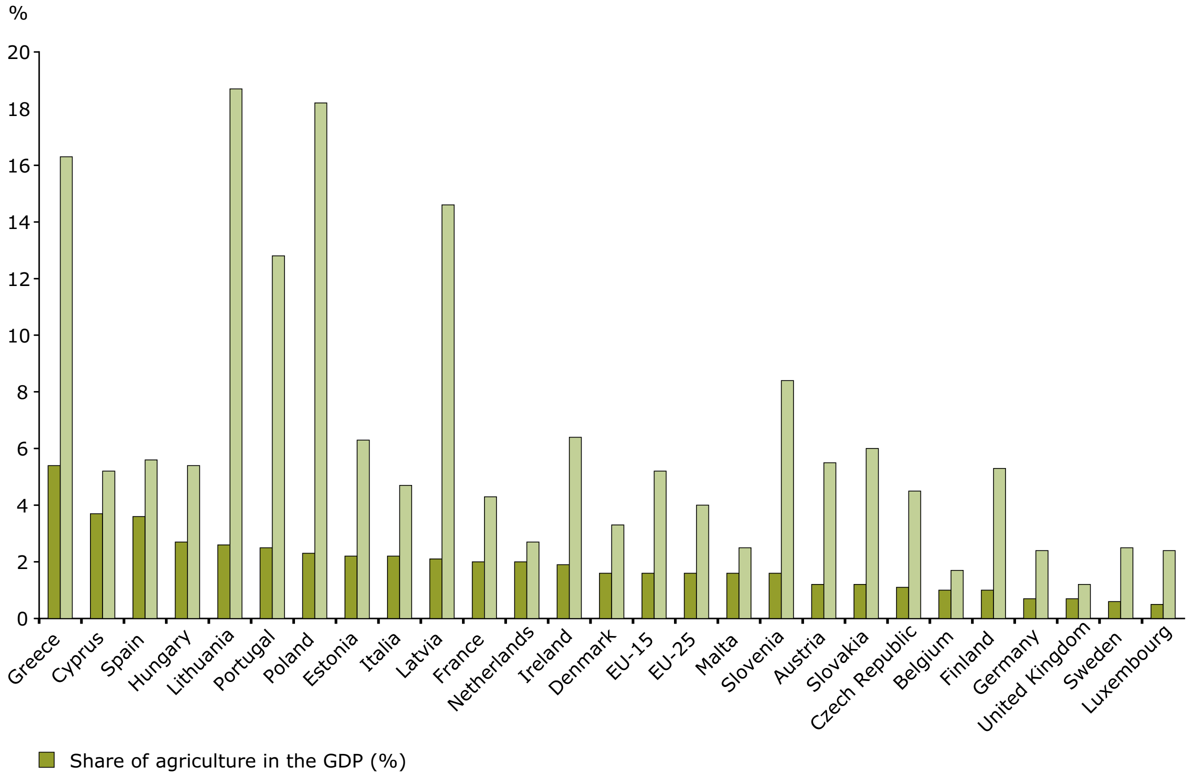
Agriculture accounts for only a small part of gross domestic production (GDP) in Europe. Therefore, the overall vulnerability of the European economy to changes that affect agriculture is low (Reilly, 1996). Regionally and nationally, however, effects may be substantial, particularly in southern and central European countries where agriculture represents a more significant sector for employment and GDP (see Figure 3). Intensive farming systems in western Europe generally have a low sensitivity to climate change, and farmers are well resourced and equipped to cope with changes. However, the agriculture sector in southern European countries may be among the most vulnerable to the direct and indirect impacts of projected climate change.

Under a changing climate, drier conditions and rising temperatures in the Mediterranean region and parts of eastern Europe may lead to lower yields (Stuczyinski *et al.*, 2000). Bindi and Moriondo (2005) showed a general reduction in yield of agricultural crops in the Mediterranean region, under the IPCC SRES (Special Report on Emissions Scenarios) A2 and B2 scenarios by 2050. Reductions in yields are expected to be more significant in the southern Mediterranean compared to the northern areas, even when the fertilising effect of increased CO_2 is taken into account. The southern Mediterranean is projected to experience an overall reduction of crop yields due to climate change by 2050 (see Table 1) (Bindi and Moriondo, 2005).

Such yield reductions have also been estimated for eastern Europe, with increased variability in yield, especially in the steppe regions (Maracchi *et al.*, 2004).

Furthermore, extreme weather events, such as hot spells, heavy storms, intense rain fall or droughts, can severely disrupt crop production all over Europe (Parry, 2000). The summer 2003 heat wave and drought conditions, for example, caused significant damage to the agricultural sector in central and southern Europe through the reduction

Figure 3 Agricultural employment and production in EU Member States



Source: European Commission, 2004b.

Table 1 Percentage changes of crop yields for the main Mediterranean regions by 2050

		Without CO_2		With CO_2	
		A2-A	**B2-A**	**A2-A**	**B2-A**
C4 summer	N-W	0.19	5.80	4.19	8,78
	N-E	– 4.43	– 2.54	– 0.60	0.21
	S-E	– 11.44	– 9.26	– 7.89	– 6.70
	S-W	– 12.87	– 8.94	– 9.38	– 6.37
Legumes	N-W	– 24.90	– 13.42	– 14.38	– 4.86
	N-E	– 18.59	– 8.11	– 7.19	0.97
	S-E	– 32.72	– 36.43	– 23.30	– 30.15
	S-W	– 33.26	– 25.81	– 23.92	– 18.48
C3 summer	N-W	– 21.79	– 10.44	– 12.41	– 2.85
	N-E	– 15.57	– 6.92	– 5.44	0.96
	S-E	– 7.44	– 8.19	3.66	– 0.41
	S-W	– 19.94	– 11.81	– 10.33	– 4.34
Tubers	N-W	– 10.37	– 4.24	4.87	7.53
	N-E	– 22.50	– 6.80	– 9.33	4.39
	S-E	– 18.22	– 15.77	– 4.31	– 5.66
	S-W	– 25.88	– 12.10	– 13.28	– 1.55
Cereals	N-W	– 10.97	– 3.49	– 0.29	4.68
	N-E	– 6.79	3.71	4.39	12.49
	S-E	– 15.08	– 17.17	– 4.88	– 10.15
	S-W	– 13.77	– 11.29	– 3.42	– 3.77

Note: N-W = Portugal, Spain, France and Italy; N-E = Serbia, Greece and Turkey; S-E = Jordan, Egypt and Libya; S-W = Tunisia, Algeria and Morocco.

Source: Bindi and Moriondo, 2005.

in production and losses of financial capital (see Figure 4). The projected increases in temperature variability over central Europe may also have severe impacts on the agricultural production in this region (Schär *et al.*, 2004).

Changes in climate and CO_2 concentration affect livestock systems in different ways. Changes can be direct through the effects of weather and extreme climatic events on animal health, growth and reproduction, or indirect through changes in availability and prices of grains for feeding, changes in productivity of pastures and forage crop, and change in distribution of livestock diseases (Parry, 2000). As a result, summer livestock production in the Mediterranean and other southern regions, will experience adverse impacts.

The distribution and intensity of existing pest, diseases, and weeds are likely to be more abundant. Currently exotic species may appear under a warmer climate, which would lead to changed effects on yield and on control measures (Parry, 2000). The need for plant protection will grow and the use of pesticides and fungicides may increase (Parry, 2000).

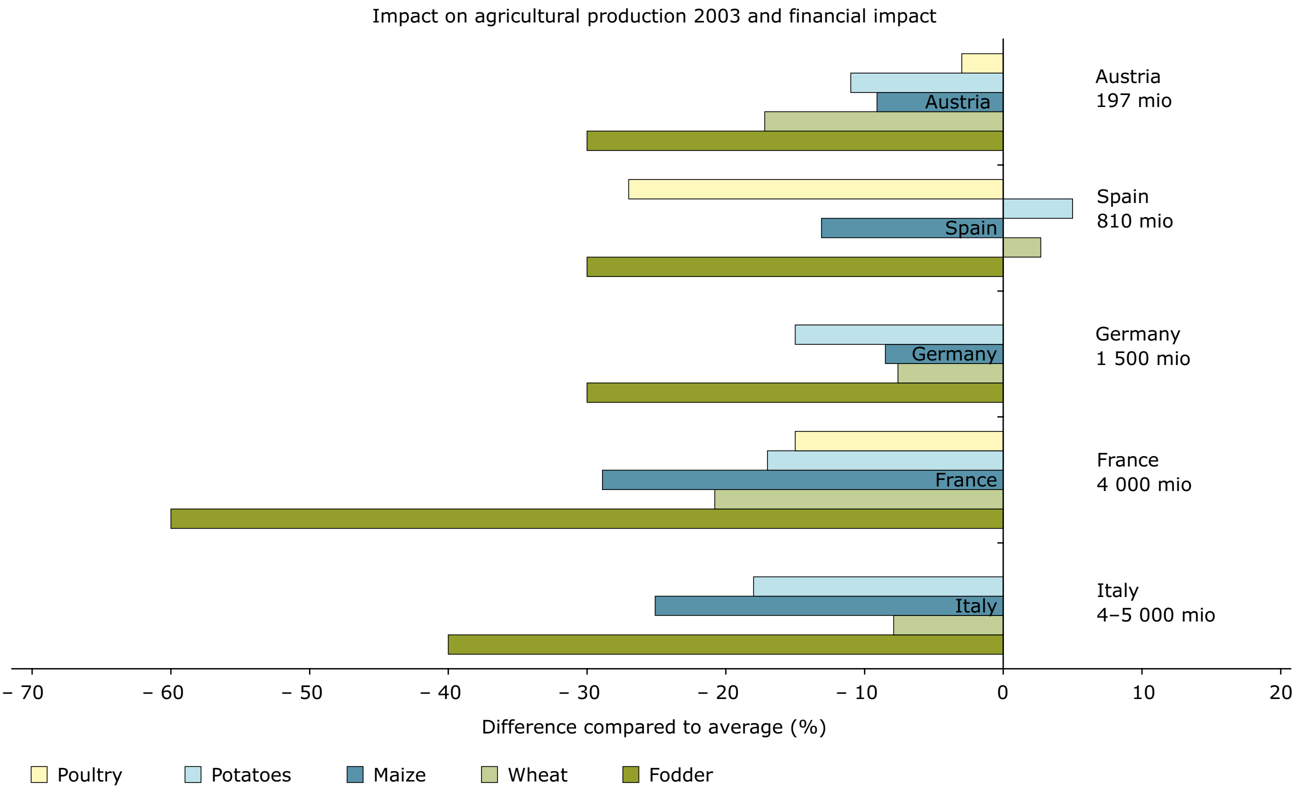
Particularly vulnerable regions in Europe are those where there is a large reliance on traditional farming systems and production of quality foods. Where such farming and production systems depend on favourable climatic conditions, climate change may cause large disruptions in rural society (Parry, 2000).

3.1.3 Fisheries

Detailed analyses of fish physiological responses to water temperature have suggested that the potential impact of climate change on freshwater and marine fish is large (Wood and McDonald, 1997). Unfortunately, studies so far have mostly focused on single species, rather than at a level of fisheries.

Studies on the likely faunal movements and range shifts suggest that there will be a northward shift in the geographic distribution of Atlantic salmon in Europe. Local extinction at the southern edge of the current range and new habitats colonised in the north are likely (McCarthy and Houlihan, 1997). Cod in the North Sea are at the warm end of their thermal range. Therefore, the ongoing warming trend in the eastern Atlantic has adversely affected the southern limits and stocks of cold-water fish such as North Sea cod.

Figure 4 Impact of the summer 2003 heat wave and drought on agriculture and forestry in five countries



Source: Adapted from UNEP/DEWA (2004); data from COPA-COGECA (2003).

Other factors are likely to combine with changes in temperature to decrease fish and shellfish productivity. Chronic levels of pollution are known to reduce marine and freshwater fish fecundity (Kime, 1995). Development of marine aquaculture may be slowed by a decreasing availability of sites with surface water that is cool enough and by increased susceptibility to disease under a warmer climate.

Climate change is one of many factors affecting the productivity and sustainability of fisheries. Resource overexploitation appears to be the single most important factor directly threatening the sustainability of many commercial fisheries in OECD countries. However, over-exploitation increases the vulnerability of fisheries to climate variability and projected climate changes (Kundzewicz *et al.*, 2001).

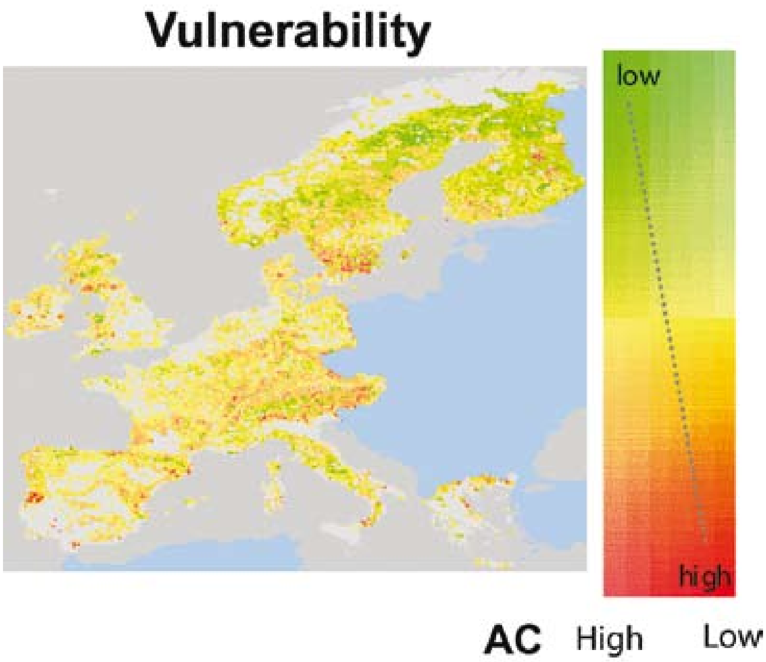
3.1.4 Forestry

About 30 % of Europe is covered by forests, which makes forest an important land cover type. In a large part of Europe, forestry represents an important economic sector and considerable potential for carbon sequestration. The natural range of European tree species is primarily governed by temperature and the availability of soil moisture. The structure and composition of many forests are further influenced by natural disturbance regimes, such as fire, insects and wind-throw. Changes in climate are therefore likely to affect the key features of forests both directly through changes in climate conditions and indirectly through disturbances and the way that forests are managed.

Model simulations suggest that, temperature rise may lead to an increase in tree mortality in southern and central Europe, where forests are at the edge of their bio-geographical distribution (Mindas and Skvarenina, 2003; Schröter *et al.*, 2004, 2005).

Under a warmer climate, it is expected that the northern range limits of most native tree species in Europe will expand. The southern boundary of some species will shift to north specifically at the boundary of steppe and forest zones. Norway spruce would withdraw from the coastal areas of southeast and central Sweden, but remain in the interior parts of southern Scandinavia (Bradshaw *et al.*, 2000). However, indirect impacts of climate change, in particular accelerating disturbance regimes, and human activities, such as forest management and fire protection, could limit the distribution of forests and species composition (Linder, 2000).

Figure 5 Vulnerability of forest production across Europe in 2080, using the A1 HadCM3 climate scenario



Source: Schröter *et al.*, 2004.

Limited moisture resulting from increasing temperature and possible reduced summer rainfall may lead to productivity declines in central and southern Europe (Lasch *et al.*, 2002). Summer temperature rise and reduction of precipitation may further increase fire risk (Lasch *et al.*, 2002). The vulnerability of forest production in central and southern Europe has recently been confirmed by the ATEAM project ([9]) (see Figure 5).

3.1.5 Mountains and sub arctic regions

Mountain cryospheres and ecosystems are highly sensitive to climate conditions. Development of industry, tourism and communication infrastructures has already put pressure on some mountain areas in Europe. Under a changing climate, some conflicts of interest in these regions between economic development and environmental sustainability are likely to occur (Diaz *et al.*, 2003).

Figure 6 Glacier change — Vernagtferner (Austria) in year 1985 (top) and 2000 (bottom)

Source: Weber; BAdW/kfG; 1985, 2000.

With the high sensitivity of snow cover to changes in temperature, a rise in temperature would result in earlier snow melt in spring. Currently observed widespread decrease in snow cover duration at various low and mid altitudes in Switzerland (Laternser and Schneebeli, 2003), Slovakia (Vojtek *et al.*, 2003) and Croatia (Gajic-Capka, 2004) is associated with temperature rise. It is estimated that 1 °C rise in temperature would reduce the snow cover duration by up to several weeks (Hantel *et al.*, 2000), even at high altitudes. A 4 °C warming would reduce the snow volume by 90 % at 1 000 m, and 30–40 % at 3 000 m in Switzerland (Beniston, 2003). It is estimated that permafrost in the low land will progressively disappear in the north of Europe with increasing temperatures (Haeberli and Burn, 2002). However, future changes in snow cover patterns, in relation to precipitation patterns in winter, may slow down the rate of such change (Harris *et al.*, 2003; Stieglitz *et al.*, 2003).

For glaciated and perennially frozen regions, temperature increase will lead to an upward shift of the glacier equilibrium line, from 60–70 m per °C (Vincent, 2002) to 140 m per °C (Maish, 2000), higher ablation and glacier retreat (e.g. see Figure 6). It is projected that most of the glaciers of the Alps are likely to disappear during the 21st century (Haeberli and Burn, 2002) (see more on vulnerability of the Alps in Appendix 1). The current reduction rate of 1.3 % per annum for glacier areas in Switzerland may accelerate, and regions below 2 500 m will be ice free by the end of the 21st century (Paul *et al.*, 2004). Decrease in glacier areas is also expected in the north of Europe. It is estimated that the Storglaciaren glacier (3 km^2), northern Sweden, may lose 30 % of its present mass and retreat by 300 m by about 2050 (Schneeberger *et al.*, 2001).

Cryospheric changes might lead to changes in the frequency and intensity of related natural hazards, such as snow avalanches (Martin *et al.*, 2001), ice avalanches (Haeberli and Burn, 2002), and rock falls (Gruber *et al.*, 2004).

Furthermore, plant species in mountain and sub arctic regions are also likely to be affected. For example, vegetation in snow beds is highly vulnerable to changes in temperature (Beniston, 2003).

Finally, winter tourism is likely to be adversely affected by rising temperature, due to its high level of dependence on reliable snow conditions. It is estimated that if snow reliability limit shifts from

([9]) With the ATEAM project, vulnerability is defined as a function of impacts and adaptive capacity. The more adverse impacts a region experiences, and the lower adaptive capacity a region possesses, the higher level of vulnerability is expected for a region.

1 200 m to 1 800 m, operations at 56 % (compared with the present level of 15 %) of Swiss ski resorts will become unviable due to snow unreliability (Elsasser and Burki, 2002) (For more discussion on tourism, see Appendix 1).

3.1.6 Water resources

Europe has a very diverse hydrological situation. In the south, there is very significant seasonal variation in river flow due to long and dry summers. To the west, there is less extreme variation, and in catchments underlain by absorbent aquifers river flows remain reasonably constant throughout the year. In the north and east, much precipitation falls as snow. As a result, significant river flow occurs during the snow melting period in spring.

There is also a wide variety of water uses, pressures and management approaches. A succession of floods and droughts in recent years has illustrated Europe's vulnerability to hydrological extremes. However, there are many other water-related pressures on Europe's environment. River ecosystems and wetlands are increasingly at risk. The quality of Europe's rivers, lakes and groundwater is being threatened by the discharge of sewage and industrial waste and by excessive application of pesticides and fertilizers. Climate change and sea level rise add other potential pressures on European water resources and management.

Studies (Arnell, 2004) indicate a decrease in annual average runoff of 20–30 % by the 2050s and of 40–50 % by the 2075s in south-eastern Europe. Here, annual rainfall and river discharge have already begun to decrease in the past few decades (Hulme, 1999; UNEP/MAP/MED/POL, 2003). Climate change may also change the timing and magnitude of both high flows (Reynard *et al.*, 2001) and low flows (Arnell, 1999). The occurrence of greatest flood risk could move from spring to winter (Ludwig *et al.*, 2003), and be enhanced by the expansion of impermeable surfaces due to urbanization (de Roo *et al.*, 2003). Model simulations indicate that low flows in central European mountain watersheds may be reduced by up to 50 % (Eckhardt and Ulbrich, 2003; Szolgay *et al.*, 2003).

Temperature rise and changing precipitation patterns may also lead to a reduction of groundwater recharge (Eitzinger *et al.*, 2003) and hence groundwater level. This would be most evident in south eastern Europe. Higher water temperature and low level of runoff, particularly in the summer, could lead to deterioration in water quality (Mimikou *et al.*, 2000).

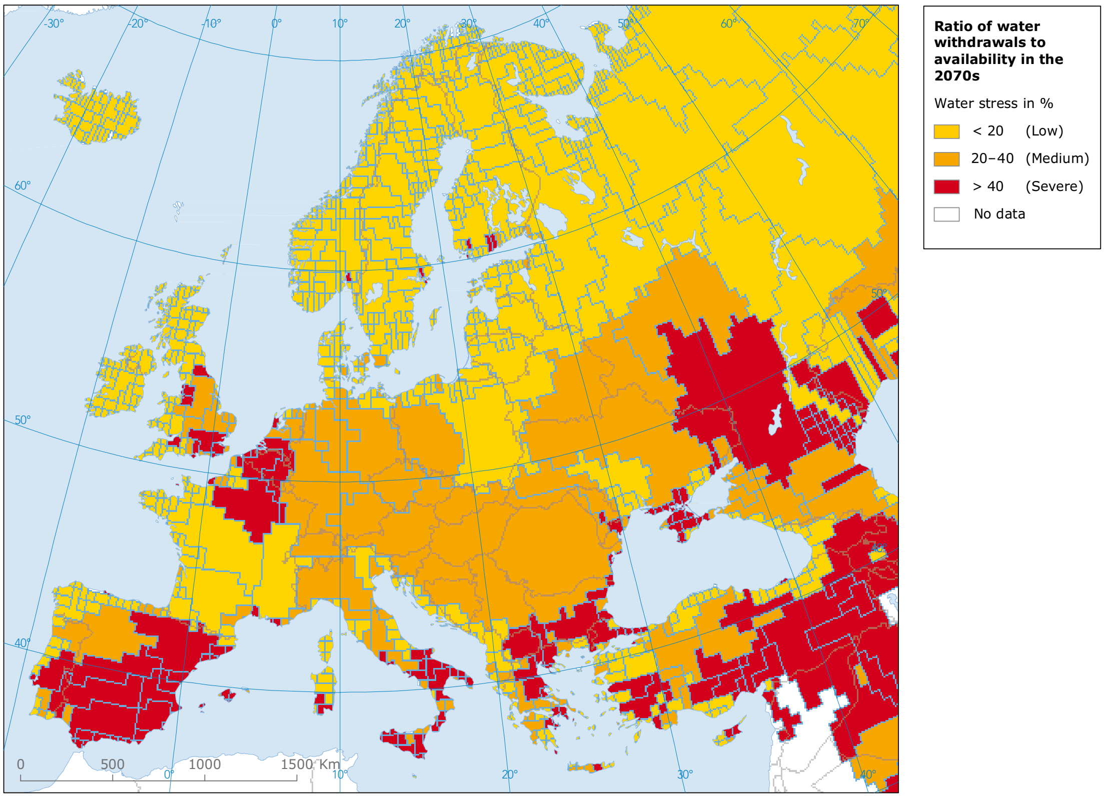
Most studies on water supply and demand conclude that annual water availability would generally increase in northern and north-western Europe and decrease in southern and south-eastern Europe (Arnell, 2004). Changes in water demand strongly depend on economic growth and societal development. The projected change is a different trend for western and eastern Europe. In western Europe under some scenarios, withdrawals would have a decreasing tendency due to the saturation of demands and increasing efficiency of water use. In eastern Europe economic growth would lead to increasing demands for water in both the domestic and industrial sectors (Alcamo *et al.*, 2003). In the agricultural sector, irrigation water requirements would increase mainly in southern and south eastern Europe (Döll, 2002). The overall balance between demand and supply under climate change suggests that water stress may occur in the Iberian peninsula (due to less supply), north-western Europe (due to increasing demand) and eastern Europe (due to changes in demand and supply) (see Figure 7). Vulnerability of water resources in the Mediterranean region is discussed in more detail in Appendix 1.

3.1.7 Coastal zones

Coastal zones in Europe contain large human populations and significant socioeconomic activities. They also support diverse ecosystems that provide important habitats and sources of food. One third of the European Union (EU) population is estimated to live within 50 km of the coast. In Denmark, the proportion is as high as 100 % and 75 % in the United Kingdom and the Netherlands (Nicholls and Klein, 2003b). Significantly inhabited coastal areas in countries such as the Netherlands, England, Denmark, Germany and Italy are already below normal high-tide levels, and more extensive areas are prone to flooding from storm surges. Hard defences to prevent such flooding and the loss of the seaward edge of coastal habitats, which are due to existing rates of sea-level rise, are already causing significant pressures on coasts in many locations (e.g. Rigg *et al.*, 1997). Deltaic areas often are particularly threatened because they naturally subside and may have been sediment starved by dam construction (e.g. Sanchez-Arcilla *et al.*, 1998).

Climate change is an additional pressure and is likely to have significant impacts on coastal zones, particularly via sea level rise and changes in the frequency and/or intensity of extreme weather events, such as storms and associated surges.

Figure 7 Water stress ([10]) in Europe in the 2070s



Source: Henrichs and Alcamo, 2001.

Direct impacts from sea level rise include inundation and displacement of wetlands, lowlands, coastal erosion, increased storm flooding and damage, increased salinity in estuaries and coastal aquifers, and rising coastal water tables and impeded drainage. Potential indirect impacts include changes in the distribution of bottom sediments, changes in the functions of coastal ecosystems and impacts on human activities.

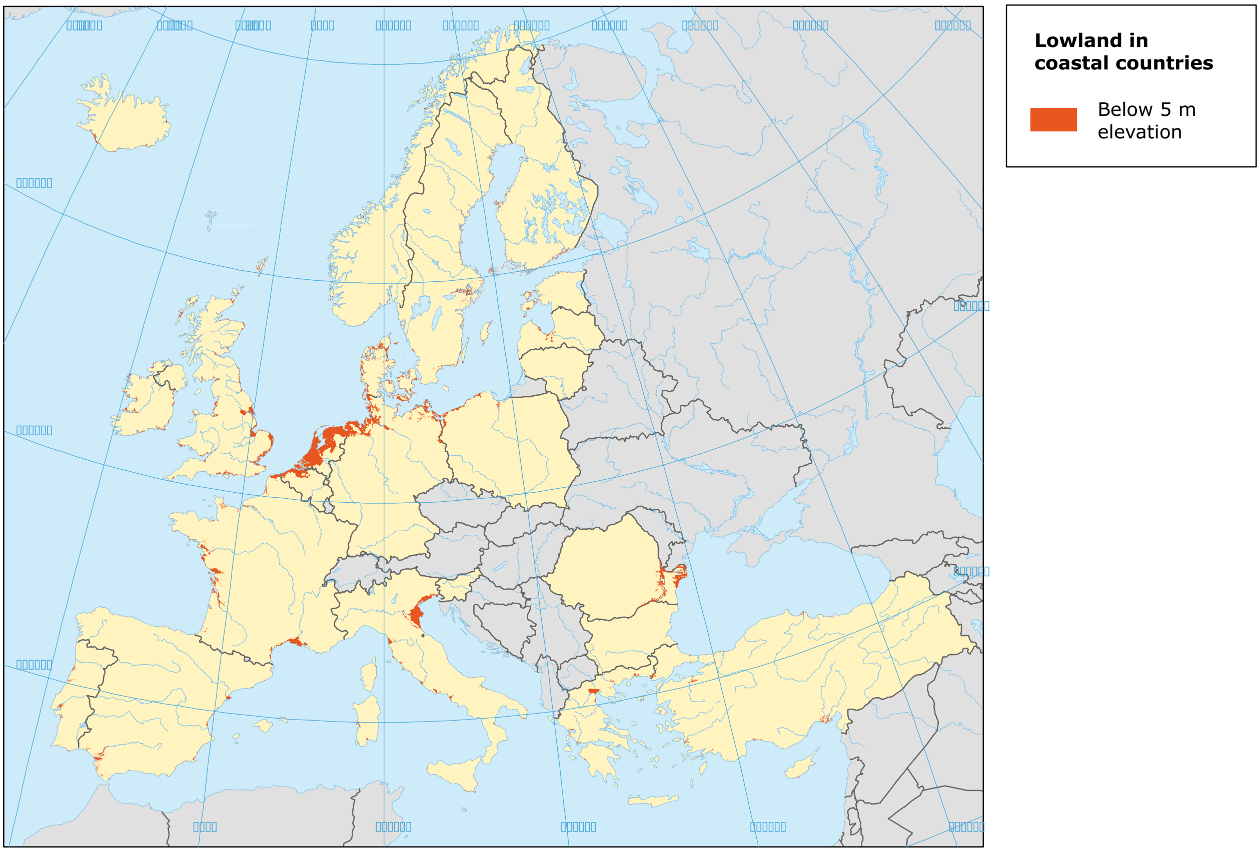
It is estimated that 9 % of all European coastal zones (12 % for EU Member States), which can be defined as a 10 km strip, lie below a 5 m elevation and are potentially vulnerable to sea level rise and related inundations. The most vulnerable areas are in the Netherlands and Belgium, where more than 85 % of coast is under a 5 m elevation. Germany and Romania have 50 % of their coasts below 5 m, Poland (30 %) and Denmark (22 %) (EEA, 2006, forthcoming) (see Figure 8). The most threatened coastal environments within Europe are deltas, low-lying coastal plains, islands and barrier islands, beaches, coastal wetlands, and estuaries (Beniston *et al.*, 1998; Nicholls and Klein, 2004). Flooding due to one metre rise in sea level would affect 13 million people in five European countries (see Table 2). However, the number of people affected varies between these five countries. The highest potential impact would be on the Netherlands, whereas Poland and Estonia would feel the least impact.

Under projected climate change and sea level rise, coastal ecosystems appear to be threatened, especially those in the Baltic, Mediterranean and Black Seas. These habitats could be severely reduced or disappear during the 21st century because of the low tidal range in these areas and the limited scope for onshore migration, which is due to the intense human use of the coastal zone (Nicholls and Klein, 2003a).

Furthermore, it is likely that sea water temperature increase and sea level rise have already led to changes in marine biodiversity, for example in the Mediterranean and the Adriatic where the establishment of thermophilic species may have been favoured (Bello *et al.*, 2004).

([10]) Water stress is assessed here as a result of changes in both climatic and socio-economic conditions (e.g. increase in water demand for generating increased volume of power supply etc.). Calculated with the Global Climate Model HadCM3, using the IPCC SRES A2 scenario.

Figure 8 Coastal lowlands (elevation below 5 metres) in Europe (EEA member countries)



Source: EEA, 2006, forthcoming.

3.2 Vulnerability of socio-economic sectors

3.2.1 Tourism

With growing income and increasing leisure time, the tourism industry in Europe is expected to continue to grow. At present, predominant tourist flows are from north to south, which helps to transfer capital. But under changing climate, if summer heat waves increase in frequency or if prolonged droughts result in water supply problems and forest fires, existing tourist flows to the Mediterranean might be reduced.

Temperature rise is likely to change summer destination preferences and outdoor activities in northern Europe may become more attractive, while summer heat waves in the Mediterranean may lead to a seasonal shift in tourism from summer to spring and autumn (Parry, 2000). The Mediterranean coast of France, for example, would be less affected by climate change than Spain or Greece, where it is already warmer (Viner and Agnew, 1999). Mountainous regions could also become more attractive due to a potentially more comfortable climate (Ceron and Dubois, 2004). The European Atlantic coast could be adversely affected by an increase in winter rainfall. Health risks related to

Table 2 Potential impacts of a 1-m sea level rise in selected European countries. This assumes the 1990 situation with no adaptation or adaptation costs to protect the human population

Country	Coastal floodplain population		Population flooded per year		Capital value loss		Land loss		Wetland loss	Adaptation costs	
	# (k)	% total	# (k)	% total	USD (10^9)	% GDP	km^2	% total	km^2	USD (10^9)	% GDP
Netherlands	10 000	67	3 600	24	186	69	2 165	6.7	642	12.3	5.5
Germany	3 120	4	257	0.3	410	30	n.a.	n.a.	2 400	30	2.2
Poland	235	0.6	196	0.5	22.0	24	1 700	0.5	n.a.	4.8 + 0.4/yr	14.5 + 1.2/yr
Estonia	47	3	n.a.	n.a.	0.22	3	> 580	> 1.3	225	n.a.	n.a.
Ireland	< 250	< 5	< 100	< 1.8	0.17	0.2	< 250	< 0.3	< 150	< 0.42/yr	< 0.6/yr

Source: Nicholls and Klein, 2003b.

high temperatures might increase. Water shortages due to extended droughts will also affect tourism flows, especially in southeast Mediterranean where the maximum demand coincides with the minimum availability of water resources (see for more discussion on water shortage in the Mediterranean Appendix 1).

The coastal zone is the primary tourist resource of Europe, and associated tourist infrastructure is at risk from sea level rise, including unique tourist attractions such as the city of Venice (Perry, 2003). Tourist resources such as beaches, wetlands and estuaries are also at risk from sea level rise and temperature increase.

Rising temperature may also undermine the financial viability of the winter sports industry in Europe. Studies show that there is a statistically significant trend in snow-cover reduction in the Alps over recent years. It is suggested that a 3 °C rise in mean temperature would lead to a rise of 300 m in the winter snow line in the central Alps, and there will not be continuous winter snow cover below an altitude of 1 500 m (see Appendix 1).

3.2.2 *Human health care*

Climate change is likely to affect human health, either directly related to the physiological effects of heat and cold, or indirectly, for example, through the spread of vector-borne pathogens. An increase in these impacts has been observed over the recent decades in Europe (e.g. summer heat waves in 2003 alone claimed more than 20 000 excess deaths) (EEA 2004b; Hajat *et al.*, 2002; Koppe *et al.*, 2004). Such impacts are projected to become more pronounced under a changing climate.

Direct impacts on human health are mainly associated with extreme weather and climate events such as heat waves, cold spells and floods. Extreme hot or cold conditions can be detrimental to many human body functions and exposure to them has an important effect on daily mortality (Beniston and Diaz, 2004). Heat waves are projected to become more frequent and more intense, and hence the number of deaths might increase if no adaptation measures took place. The risk of excess winter death seems to be widely distributed among the elderly population in Britain. Cold spells are also a risk for warmer regions when they occur in conjunction with ecological disturbances, catastrophes or societal conflicts, such as the war in Bosnia (WHO European Centre for Environment and Health, 2004). Fewer cold spells under a warmer climate are likely to reduce the number of cold-related deaths.

Increasing intensity of heavy rainfall is likely to make extreme floods more frequent in some areas of Europe. The number of deaths can be particularly high during sudden flash floods. Flood events cause physical (e.g. injuries) as well as mental (stress and depression) disorders. Water- and food-borne diseases could increase under a changing climate, particularly when water availability decreases and high temperatures affect the quality of food. Furthermore, the seasonality of allergic disorders may change due to a shift in the flowering period of plants.

The health impacts of the 2003 heat-wave in France — the hardest hit country in Europe — are summarised in Box 2.

The human health impacts of the heat-wave and the cold-waves of 2003 and the flooding in 2002 were summarised at a WHO symposium on human health responses to extreme weather and climate events (see Box 3).

The projected rise in temperature is likely to increase the geographical extent of ticks and the infestation of areas currently tick-free. These diseases are of

Box 2 Health impacts of the 2003 heat-wave in France

A heat-wave struck France in early August 2003. Daily minimum, maximum and average temperatures during the period of 4 to 12 August broke all historical records since 1873 for Paris. The heat-wave was associated with high levels of air pollution. There were 14 802 excess deaths between 1 and 20 August, compared with the average daily mortality for the same period in 2000 to 2002. This represents an increase of 60 % in mortality from all causes, and the worst health crisis since World War Two. The elderly (above 75 years of age) experienced a 70 % increase in mortality. Excess deaths among women were 15~20 % higher than men and mortality rates were highest in nursing homes, where twice as many deaths occurred as expected.

Source: WHO European Centre for Environment and Health, 2004.

Box 3 Human health impacts in Europe of the heat-wave and of the cold-waves occurring in 2003 and of the flooding in 2002

- During the severe heat-wave that affected much of western Europe in summer 2003, 75 year old women and older were at highest risk.
- Winter mortality is still higher than summer mortality, while some of the winter time excess deaths relate to hypothermia, the greatest component is due to respiratory and cardiovascular diseases.
- Flooding in 2002 caused serious re-organisation of health care services and required advice on hygiene and immunization by health authorities.
- Fatalities are often caused by entrapment in automobiles and behaviours that clearly disregard dangers. Other health effects included gastrointestinal infections due to contamination of food and water, and psychological effects.

Source: WHO European Centre for Environment and Health, 2004.

increasing importance, in many parts of Europe. An increase in cases of tick-borne diseases has been observed since the 1980s in the Baltic, central European countries, and Russia (Izmerov *et al.*, 2004; Lindgren and Jaenson, 2004; Randolph, 2004). However, due to lack of knowledge on causal relationships between climate change and increases in ticks, the future projected rates of tick activity and infection could not be estimated. Climate-induced changes in the potential distribution of malaria are projected mainly in poor and vulnerable regions. In Europe localised outbreaks are expected in areas where the disease has been eradicated, but vectors (in particular, *Plasmodium vivax)* are still present (Reiter *et al.*, 2004).

The impacts of climate change on human health are being exacerbated by reduced environmental quality in ambient air and natural ecosystems, increases in aeroallergens and by other factors such as water- and food shortage and changes in agrochemical use.

Finally, vulnerability of populations is highly dependent on current and future public health care systems. Difficult economic conditions during the past decade had serious implications for the delivery of health care and the public health infrastructure in some countries in central and eastern European countries. These countries are particularly vulnerable to potential health impacts of climate change.

3.2.3 Energy

Energy industries are the single most important source for greenhouse gas emissions in Europe. They contribute 29 % of total emissions in western Europe, 42 % in the new accession countries and about 20 % in Eastern European (EEA, 2003).

Studies have demonstrated that energy demand is linked to climatic conditions (Sailor, 2001). Electricity usage and demand in Europe have been rising steadily since the mid-1990s and this trend is expected to continue (EEA, 2004a). Throughout Europe, but particularly in southern Europe, energy demand, especially for air conditioning, is likely to increase in the warmer seasons (Giannakopoulos and Psiloglou, 2004; Majithia, 2003; Valor *et al.*, 2001). However, this increase will be partly compensated for by global temperature increases which will lead to a reduced demand for heating in the winter.

Climate change may also alter the seasonal cycle in energy demand, with lower demand in winter and higher in summer. A specific temperature at which energy demand is at a minimum can be identified (for example, 22 °C in Athens) (Giannakopoulos and Psiloglou, 2004). This temperature value is expected to be lower in the north of Europe. Extreme temperature events have an impact on daily peak power demands primarily through increased use of air conditioning. Thus more frequent hot spells projected under a warmer climate would increase energy demand. Such extra power demand could cause transmission lines to sag, hence stressing the effectiveness and efficiency of the distribution system (Colombo *et al.*, 1999).

Other climate variables also affect energy demand. In the United Kingdom energy demand is also affected by heavy precipitation and by the cooling power of the wind (Majithia, 2003). An increase of 10 knots in wind speed in winter is associated with a 4 % increase in demand. Moreover, cloud cover can give a 4–5 % rise in demand (Majithia, 2003).

Climate change induced water resource change is expected to affect energy production in Europe, directly through impacts on hydropower production and indirectly through limits to water supply for cooling power plants. Hydropower makes up a significant percentage (about 20 %) of the total installed capacity for electricity generation in Europe (European Commission, 2000). This capacity may be expanded especially in southern and eastern Europe to provide electricity for economic growth (Alcamo *et al.*, 2001). It is however estimated that, the gross hydropower potential (11) would decrease from the present level of 2500 TWh/a to 2400TWh/a in the 2070s, under the HadCM3 simulated climate scenarios. A decrease of 25 % or more is projected by the 2070s for hydropower potential of about 6 000 European power plants in southern and south-eastern Europe (see Figure 9) (Lehner *et al.*, 2001).

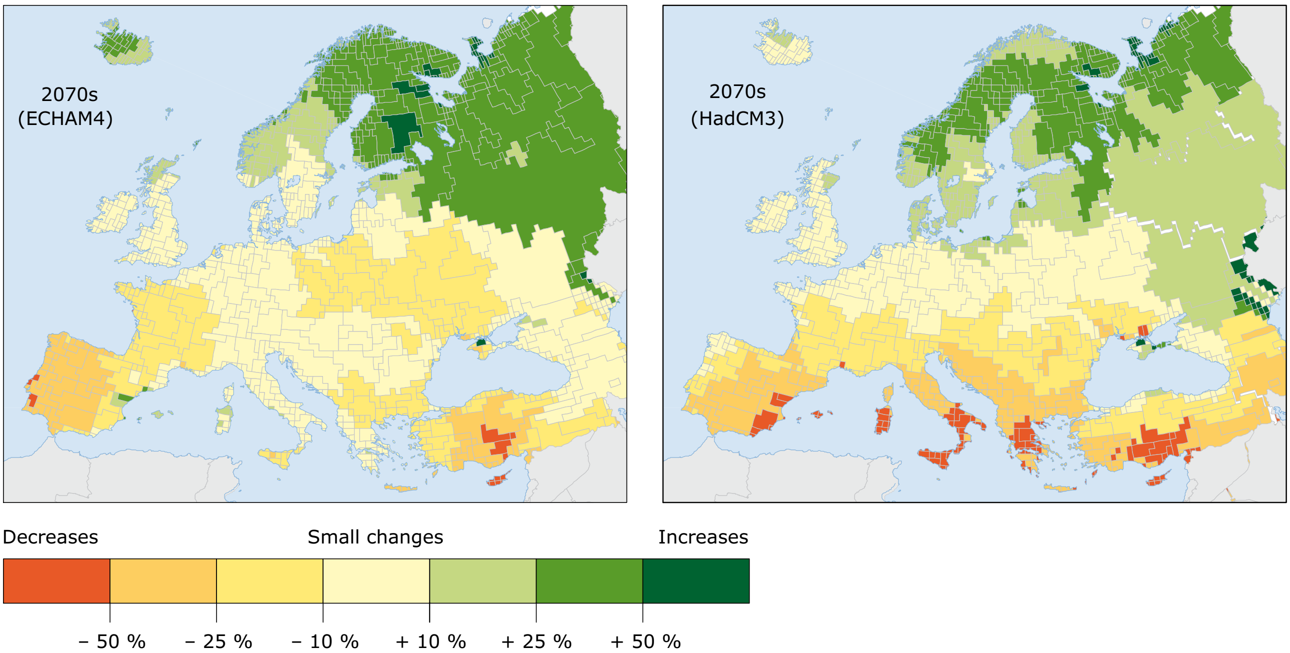
3.3 Conclusions

3.3.1 Key vulnerability issues

The following conclusions can be drawn in relation to the key vulnerability issues for Europe's natural environment and its society:

- Europe's natural environment and associated services, its production systems (agriculture, fisheries, forestry, terrestrial ecosystems) and other key socio-economic sectors (tourism, energy and human health care) are under pressure from environmental change and socio-economic development. Climate change is an additional pressure and impacts of changing climate on the environment and society are observed across the region.
- Projected changes in climatic conditions (including extremes and sea level rise), compounded by other environmental changes and ongoing socio-economic development, are expected to have wide ranging impacts on natural and human systems in Europe. Some of the impacts will be positive for certain regions or sectors. Many impacts are, however, highly adverse, and often fall onto systems and regions already under pressure from other environmental change and development processes.
- South-eastern and the Mediterranean are likely to be Europe's most vulnerable regions. This is because of impacts of current and projected climate change on especially water resources,

Figure 9 **Projected change in annual average river discharges for European river basins in the 2070s compared to 2000**



Note: Two different climate models are used.

Source: Lehner *et al.*, 2001.

(11) Gross hydropower potential is defined as the annual energy that is potentially available when all natural runoff at all locations could be harnessed down to sea level without any energy losses regardless whether there currently is a power station or not (Alcamo *et al.*, 2001 and Lehner *et al.*, 2001).

agriculture, tourism and public health care. Future trends in economic, social, institutional, and technological development in these regions also need to be taken into account.

A summary of vulnerability by sector and by country is given in Appendix 2.

3.3.2 *Limitations of vulnerability assessments and further needs*

Many research programmes and projects have been undertaken to assess the characteristics of climate change, its potential impacts on natural and human systems. Relatively recent research efforts have been initiated to assess the adaptive capacity of the natural environment and society, and identify and evaluate adaptive responses to reduce the vulnerability of natural and human systems. Most of the existing assessments have so far followed the standard IPCC scenario-based approach (Carter *et al.*, 1994; Parry and Carter, 1998). Within this framework, climate, non-climate, and socio-economic scenarios are developed and applied to sectoral impact models. Two issues are crucial to this approach, namely, the development and application of sectoral impact models and the development and application of scenarios.

Sectoral impact models are often developed within a single disciplinary context (e.g. crop physiology, hydrology etc.), rarely considering the interactions between climate and other non-climate factors within the modelling unit. Although sectoral models bring with them a wealth of knowledge in specific subject areas, such models often fall short in allowing additional drivers to be considered, hence making cross-sectoral integrated assessment very difficult, if not impossible. Furthermore other, e.g. social, processes determining vulnerability are not easy to describe and analyse in a formal, quantitative modelling framework. Therefore, other methods and tools rather than computer models are needed to enhance understanding of vulnerability to climate change.

To provide input for impact assessments, most studies derived climate scenarios from general circulation model (GCM) simulations. Such models are usually resolved at a much coarser resolution (typically a few hundred kilometres) than what is required by impact and vulnerability assessment. Therefore, where resources and capacities exist, assessments applied different downscaling techniques to interpret GCM results. Europe is leading research on regional climate modelling and quantifying uncertainties of climate projections (e.g. EU-funded PRUDENCE and ENSEMBLES projects, see Table 5). However, regional climate modelling is highly demanding in resource and technical capacity. Its development and application are currently rather limited to a few well-resourced and equipped climate centres in Europe. In addition to the issue of spatial resolution, temporal resolution of climate scenarios is also a major barrier to robust vulnerability assessment. The most profound impacts of climate change are caused by changes in the frequency and/or intensity of extreme weather events, rather than changes in mean values. But the current generation of GCMs has rather limited capacity in providing such detailed information on extreme weather events. Therefore, while progress is being made to improve the regional precision of climate change scenarios, it is equally important to develop robust techniques and guidance for creating climate scenarios at finer spatial and temporal resolutions, preferably with probabilities attached. These scenarios prove to be more desirable for robust vulnerability assessment and for informing adaptation planning.

In addition to climate scenarios, most assessments also require socio-economic scenarios. The IPCC Special Report on Emissions Scenarios (SRES) has been a common source for deriving such socio-economic futures. Since SRES is a global exercise, it does not provide national or sub-national details on key socio-economic trends. Consequently, most studies adopted different methods and techniques to 'downscale' SRES socio-economic scenarios. Without clear guidance and detailed local datasets, there is a large uncertainty in the final assessment results, partly associated with such 'downscaling' procedures. Therefore, there is a need for developing local socio-economic and environmental scenarios consistent with the global (SRES) scenarios.

Moreover, knowledge is still limited on the nature and impacts of abrupt climate change. Such extremes include an abrupt cessation of the North Atlantic thermohaline circulation (THC) leading to climatic cooling over northwest Europe, or the disintegration of the West Antarctic Ice Sheet (WAIS) causing rapid global sea-level rise. Despite the potentially high magnitude of impacts that these abrupt changes could lead to, the scientific understanding of the mechanisms required to trigger these events is currently poor. Therefore, further research is required to better characterise such abrupt changes and their impacts in Europe.

Furthermore, 'traditional' impact assessments fall short in providing information relevant to adaptation decision making. Information is needed on issues such as 'how much of the (adverse) impacts can our natural environment and society cope without taking deliberate action?' i.e. the issue of adaptive capacity; 'what are the adaptation hotspots in a country/region/sector?' i.e. the issue of developing transparent and quantitative vulnerability indices. Therefore, assessments need to go beyond the characterisation of potential impacts and move towards the development of operational adaptive capacity and vulnerability indices.

Education and engagement of stakeholders has a primary role to play in establishing a foundation to build equitable and sustainable strategies for adapting to climate change (Eisenreich, 2005). One way to engage stakeholders is to involve them in various stages of vulnerability and adaptation assessment, e.g. developing socio-economic scenarios, identifying key climatic thresholds, reflecting on past experience of extreme weather events and their impacts, and identifying and analysing adaptation options. As part of the assessment process, some studies included a stakeholder involvement component. However, most of such exercises involve stakeholders at the very end of the assessment focusing on dissemination of research findings. But in order to ensure the maximum relevance of climate change assessment to stakeholders, techniques and tools are needed to facilitate active engagement of the stakeholders.

4 Adaptation to climate change impacts in Europe: country perspectives

4.1 Introduction

This section provides a review of adaptation responses being implemented and/or planned in EEA member countries. These responses are aimed at facilitating information exchange and experience sharing among member countries.

As a region of industrialised nations, Europe has a strong commitment to mitigating climate change by reducing greenhouse gas emissions. However, numerous scientific studies, as summarised in Section 3 of this report, and the considerable losses resulting from extreme weather events over recent years (EEA 2004a; see Table 3 for UK examples) demonstrated the vulnerability of Europe's natural environment and its society to projected climate change impacts. There is growing recognition that Europe should adapt to such impacts in order to maintain sustainable functioning of ecosystems and wellbeing of its population. Many EEA member countries have started to adjust their overall national climate policy framework to include climate change adaptation as an equally important component as mitigation. A wide range of adaptation responses have been initiated at varying governmental levels and in different sectors.

Information on existing and planned adaptation measures in EEA member countries was compiled and collated from several national information sources, in particular national communications to the UNFCCC and responses to a questionnaire sent by EEA to the National Focal Points (see Appendix 3). Eighteen countries and the European Commission's Joint Research Centre provided information on the characteristics (e.g. scientific basis, policy relevance, institutional arrangement, key stakeholders and their roles) of existing and planned adaptation initiatives in their respective countries ([12]) (Table 4).

The amount of information and level of details on adaptation initiatives vary considerably between these responses. Some (e.g. the Netherlands, the United Kingdom, Norway, Austria) contain comprehensive and in-depth accounts of wide ranging adaptation activities while others merely point out that adaptation is still at its early stage of development. Some countries (e.g. Sweden, Germany, the Netherlands) also provided insights into the major challenges and opportunities for making progress in climate change adaptation. Such diverse responses could partially be explained by the fact that countries are at widely varying

Table 3 Economic impacts of recent extreme weather events in the United Kingdom

1987	Hurricane-force winds caused over GBP 1.2 billion in property damage, giving rise to 1 million claims in a single day.
1990	Storms and coastal flooding in January and February led to GBP 2.1 billion in insurance claims, the highest figure for weather related claims to date. Over a 4 week period 3 million claims were received.
1995	Following the hot, dry summer subsidence claims rise to GBP 3 226 million in 1995 and GBP 333 million in the following year. It is difficult to disentangle subsequent claims from other contributory factors, including dry conditions in 1997. However, claims remained at a raised level until 2000.
1998	Easter floods in 1998 led to the evacuation of 1 500 people from their homes, and a cost to the insurance industry of around GBP 500 million.
2000	The United Kingdom experienced its wettest autumn for almost 300 years, with heavy rainfall leading to damage of 10 000 properties, and nearly GBP 1 billion in insurance claims.
2003	The United Kingdom experienced its hottest summer temperatures on record, leaving insurers with close to GBP 400 million in subsidence claims in that year alone.

Source: ABI, 2004.

([12]) Information on adaptation measures included in such national responses are not meant to be exhaustive, as the institutions/personnel providing responses are not always aware of the many individual and local initiatives that have taken place within their respective countries.

Table 4 Responses to the questionnaire

Country/institution	Responding agency/group	Date of response
Austria	Austrian Federal Environmental Agency	03/12/04
Belgium	Environmental Agencies	
Bulgaria	Executive Environment Agency	29/10/04
Czech Republic	1. Czech Environment Institute 2. Czech Hydrometeorogical Institute	1. 06/12/04 2. 16/12/04
Denmark	Danish Environmental Protection Agency	10/01/05
Finland	EEA NFP	1/11/04
France	ONERC	07/12/04
Germany	Federal Environmental Agency	30/11/04
Hungary	EEA NFP	5/11/04
Institute for Environment and Sustainability, DG Joint Research Centre, EC	Land Management Unit	30/10/04
Ireland	EPA Regional Inspectorate	12/01/05
Italy	EPA	20/12/04
Latvia	Ministry of Environment	28/10/04
Netherlands	Wageningen University and Research Centre (upon the request of the Ministry of Agriculture, Nature Conservation and Fishery)	01/12/04
Norway	CICERO	26/10/04
Slovenia	Ministry of the Environment, Spatial Planning and Energy	28/10/04
Sweden	EPA	8/12/04
Switzerland	Swiss Agency for the Environment, Forests and Landscape (SAEFL)	9/11/04
United Kingdom	1. DEFRA 2. Environment Agency	1. 03/11/04 2. 11/11/04

stages in adapting to current and projected climate change impacts. Therefore, it would be beneficial for countries to exchange information, share experience and learn lessons from each other.

This section begins with an overview of national policy frameworks for adaptation in Europe (Section 4.2). Section 4.3 reviews the major research programmes on various aspects of climate change adaptation in the EU and member countries. Adaptation measures in member countries are reviewed in Section 4.4, using the key vulnerability issues identified in Section 3. These include policies and measures to sustain the functioning of natural ecosystem in Europe (Section 4.4.1); strategies to manage increasing stress on Europe's water resources (Section 4.4.2); plans and actions to address increasing flood risks (Section 4.4.3); measures to prevent and manage climate change related natural hazards (Section 4.4.4); policies and measures to address human health risks projected under a changing climate (Section 4.4.5); and strategies for business community to moderate losses and benefit from opportunities associated with climate change (Section 4.4.6). The Section concludes with a summary of existing and planned adaptive responses in Europe.

As discussed in Section 3, sectors/systems vulnerable to projected climate change impacts and vulnerability level vary from country to country. Coastal and low-lying countries in the northwest, for example, are more likely to be threatened by coastal flooding hence coastal defence and flood management are taken as their adaptation priority. Therefore, countries are only featured in the sections dealing with their adaptation priority areas in Section 4.4.

4.2 National policy frameworks for adaptation

As adaptation resumes increasing significance on national policy agenda in Europe, governments are actively being engaged in revising existing and/or developing new national policy frameworks directed towards adaptation.

Supported by scientific research, a few countries have approved or are close to launching their national adaptation policy frameworks.

In the **Czech Republic**, adaptation measures identified by the research have been included into the National Climate Change Action Plan. These measures were approved by the Government in March 2004. Adaptation strategies and measures have been given similar importance as mitigation strategies. The National Program sets out the framework and responsibilities for adaptation measures to be developed and implemented by the

Box 4 Finland prepares to adapt to climate change

A wide-ranging strategy for adaptation to climate change has been proposed by Finland's agriculture and forestry ministry. It recommends that long-term investments should already consider likely impacts of global warming, particularly in the construction, hydropower, transport infrastructure and forestry sectors.

For agriculture and forestry, in particular, the strategy suggests that in the short term economic benefits of climate change may outweigh disadvantages due to longer growing seasons and increasing plant productivity. However, it warns that negative impacts could grow more serious in the longer term.

Elements of the proposals will be incorporated into a national climate strategy due to be published in 2005.

relevant sectoral ministries: Ministries of Agriculture and Environment for adaptation measures in water management and forestry; Ministry of Health for actions in the public health sector ([13]).

In **Finland,** the Parliament requested the Government to draft a programme for adaptation to climate change. This programme should be integrated into the revised National Climate Strategy, which was approved by the Parliament in 2001. The Strategy is currently under revision and should be re-launched in 2005 (see Box 4). In co-operation with four other ministries (Finance, Transport and Communications, Trade and Industry, and Environment), the Ministry of Agriculture and Forestry has the lead responsibility in coordinating the Adaptation Programme.

Adaptation to climate change is formally on the national climate policy agenda of **France** since the publication of the 'Plan Climat' on 22 July 2004 by the Minister of ecology and sustainable development. It has been decided within this new programme that a strategic plan on adaptation to climate change is to be proposed by ONERC ([14]). This strategy may lead at a later stage to a national programme on adaptation.

Recognising the commitment of all Parties to the UNFCCC to formulate, implement, publish and regularly update national programmes containing measures to facilitate adequate adaptation to climate change, the **German** government has decided to develop a comprehensive national adaptation concept. The need for such an implementation oriented strategy as well as essential requirements are explicitly emphasized in the revised German Climate Protection Programme 2005. A research programme focusing on adaptation to climate change accompanies and supports the development of the national strategy. A vulnerability assessment was prepared presenting the main vulnerable regions and sectors in Germany (Zebisch, *et. al*, 2005*).* These results may be used as input to the development of climate change adaptation strategies in Germany.

Denmark intends to launch its national adaptation policy framework in 2005.

In the **United Kingdom,** consultation started in November 2005 on a first national adaptation policy framework (APF), which aims to develop a better understanding of climate change adaptation across the United Kingdom. It should provide stronger strategic direction by setting agreed cross-cutting objectives and measuring progress. It should also ensure that adaptation to climate change is integrated into the wider policy making process. Responses to the consultation will be collated in 2006 and used to develop a picture of adaptation across the United Kingdom.

In a report compiled by the UK Climate Impacts Programme (West and Gawith, 2005a) climate impacts and emerging adaptation options in the United Kingdom are presented. Various tools have been developed within UKCIP, such as the UKCIP adaptation wizard and the risk, uncertainty and decision making framework. These tools help stakeholders set realistic adaptation goals and recognize and manage the risks associated with a changing climate.

In **Portugal**, a national strategic plan for adaptation is being developed, based on the findings from the

([13]) Source: Third national communication of the Czech Republic to the UNFCCC — http://unfccc.int/resource/docs/natc/czenc3.pdf
([14]) Observatoire national sur les effets du réchauffement climatique en France métropolitaine et dans les départements et territoires d'outre mer, http://www.onerc.gouv.fr.

SIAM project. Also **Spain** is considering developing plans for adaptation, based on an extensive preliminary assessment of the impacts of climate change. This will be finalised in 2005. Recent research programmes may lead to the preparation and legal approval of a national adaptation strategy in **Hungary.**

For countries where there is not a formal national adaptation policy framework the importance of and need for climate change adaptation are stated in governmental documents. For instance, the **Norwegian** government White Paper no. 25 (2002–2003) indicated that impacts and adaptations are key issues for future settlement in Norway. The Arctic environment is emphasised as particularly vulnerable. The latest **Dutch** Water Policy (Ministry of Transport, Public Works and Water Management, 2000) incorporates the objective of addressing climate change impacts and recognises the need for adaptation in water management.

Despite the absence of an explicit national adaptation policy framework, adaptation measures and activities are taking place in many countries, often in the contexts of natural hazard prevention, environment protection, and sustainable resource management. These measures are often initiated on an ad-hoc basis. These measures are usually initiated with a sectoral view (e.g. water resource management) and implementation by different sectors and organizations (e.g. local authorities), and often prompted by the impacts of recent extreme weather events. This represents the situation in most EEA member countries, such as **Austria, France, Sweden, the Netherlands, Belgium, Italy,** and **Switzerland.**

Hindered by the uncertainties associated with the science of climate change and its impacts, countries like **Iceland** have so far given minimum attention to adaptation ([15]). Similarly, climate policy in **Bulgaria** has been focusing on mitigation (i.e. meeting Kyoto targets) and compliance with EU regulations. Adaptation to climate change has not received much attention because other issues are considered to be more important at present ([16]).

Regarding the institutional arrangements for adaptation, some countries (e.g. **the United Kingdom, Finland, Denmark** etc.) have appointed ministries to lead the co-ordinating role in developing and implementing sectoral adaptation strategies in close collaboration with other ministries (e.g. Ministry of agriculture for adaptation in the agriculture sector). This ministry usually appointed to take the leading role is the Ministry of Environment. However, in most cases countries do not yet have a governmental body to do this. Instead, programmes and plans are initiated from single sectors and/or ministries. However, this arrangement appears to be less than effective. For example, since different sectors involved in the coastal zone management often have different decision priorities, it is very difficult to implement integrated coastal zone management strategies. Therefore, it is important to improve collaboration between coastal planning to deal with possible future impacts, and coastal defence for the preservation of the present situation ([17]).

Finally, in order to fully implement adaptation plans in some sectors, for example, water resources, international collaboration in the region is important. In this regard, the EU flood prevention and management action plan, which is currently under development, would ensure co-ordinated efforts for flood prevention and management in Europe ([18]). **The Netherlands** has reported that due to its high level of dependence on activities in the upstream countries in the relevant river catchments, trans-boundary cooperation is taking place with neighbouring countries to implement measures ([19]). Such trans-boundary institutional arrangements for addressing adverse climate impacts are also emerging in other countries, e.g. in the Alpine Convention Framework and its Protocols (see Appendix 1). In addition, networks such as 'DYNALP' ([20]) and 'Eurocities' ([21]) help to discuss and establish more sustainable concepts for tourism and transport and may help to implement mechanisms for adaptation and mitigation to global change. CIPRA and other NGOs support these processes by offering a wealth of information through workshops, reports and by incorporating sustainable targets into policy and planning. Adaptation efforts in countries of the Mediterranean to address drought risk could benefit from a similar regional institutional framework, whereby knowledge and experience could be shared and enhanced (see Appendix 1).

([15]) Source: Iceland's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/icenc3.pdf).
([16]) Source: Bulgaria's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/bulnc3.pdf).
([17]) Source: Belgium's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/belnc3.pdf).
([18]) See http://www.europa.eu.int/comm/environment/water/flood_risk/index.htm for details.
([19]) Source: The Netherland's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/netnc3.pdf).
([20]) See http://www.dynalp.org/.
([21]) See: http://www.eurocities.org.

Table 5 Examples of international research projects in support of climate change adaptation in Europe

Project	Funding source(s)	Objectives	Participating European countries/ organisations	Policy relevance	Links to details
cCASHh (Climate Change and Adaptation Strategies for Human Health)	**EC (5th FP)**	(1) Identification of the vulnerability; (2) review of current measures, technologies, policies and barriers to improving the adaptive capacity; (3) Identification of the most appropriate measures, technologies and policies, and of the most effective approaches to implementation, for European populations to successfully adapt; (4) estimate the health benefits of specific combinations of strategies for adaptation; (5) estimate costs of damages and adaptation measures	WHO regional office for Europe; the United Kingdom, Sweden, Italy, Czech Republic, Germany, the Netherlands	Objectives (2) ~ (5) are all policy relevant	http://www.euro.who.int/ccashh
PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects)	**EC (5th FP)**	(1) To address and reduce the deficiencies in climate projections; (2) to quantify our confidence and the uncertainties in predictions of future climate and its impacts; (3) to interpret these results in relation to European policies for adapting to or mitigating climate change	Denmark, the United Kingdom, France, Germany, the Netherlands, Norway, Sweden, Spain, Finland, Switzerland, Czech Republic, Italy	By providing a better appreciation of the uncertainty range in calculations of future impacts from climate change, the project may offer new insight into the scope for adaptation and mitigation responses to climate change	http://prudence.dmi.dk
DINAS-COAST (Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of COASTal Zones to Climate Change and Sea Level Rise)	**EC (5th FP)**	To develop a dynamic, interactive and flexible CD ROM-based tool that will enable its users to produce quantitative information on a range of coastal vulnerability indicators, for user selected climatic and socio-economic scenarios and adaptation policies, on national, regional and global scales, covering all coastal nations	Germany, the United Kingdom, the Netherlands	The final product will be of practical use to policy-makers and other stakeholders	http://www.dinas-coast.net
ESPACE (European Spatial Planning: Adapting to climate Events)	**INTERREG IIIB; North West Europe Programme; the UK Office of the Deputy Prime Minister**	(1) to develop a dynamic transnational approach to adaptation to climate change within spatial planning mechanisms which can be implemented by the Partners; (2) to recommend a suitable approach at European, national, regional and local levels	The United Kingdom, Belgium, the Netherlands, Germany	Objective (2) is directly linked to inform policy decision for spatial planning adaptation	http://www.espace-project.org/index.htm
ENSEMBLES	**EC (6th FP)**	(1) to develop an ensemple prediction system for climate change; (2) to quantify and reduce uncertainty in the presentations of processes and feedback in the Earth System; (3) to maximise the exploitation of the results	66 partners from across the EU, Switzerland, Australia, USA	The final output of the project, an objective probabilistic estimate of uncertainty in future climate should be of direct relevance to adaptation	http://www.ensembles-eu.org

4.3 Enhancing scientific capacity for adaptation

As a cross-cutting adaptive response to climate change, a large number of regional and national research programmes have been undertaken to develop and/or advance the knowledge on the characteristics of climate related risks and strategies to manage them, in multiple sectors and at different scales. A large body of knowledge and information has resulted from these efforts, especially on the trends of past climate, projections of climate change in the 21st century, potential impacts of such projected changes on different sectors, systems, communities and regions, and possible options to adapt to projected changes and their impacts.

A selection of major international projects and national research projects in support of climate change adaptation are presented in Tables 5 and 6, respectively. A more comprehensive list of national research programmes on various aspects of climate change are summarised in (Gabriel *et al.*, 2005).

In response to the growing need for improved knowledge and guidance for adaptation planning and decision-making, research efforts have been gradually moving from scientific driven, single sector/system-focused sensitivity analysis (i.e. to answer questions, such as: 'Is climate changing now?', 'Does climate change matter in my sector of responsibility?' etc.) towards a more policy-driven, multi-disciplinary integrated assessment (i.e. to

Table 6 A selection of national research projects/programmes in support of climate change adaptation in EEA member countries

Country	Programme/project	Funding agency	Links for details
Finland	FinADPT (Assessing the adaptive capacity of the Finnish environment and society under a changing climate)	Ministry of the Environment	http://www.environment.fi/syke/finadapt
France	GICC	Ministry of the Environment	
Germany	Fona – part: Research for Climate Protection and Protection Climate Impacts	Federal Ministry of Education and Research	http://www.fona.de/eng/1_research/industry_business/climate_protection/index.php
Hungary	VAHAVA (Impacts and responses concerning global climate change in Hungary)	Ministry of Environment and Water; Hungarian Academy of Sciences	http://www.vahava.hu
The Netherlands	1. NRP-CC (National Research Programme on Global Air Pollution and Climate Change) 2. BSIK-KvR (National Research Program 'Climate changes Spatial Planning')	National Government, co-financed by project partners including the private sector	http://www.klimaatportaal.nl
Norway	NORKLIM (Climate Change and Its Impacts in Norway)	Norwegian Research Council	http://www.forskningsradet.no/servlet/ContentServer?pagename=norklima/Page/HovedSide&c=Page&cid=1088796719022
Portugal	SIAM (Climate Change in Portugal, Scenarios, Impacts and Adaptation Measures – Phase II)	Ministry of Cities, Spatial Planning and the Environment	http://www.siam.fc.ul.pt
United Kingdom	UKCIP (UK Climate Impacts Programme)	Department for Environment, Food and Rural Affairs (DEFRA)	http://www.ukcip.org.uk
Sweden	COPE	Environmental Agency	
	SPCC	Nat. Research Council	
Spain	ECCE (Preliminary Assessment of the Impacts in Spain due to the Effects of Climate Change)	Ministry of the Environment	http://www.mma.es/oecc/ccespana/cce_ia.htm (Spanish) http://www.mma.es/en/oecc/ccespana/cce_ia.htm (English)

Box 5 FINADAPT: Assessing the Adaptive Capacity of the Finnish Environment and the Society under a Changing Climate

The FINADAPT Consortium seeks to address both scientific and policy needs by conducting the first in-depth investigation of the adaptive capacity of the Finnish environment and society to the potential impacts of climate change. The Consortium is being funded for the period 2004–2005 as part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment.

The primary objective of FINADAPT is to produce a scoping report on vulnerability and adaptive capacity under a changing climate in Finland. The report:

- outlines knowledge about current climate variations;
- describes future changes in climate and other environmental and socio-economic factors projected for the 21st century;
- characterises adaptive capacity to cope with present-day climatic conditions;
- provides estimates of potential impacts under future climate change, including costs where appropriate;
- lists potential measures/strategies for adapting to climate change (including costs);
- assesses the relative vulnerability of different systems, regions, sectors or communities to climate change, identifying priority areas for attention;
- identifies the major gaps in knowledge and needs for new research;
- distils the major findings in a summary for policy makers.

Source: SYKE, 2004.

address issues like 'What are the likelihoods of critical thresholds being exceeded under a changing climate?', 'How to best manage climate risks in a cost-effective fashion?' etc.). Hence, not only have the research questions been directed more closely towards policy issues, the approach of such research activities has changed to include a strong stakeholder involvement component. An example of such a policy-oriented research initiative from Finland (FINADAPT) is given in Box 5.

Although progress is being made in assessing vulnerability and adaptive capacity, several aspects are not sufficiently studied. These include processes of adaptation decision-making, conditions that stimulate or constrain adaptation, the roles and responsibilities of varying stakeholders in adaptation process, and the role of non-climatic factors. A robust methodological framework for evaluating adaptation options is still to be developed (see Section 5.1.2).

4.4 Adaptation measures to address key vulnerability issues

Recognising the potential threat from climate change to achieving sustainable development, a wide range of actions are being taken, deliberately or not deliberately, to avoid or reduce adverse impacts, and to take advantage of beneficial impacts of climate change. This section reviews adaptive responses in member countries in relation to natural ecosystems, water resources, coastal and river floods, natural hazards, human health and the business sector.

4.4.1 Maintaining the health of Europe's ecosystems

To address the wide ranging adverse impacts of climate change to Europe's terrestrial ecosystems, a variety of measures have been initiated or are being planned. This is often carried out in the context of nature conservation and sustainable resource management rather than deliberately directed at adapting to climate change.

Liechtenstein, is highly dependent on the stability of its ecosystems as it is a mountainous country. This has strongly motivated the introduction of an active national climate policy and the participation of the country in international processes, such as the Alpine Convention. Strategies to address climate change as a new risk are largely of a regulatory nature and are all designed primarily to address the issues related to sustainability, i.e., by introducing sector-oriented legal documents, such as the Nature and Landscape Protection Act (1996); the Forest Act (1991); the Preservation and Protection of Agricultural Lands Act (1992); the Ordinance on the integrated rehabilitation of the Alpine and mountain regions (1968) and the revised Tourism Act (2000) ([22]).

In **France,** forest managers have been working on measures to improve the resilience of forests since the storms of December 1999 and the drought conditions associated with the 2003 heat wave. It is considered most important to develop a larger biodiversity among forest stands with more diverse varieties and through more genetic diversification. It is also necessary to install or regenerate species which are better adapted to present and future local conditions, so that they are more resilient to biotic and abiotic environmental conditions. Tools are being elaborated in order to improve the choice of species. More dynamic forest management practices with wider spacing and strong and early thinning can reduce vulnerability to wind storms and at the same time improve the water budget and therefore resistance to drought conditions. Better forest management practices and the presence of understory vegetation increases biodiversity and soil protection improves recycling of mineral elements and reduces mineral leaching. Development of heating plants or district heating using wood has been proposed in order to mitigate climate change. This would also help to utilise forest residues after storms and decrease the regeneration cost of damaged forests.

As a means to implement the Habitats Directive 92/43/EEC, the **German** Federal Nature Conservation Act (of 25 March 2002) states that the Federal Laender shall establish a network of interlinked biotopes covering at least 10 % of the total area of each Federal Land. The required core areas connecting areas and connecting elements shall be legally secured via the designation of appropriate areas, detailed planning in accordance with the provisions of planning law, long-term arrangements (contractual nature conservation) or other appropriate measures. This is intended to safeguard an interlinked network of biotopes in a sustainable fashion. Such a network of interlinked biotopes is particularly important and represents a

([22]) Source: Liechtenstein's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/licnc3.pdf).

dynamic response of ecosystems to global change to protect biodiversity.

In their national communications, many countries reported their concerns over issues such as goods and services of terrestrial ecosystems (e.g. timber production, biodiversity etc.) that may be threatened under a changing climate. But very few countries go beyond the list of general adaptation options for forest management and biodiversity protection. Emerging from this is the inadequacy of knowledge on potential impacts in terrestrial ecosystems and practical guidance for adaptation.

In addition, some multi lateral initiatives have been taken in order to establish a stronger (i.e. 'climatically robust') network of ecological areas within Europe. An example of such an initiative is the Pan-European Ecological Network PEEN ([23]).

4.4.2 Managing Europe's water resources

Rising temperature and changing rainfall patterns are expected to change the availability of water resources in Europe.

The integrated management plans for water resources in **Spain** constitute one component for adaptation to climate change. The National Water Plan, Law 10/2001 of 5 July (Analysis of Water Systems) accounts for potential climate change induced reduction in water availability and analyses the effect of these reductions on management and planning.

Drought mitigation has been recognised as a national priority for **Hungary**. The improvement of drought forecast, for example, through development of reliable drought indices is recommended as an important adaptation measure. A national drought mitigation strategy is to be developed ([24]).

In **Greece**, an integrated water management plan is considered imperative to address the present day problem of low water use efficiency, which results from the combination of irrigation and cultivation practices. The preparation for the full implementation of this plan has started. Cross governmental departments have drafted a legislative framework for its implementation ([25]).

In the **Netherlands**, climate change and adaptation measures are explicitly integrated into the water policy agenda. Emphasis is placed on 'no-regret' strategies. Although flood risks seem to dominate the adaptation agenda in water policy, the increased risk of dry spells and water shortage are also recognised. The spatial implications of the Cabinet's position on water management and the associated adaptation measures have been incorporated in the Dutch Spatial Policy. Inclusion in the policy for Rural Areas offers an opportunity to combine the implementation of measures in rural areas for increased safety and flood prevention with measures for such objectives as improving water quality, combating dropping water-tables, reconstructing rural areas and improving the ecological infrastructure.

Organizations involved in providing water services also started to explore the implications of climate change in terms of vulnerability and options for adaptation. The **Norwegian** Water Resources and Energy Directorate is an example. In the **United Kingdom**, organizations in the water resources sector are also taking actions to prepare for a changing climate ([26]).

4.4.3 Protecting people and infrastructure from coastal and river floods

Coastal and low-lying areas constitute a substantial part of Europe. With changing rainfall pattern (including extremes) and global warming induced sea level rise, a number of countries will be facing increased risk of coastal and river flooding. Benefiting from the long tradition of dealing with extreme weather events, flood defence is among the areas with best developed adaptive measures. Policies, guidance documents, regulations, and even concrete technical adaptation actions have been developed at the EU, national, and sub-national levels. Some of these measures are not deliberately designed for adaptation to long-term climate change impacts, though. Instead, they are developed for addressing short-term extremes.

At **EU** level, a flood prevention and management action plan is being developed. EU Environment Ministers asked the European Commission to table a formal proposal for the plan, which will be based on solidarity and will make provision for an early warning system, integrated flood basin and flooding management plans and the development of flood risk maps. The plan includes a possible future Floods Directive.

([23]) See: http://www.ecnc.nl.
([24]) Source: Hungary's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/hunnc3.pdf).
([25]) Source: Greece's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/grenc3.pdf).
([26]) See: http://www.bitc.org.uk/resources/case_studies/severntrentcca.html.

Box 6 Changing flood risk management policy guidance for adapting to climate change

UK Department for Environment, Food, and Rural Affairs (Defra) periodically reviews and updates its flood management policy guidance. It takes into account new information on climate change projections and their impacts.

For coastal flood management, an allowance of 4.5 mm p.a. was adopted for the next 40–50 years plus adjustments for local land movements (MAFF, 1999). The allowance was reviewed after the publication of UKCIP02 climate scenarios and no change was made for mean sea levels. However, revision of extreme levels was advised (Defra, 2003). A new recommendation was made after the publication of UKCIP02 scenarios that there is a need to test sensitivity to 10 % increase in offshore wind speeds and wave heights by 2080s and 5 % increase in wave periods, in relation to depth limited conditions inshore (Defra, 2003).

As for river flood management, following analysis of flood flows on Thames and Seven rivers using HadCM2 outputs, it was decided that 'sensitivity analysis of river flood alleviation schemes should take account of potential increases of up to 20 % in peak flows over the next 50 years' (MAFF, 2001). This followed analysis of flood flows on Thames and Seven rivers using HadCM2 outputs. No change was made following the review after the publication of UKCIP02 scenarios, although further research is currently underway.

Source: West and Gawith, 2005.

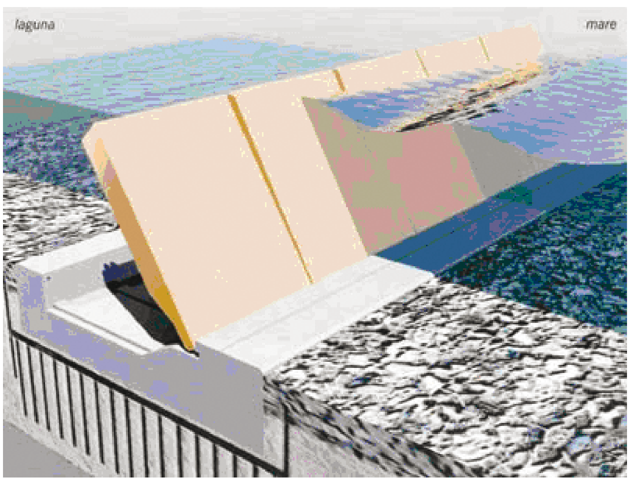
At national level, many northern and western European countries have national flood management policies and guidelines. Integrating new information on climate change and its potential impacts, such policies and guidelines are being reviewed and adjusted periodically.

In the **United Kingdom**, the trauma of human misery and property loss caused by the 1953 coastal flooding alerted the Government to the potential dangers. A radical rethinking led to major new flood defence infrastructure being built and eventually the commissioning of the Thames Barrier in 1987. The first major IPCC Assessment (1991) led to changed approaches to coastal planning throughout the United Kingdom. This has incorporated an allowance for climate change and sea level rise built into all new coastal flooding infrastructure (see Box 6). Planning Policy Guidance 25, published by the Office of the Deputy Prime Minister (ODPM, 2001), takes a precautionary approach to managing development and flood risk. It aims to direct new development away from areas at highest risk of flooding and takes account of climate change.

In **France**, upon the request of the Direction des risques majeurs of the Ministry of Ecology, Météo-France has performed studies in the overseas departments and territories (Antilles- Guyane, La Réunion, Nouvelle Calédonie and Polynésie française) in order to evaluate the importance of storm surges. These studies have used a shallow water model driven by wind and pressure fields, validated by a weather forecaster, in order to simulate sea level changes resulting from tropical storms or cyclones. Mapping of the sea level rise is now available for each of these territories.

In **Italy**, the 'MOSE system' (see Figure 10) has been approved. The system includes mobile flood barriers located at the lagoon inlets in order to isolate the Venice Lagoon from the sea in times of

Figure 10 'Smart' barriers to shield *La Serenissima* from freak tides (27)



(27) See: Agenzia Giornalistica Italia, http://www.italydownunder.com.au/issueeleven/venice.html.

tides higher than the pre-established height or the so-called 'complementary measures'. It also includes a series of works capable of increasing the friction in the canals at the lagoon inlets with the aim of abating the level of the most frequent tides and the local defences. This is carried out by 'raising up' the lagoon banks and public pavement in the areas that lie the lowest on the water. In May 2003, the President of the Council of Ministers inaugurated the start of the works for the MOSE System.

In the **Netherlands**, criteria and boundary conditions for the safety features of all dykes and other protection infrastructure are periodically updated to incorporate the available information on climate change and other environmental changes. The Dutch coastal policy plan (3rd Coastal Policy, 2000) strongly emphasises the new challenges caused by climate change, especially sea level rise and an increase in the number of storms. Various national and sub-national policy plans like the Dutch Spatial Policy (Ministry of Housing, 2004) and the Water Policy Plan 21st Century (Nota Waterbeleid 21ste eeuw) (Ministry of Transport, 2000) recognize the need for adaptation in water management and coastal zone management. An example of an adaptation action for rivers is in Hengelo ([28]), where the peak flow of the Woolderbinnenbeek can be reduced by 60 %, to prevent the downstream agricultural land and town centres from getting flooded.

In **Denmark**, a rise in water level of around 0.5 m was taken into account for the steps leading down to Metro stations during the planning of the new metropolitan district 'Orestad' ([29]).

Germany's coastal protection structures have long been designed with an allowance of 25 to 30 cm sea level rise in 100 years in Mecklenburg-West Pomerania. In addition to this centennial sea level rise, Lower Saxony introduces plans to give an extra allowance of 60 cm for all newly planned coastal protection infrastructure to account for climate change induced sea level rise. Developments along coastlines are constantly monitored and carefully evaluated in order to permit prompt response to any changes that cannot be foreseen at the present time ([30]).

In order to avoid damage in the Alps, increasing pressure is being put on communities not to authorise the establishment of new settlements and industrial facilities in areas with high risk of flooding. Programs are started to improve flood protection facilities like dams, create flood plains, and keep areas with high risks for flooding clear from housing and constructions in countries of the Alpine region, e.g. the Bavarian flood protection programme. A 15 % allowance is made for the construction of new flood protection facilities in Bavaria, Germany in order to account for the changing features of flood risk under climate change ([31]). Considering possible future climate changes, Baden-Wuerttemberg also gives similar allowances of 15 to 40 % in the design of flood defence facilities depending on the frequency of flood occurrence in the given catchment area.

In **Slovakia**, an extensive Flood Warning and Forecasting System POVAPSYS, which is funded by the government, was approved in 2002 (Martinka and Poprendova, 2003). Within the Slovak National Climate Program several studies on flash floods risk assessment have been introduced (e.g. Lapin and Hlavcova, 2003).

In **Belgium**, the Flemish Government introduced regulations to prevent activities having a negative impact on the water systems; to assess the risk of flooding and its impacts and to implement flexible water discharge for flood prevention. In **Ireland**, Dublin City Council altered planning regulations to account for projected sea level rise and changes in river flooding patterns. In **Iceland**, projected sea level rise has been taken into account in the design of new harbours.

4.4.4 Preventing and managing natural hazards

Natural hazards such as torrent and snow avalanches are projected to be a major concern under changing climatic conditions, particularly in mountainous areas (e.g. the Alpine Region). From experience with catastrophic events, local communities have developed a high level of awareness of such risks and devised strategies to prevent and manage them (e.g. Bader and Kunz, 1998).

Research programmes such as Interreg IIIb projects 'MeteoRisk', 'CatchRisk' and 'Dis-Alp' are initiated to improve the forecasting and management of extreme events and on the development of early warning

([28]) See: http://www.reggeendinkel.nl.
([29]) See: http://www.mst.dk/udgiv/publications/2003/.
([30]) Source: Germany's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/gernc3.pdf).
([31]) See: http://www.kliwa.de.

systems for natural hazards. Special focus is placed on the trans-national exchange of information, which is often crucial for early warning in the Alpine region. Programmes were started (e.g. the Interpraevent network ([32])) or are planned to train rescue services and decision makers on local and regional level for disaster management.

In **France**, the technical services of the Ministry of Equipment (Centre scientifique et technique du bâtiment) are presently giving more consideration to climate change adaptation in their work, whereas previously the focus used to be energy efficiency. Also, the Directorate of the economic and international affairs of the same ministry has initiated a research project on adaptation of infrastructures to climate change.

In 1997 **Switzerland** initiated the 'Platform for Alpine Natural Hazards (PLANAT ([33]))' to improve the management of extreme events and create risk maps. Similar initiatives were started in Germany (e.g. FeWIS ([34])) and Austria (e.g. 'Mapping of Hazard Zones' ([35])). An alpine wide platform is now implemented in the Alpine Convention Framework (UBA, 2004). The CIPRA programme 'Future of the Alps'([36]), an interdisciplinary platform, is set up for developing and communicating strategies for sustainable development under global change. The EU-Project GLOCHAMORE aims to facilitate the exchange between research groups in the Alps. Currently CIPRA Austria is preparing the programme 'Climate Change in the Alps'. It aims to raise public awareness and to develop strategies for adaptation commonly with partners as 'Alliance in the Alps'. In **Austria**, preventive measures, such as torrent and avalanche control, are well established and are of significant importance in view of a changing climate ([37]).

Crucial for the risk assessment of natural hazards is the information on frequency and intensity of extreme weather events for the present and the future. The EU-wide project PRUDENCE ([38]) (see Table 5) and national projects, such as StartCLIM (Austria ([39])) and Proclim (Switzerland ([40])) aim to improve the scientific basis for assessing trends in extreme weather events.

4.4.5 *Ensuring good health of the population*

Despite the high level of health care facilities and medical services in most parts of Europe, sections of the population could be highly vulnerable to extreme weather conditions. The alarmingly large number of excess deaths in Southern European countries caused by the heat waves in the summer of 2003 demonstrates this vulnerability. This has resulted from a combination of factors. The key factors are the lack of preparedness of health care and social systems to cope with such extreme weather events, inadequate exchange of information between relevant public organizations and the lack of community-based intervention plans (Koppe *et al.*, 2004: WHO European Centre for Environment and Health, 2004).

In **France**, several studies were undertaken to investigate the risk factors associated with the heat-wave in the summer of 2003. These studies have resulted in a national heat wave plan, which includes four levels of information or alert developed by the Ministry of Health and Social Affairs ([41]). It is to be implemented at local level and in a number of cities, such as Paris, where the local adaptation plan to heat waves are coordinated with the national plan. At the first level of alert, a seasonal survey is made for the summer period (from 1 June to 30 September) to check the different action plans and to inform the public on prevention. At the level 2, public services are mobilised from the local to the national scales, and a forecast is made for the next three days of possible exceedence of bio-meteorological thresholds. At level 3, a number of medical and social measures are implemented. If the heat wave is intense and persistent (level 4), exceptional measures are applied. The different thresholds used have been established for cities and regions in order to take into account the differences in local experiences with protection against heat. The management of retirement homes and hospitals will be improved by creating air-conditioned areas and by recruiting 13 200 additional care workers by 2007.

The **German** Weather Service has developed a heat warning system, which has been operational since

([32]) See: http://wasser.ktn.gv.at/interpraevent/.
([33]) See: http://www.planat.ch.
([34]) See: http://www.dwd.de/de/SundL/Oeffentlich/Feuerwehr/Leistungen/FeWIS_start.htm.
([35]) See: http://www.umweltbundesamt.at/.
([36]) See: http://www.cipra.org/.
([37]) Source: Austria's third national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/autnc3.pdf).
([38]) See : http://www.prudence.dmi.dk/.
([39]) See : http://www.austroclim.at.
([40]) See : http://www.proclim.unibe.ch.
([41]) Source: http://www.sante.gouv.fr/canicule/doc/plancanicule.pdf.

May 2005. The information is distributed through the internet and the press, and directly targeted at the municipal level. Based on these warnings, several German Laender have improved their emergency plans and introduced regional warning systems. For example, Hessen has established a system which includes two warning levels of heat stress severity, that gives concrete urgent measures for the management of retirement homes (level 1), all local health authorities and the public (level 2). There is also an improved capacity building and awareness raising programme to accompany these measures.

In 2003, an **Italian** network was established for the prevention of the health effects of heat-waves coordinated and financed by the National Department of Civil Protection at the national level. In collaboration with a centralised data centre, the Department coordinates a network of experts from epidemiological departments, local health authorities and regional agencies of the environment and civil protection. At the municipal level, local centres coordinate the work. The implementation of this plan includes development of a forecasting model; identification of intervention plans for each city; identification of the network of organisations /services to be involved; and evaluation of the effectiveness of the system in preventing excess mortality. The heat/health watch/warning system (HHWWS) is to be improved and its operation to be expanded to other Italian cities.

In **Belgium**, the national government is currently improving retirement homes to reduce the vulnerability of the elderly to extreme weather conditions.

At **EU** level, the European Commission funded a research programme, cCASHh under its Fifth Framework Programme (FP5) to systematically investigate the ways climate change affects human health, and identify policies and strategies for adaptation in Europe (see Table 5). Under the auspices of this project, a workshop (Vulnerability to Thermal Stresses) was convened in May 2003 to review current knowledge about the effects of heat-waves. This workshop includes the physiological aspects of heat stress related illness and epidemiological studies on excess mortality, and makes recommendations for preventive action. It concluded that measures such as heat health warning systems and appropriate urban planning and housing design are needed to reduce heat related mortality and morbidity. It is recommended that more heat health warnings systems need to be implemented in European countries. This requires good coordination between health and meteorological agencies, and the development of appropriate targeted advice and intervention measures. More long-term planning is required to alter urban bioclimates and reduce urban heat islands in summer. Appropriate building design should keep indoor temperatures comfortable without using energy-intensive space cooling. As heat-waves are likely to increase in frequency because of global climate change, the most effective interventions, measures and policies to protect the health of vulnerable Europeans need to be developed and evaluated (Koppe *et al.*, 2004).

4.4.6 Coping with changing dynamics in business

As a result of climate change impacts on the natural environment, human health, settlements and infrastructure, a range of businesses are expected to be affected. In particular, changing climate and its impacts on other sectors/systems will present both threats and opportunities for the tourism, insurance, and construction industries. Actions are already being taken in the business communities to mediate threats and seize opportunities.

Faced by the challenge of unreliable snow cover, owners of lower altitude ski-resorts are adjusting their business strategy. These changes include diversification of services, for example opening spa-programmes, eco-tourism (Schneider, 2004), investing in snow making facilities, relocating skiing resorts to higher altitudes, especially on glaciers. But the risk of heavy snowfall and strong wind is higher at these locations. Concentration of winter tourism at high altitudes also poses conflicts with nature conservation (e.g. Alpenverein, 2004).

Construction and insurance industries are also taking proactive actions to adapt. In **Norway**, the private sector, such as construction and insurance industries are actively engaged in activities in preparation for climate change adaptation (see Box 7). In **Switzerland**, the hydro-power production and the insurance industries are taking action in order to assess the potential consequences of a different climatic regime on their business activities. In the **Netherlands**, studies are being conducted to identify and evaluate insurance adaptation strategies. Insurance scheme AquaPol has recently been implemented in the Netherlands. This scheme offers farmers insurance against damage from rain storms. In the **United Kingdom**, the Association of British Insurers (ABI) recognised the importance of climate impacts to the insurance sector and has undertaken a variety of measures to help the industry to adapt. These measures include:

Box 7 Private sector preparing for adaptation to climate change

This six-year concerted research programme was launched in August 2000 in Norway. This is a rather unique effort in the sense that it is initiated and funded by NBI, and the building and insurance sectors rather than Research Council of Norway programmes. A large number of key actors in the construction industry are involved in the Programme. The programme's principal objectives are to:

- Survey and increase knowledge about potential impacts of climate change on the built environment and how society can best adapt to these changes.
- Develop and update methods, tools and solutions in principal for the planning and design of buildings (materials, structures and external enclosures), in order to increase both durability and reliability in the face of external climatic impact.
- Define more accurate criteria and Codes of Practice concerning building performance in severe climates.'

Source: Lisø *et al.*, 2003.

appointing senior staff with specific responsibility for work related to climate change risk; organizing staff development events and commissioning a major research initiative to explore the impacts of climate change upon the sector (ABI, 2004).

4.5 Summary

There has been growing interest in adaptation to projected climate change and associated impacts among the EEA member countries. A wide range of activities have been initiated, and good progress has been made in building and enhancing adaptive capacity across the region through a variety of measures.

Several countries (e.g. Finland, Hungary, the Netherlands, Portugal, Spain and the United Kingdom) have undertaken or are in the process of implementing comprehensive, interdisciplinary, multi-sector national assessments of climate change. These assessments make use of the most up-to-date science, computing technology and newly available data/information. Knowledge resulting from such research initiatives is of great importance to supporting adaptation planning. However, further efforts are required to improve the quality of climate scenario at scales relevant to adaptation, develop methods and tools to reduce and/or better represent uncertainties in climate assessment, and to evaluate, cost and prioritise adaptation options.

Government, non-government, business, resource management and nature conservation organisations have started to realise the business relevance of climate change, and the adoption of new policies, regulations and standards to take this into account. These provide important institutional support and leverage for concrete adaptation actions.

Existing adaptive measures are very much concentrated in flood defence which has enjoyed a long tradition of dealing with climate extremes. There is considerable scope for advancing adaptation planning and actions in sectors such as public health, water resources and management of ecosystems. These sectors are vulnerable, but up till now little attention has been given to adaptation within them. A prerequisite to sound adaptation planning is the development and communication of knowledge on the potential impacts of climate change on these sectors, and a robust adaptation policy appraisal framework to evaluate adaptation strategies.

Finally, due to a combination of technical, economic, and institutional factors, concrete adaptation practices and projects are still scarce. Many of the existing adaptive responses have been triggered by the substantial losses from extreme weather events in recent years (e.g. 2002 floods and 2003 heat waves and droughts). These measures are often directed at reducing vulnerability to current climate variability and extreme weather conditions. Proactive policies and measures designed to address long-term climate change and its impacts are still to be developed in many countries.

5 Key challenges and opportunities for adaptation in Europe

Although the need for adaptation in Europe is recognised by governments and organisations, work on adaptation is still at an early stage and has been predominantly of a preparatory nature. Drawing upon the insights and experience from member countries and climate adaptation literature, this section highlights the major challenges and opportunities for climate change adaptation in Europe.

5.1 Challenges

As a relatively new issue, adaptation to climate change in Europe has been hindered by a combination of factors. They include:

- significant uncertainties associated with climate and non-climate scenarios required for impact, vulnerability and adaptation assessments (Section 5.1.1)
- gaps in knowledge about the underlying causes of vulnerability and the theory of adaptation (Section 5.1.2)
- lack of policy guidance and institutional support (Section 5.1.3)
- insufficient coordination between sectors and countries (Section 5.1.4).

The first two sections are of a technical nature while the latter has more bearing to institutional characteristics.

5.1.1 Limitations in scenarios

Uncertainty associated with climate change, including extremes, and its impacts seem to discourage some actors from being actively engaged in adaptation activities. For many decision makers, climate impacts are still perceived to be too elusive and far into the future to be relevant now. The most readily available climate projections are for a few decades into the future but typical business planning horizons are 3–5 years in most sectors. In fact, they are even becoming progressively shorter. This implies that long term anticipatory adaptation is beyond the scope of many organisations. The major uncertainties associated with climate change and their impacts act to prevent some stakeholders from taking concrete action to adapt to potential impacts. For example, as suggested by a recent report requested by the Swedish Environment Protection Agency, more knowledge about climate change itself, detailed and local climate scenarios and impact studies on local scale are needed for promoting efforts on adaptation in Sweden (Rummukainen *et al*., 2005). Iceland stated in its third national communication to the UNFCCC that '*Emphasis on adaptation measures has been minimal. The main reason for this is the considerable uncertainty associated with the impacts of climate change*' (see Footnote 16 for details); and Sweden stated that '*Information and advice that is concrete and detailed on local scale is a recurring prerequisite for action.*' In some cases, the lack of quality scenario data prevents quantitative assessment, as indicated by Belgium its third national communication.

The most significant impact of climate change often result from changes in extreme weather and climate events rather than changes in mean climate conditions. In addition, climate change varies considerably over space, especially in areas with heterogeneous orography. Therefore, adaptation planning often requires information on trends of extreme weather events on a local scale. However, climate scenario data are mostly available at a much coarser resolution (see Section 3.3). Due to the limited data availability, scenarios on extreme weather events are particularly difficult to obtain with confidence at present. This has been a major constraint to robust impact, vulnerability and adaptation assessment for sectors such as water resources, coastal and river flooding, and public health.

Furthermore, climate change is not the only factor affecting the state and performance of the natural environment and human society. Its impacts occur or are projected in the context of changes in other non-climatic factors and socio-economic drivers. Therefore, to plan for adaptation to climate change, information is also needed on non-climate environmental (e.g. air quality, land-use, land-cover), socio-economic (e.g. wealth, education) and institutional (e.g. structure and capacity of institutions) variables. But trying to obtain such information, particularly for the future, at the appropriate scale and consistent with the climate scenarios has proven to be very challenging.

Given the intrinsic uncertain nature of climate and human systems, uncertainties will always feature climate and socio-economic futures. With enhanced knowledge and computational power, it may be possible to reduce and/or quantify some of the uncertainties over time. Managing climate risk will be featured with decision making under uncertainties. In fact, many business decisions are made with major uncertainties, particularly, in the economic climate. Therefore, uncertainty alone should not hinder decision taking. Most uncertainty is in the magnitude of projected changes, but not in the direction. Climate models show the same trend in temperature and precipitation changes under different emission scenarios (Schröter *et al.*, 2005). Furthermore, as suggested by some experts (e.g. Jones, 2003; Lim *et al.*, 2005; Smit *et al.*, 2001; Willows and Connell, 2003), managing risks associated with current climate variability and extreme weather events might act as a useful linkage between planning for adaptation to long-term climate change and sustainable development. As demonstrated by examples in many countries (e.g. Sweden, Germany (Zebisch *et al.*, 2005), Belgium, France, Italy) existing adaptation measures are largely triggered by extreme weather events over the recent years and the considerable losses resulting from these events. In view of this, it might be helpful to engage stakeholders in identifying critical climate thresholds in relation to their business and activities, and in assessing vulnerability to present day climate variability and risks. Insights can then be drawn on the scale of potential climate risks in the future.

5.1.2 *Gaps in knowledge for supporting adaptation decisions and actions*

The large number of studies on climate change impacts, vulnerability and adaptation undertaken in Europe has generated sufficient knowledge to justify adaptation, but insufficient for effective adaptation planning. It also is insufficient for vigorous evaluation of adaptation policies and measures. Studies considering adaptation rarely go beyond identifying adaptation options that might be possible. There is little research on the dynamics of adaptation in human systems, the processes of adaptation decision-making, conditions that stimulate or constrain adaptation and the role of non-climatic factors. There also has been little research to date on the roles and responsibilities of individuals, communities, corporations, private and public institutions, governments and the EU.

Therefore, there continues to be substantial needs for further research and assessment that is targeted at supporting adaptation decisions. A key research challenge is to evaluate the feasibility, costs, and benefits of potential adaptation options.

The 'Science in Support of Climate Change Adaptation' side-event at the Tenth Conference of the Parties to the UNFCCC (COP10) recommended areas of priority research and assessment areas for supporting adaptation decisions and actions. These areas include the changing vulnerability to climate stresses and their causes; lessons from past and present adaptations; evaluating the performance; costs and benefits of adaptation actions; characterising and quantifying uncertainty; combining knowledge from empirical case studies and quantitative modelling research; and evaluating and improving methods for creating regional climate change scenarios ([42]). Research and assessment should benefit from being multidisciplinary and be carried out by partnerships among scientific, decision-making, practitioner and stakeholder communities.

5.1.3 *Lack of policy guidance and institutional support*

Many adaptation decisions cannot be made or implemented without supportive policy framework and resources. In particular, there have not been many concrete adaptation actions and hence there are not enough precedents to follow.

As discussed in Section 3, vulnerability to climate change is highly variable across sectors, systems, communities and regions. Therefore, adaptation strategies designed to reduce vulnerability are highly case-specific. There is no one-size-fits-all easy answer to adaptation questions such as, 'Is adaptation really warranted in our business context?', 'What is the best adaptation option?', 'How to ensure the success of our adaptation efforts?' and so on. However, despite the variations in adaptation contexts, there may be some generic lessons that are transferable. For example, we know from past flood events that using a disaster management approach

([42]) Source: http://www.aiaccproject.org/whats_new/Science_and_Adaptation.pdf.

to flood risk can reduce exposure and sensitivity to the event. This can be applied in the context of flood risk management under a changing climate. Indeed, water resource and coastal zone management agencies across Europe have applied such principles in developing their flood defence plan in face of climate change and associated sea level rise.

Another issue is the distribution of financial resources. Decision makers (e.g. local authorities) often find it difficult to justify additional investment in climate-proofing measures without the legitimacy and justification provided by agreed policy, regulation or technical standards. The UK Environment Agency (EA), for example, feels there is an enormous task ahead for adapting to climate change but that it will be difficult to resource in an era when public expenditure is under pressure. Local authorities are subject to external drivers such as best value performance indicators. Until such indicators include adaptation targets, local authorities are broadly constrained to prioritise other issues. Sometimes regional authorities struggle to legitimise adaptation activities as it is an area where national policy does not exist (e.g. in the Netherlands).

Furthermore, the presence of current technical standards and guidance based on historic climate data can be seen as a constraint to climate adaptation since facilities constructed using these data may not perform as intended over their lifetimes. Hence, there is a need to introduce periodical review and update of such standards and guidance in order to keep in line with the most up-to-date climate projections.

5.1.4 Insufficient coordination between sectors and countries

Currently adaptation measures have been largely initiated and implemented by different actors in the public and private sectors. This has been carried out in the context of sustainable resource management, natural hazard prevention, spatial planning and so forth. Furthermore, they are mostly limited in scope (e.g. directed towards flood defence in a particular section of a watershed). Such activities are designed to have a distinct sectoral and local focus and lack interaction with other sectors and/or with other regions within the country or with other countries. Consequently, there is little co-ordination between sectors and between countries in planning and implementing adaptation measures. But risk management may be more efficient through cross-sectoral and international efforts. Examples include: multinational monitoring and operational early warning systems for flood protection and weather forecasts; improving risk management by developing risk maps for natural hazards; and providing guidance, training for local and regional decision makers. Such improved international coordination is being discussed in the context of the development of a European action programme on flood risk management, which includes a possible future Floods Directive.

At present, in the EU and many member countries, nature conservation policies are site-specific, for instance, Special Areas of Conservation (SACs), EU Habitats Directive. Therefore, they are not flexible enough to account for species movements under a changing climate. Nature conservation agencies have started to recognise that some protected sites may be lost or changed with changing climate and that some species may be lost from current habitats all together. Discussions have been initiated on the integration of these sites in a wide ecological network, which could also help adaptation to climate change.

Decisions on public services and risk management in most countries are currently divided between numerous institutions and offices. There tends to be a need for enhanced communication and co-ordination between local regional and national agencies (vertical integration) and between agencies of different sectors, such as, water, nature protection and planning (horizontal integration). Inadequate exchange of information between relevant public organisations was identified as one of the deficiencies in the French public health systems which contributed to the health consequences of the 2003 heat wave (WHO European Centre for Environment and Health, 2004). In this context, Sweden called for closer co-ordination of responsibilities among different public and private sectors. Experts at the recent WHO meeting on human health responses to extreme weather and climate events highlighted the need to enhance collaboration and coordination between the health and meteorological communities. This included the use of meteorological indicators by the health community (WHO European Centre for Environment and Health, 2004).

5.2 Opportunities

Although adaptation to climate change is still in its early stages of development in Europe and is hindered by a combination of factors already discussed, opportunities do exist for countries to make progress. This section will discuss growing awareness (Section 5.2.1), market opportunities (Section 5.2.2), 'win-win' options (Section 5.2.3), and 'no-regret' strategies (Section 5.2.4).

5.2.1 *Growing awareness*

Due to campaigning, and partially as a result of the considerable losses from extreme weather events in recent years, public awareness in Europe about risks associated with climate and extreme weather has been grown. The large media coverage across the world following the publication of EEA's report on climate change impacts in Europe illustrates a high level of public interest and awareness on this subject. As a result of a public awareness programme in 2003 in the United Kingdom, 72 % of those at risk of flooding are now aware that they are at risk, and 96 % are aware of at least one action they can take to reduce their flood risk (WHO European Centre for Environment and Health, 2004).

Governments and organisations at the EU level, national and sub-national level, have developed or are in the process of developing adaptation strategies. These strategies are at least partially driven by increased public awareness. Business communities are starting to prepare for adapting to changing dynamics of the business risks and opportunities under a changing climate. Tourism, insurance and construction industries are exploring the implications of climate change to their businesses and adjusting their business strategies. Furthermore, the general public in Europe are aware of the implications of climate change for their well-being and can be persuaded to adapt through changes in lifestyles, consumption behaviour, preparedness for risks etc. Therefore, there is an opportunity to make progress on adaptation by actively engaging actors from all sections of the society.

5.2.2 *Market opportunities*

Climate change impacts are often perceived as purely potential threats. However, there are market opportunities which changing climate patterns would bring about. For example, in the United Kingdom, the National Farmers Union (NFU) has identified opportunities for farmers with appropriate land holdings to create small reservoirs for the storage of increased winter rainfall that could be used during the hotter drier summers (West and Gawith, 2005a, b). Market opportunities arise simply by exploiting the advantage of being 'an early mover' in new business areas. For example, there is considerable scope for new design skills and new environmental technologies in the adaptation of buildings and infrastructure. Excessive summer temperatures are anticipated to lead to a decline in summer tourism over time in many of the traditional Mediterranean resorts (Entec UK Ltd, 2003). This is seen as a commercial opportunity for tourism managers in the United Kingdom and other northern European countries, particularly in areas where summer temperatures will become comfortably pleasant or more reliable. The same is true for certain market garden products, such as salads and fruit, where climatic changes will restrict production in some traditional growing areas, both in the United Kingdom and abroad (West and Gawith, 2005a, b).

5.2.3 *'Win-win' options*

'Win-win' opportunities exist where there are adaptation options that minimise harmful climate impacts and also have other social, environmental or economic benefits. Some of the most significant in the climate change context are those that address climate impacts but which also contribute to the mitigation objectives. For example, rising temperatures expected in winter will reduce demands for space heating in buildings. This has led to lower specifications in plant and equipment (boilers, radiators, etc) and also less winter energy use. So, greenhouse gas emissions are reduced and both capital and revenue expenditure are saved.

Some examples of 'win-win' opportunities are mentioned here. Malta identified a range of 'win-win' adaptation options including efficiency in energy production with an emphasis on renewable sources, promoting energy-efficient building design, upgrading the roads network, improving farming methods, afforestation ([43]). In the Czech Republic, adaptation priority would be given to 'win-win' measures due to financial constraints. In Spain, the national adaptation strategy is to be based on a comprehensive assessment of climate change impacts on various sectors. The strategy will be to integrate climate change adaptation in different environmental policies and instruments in the areas of water, biodiversity and coast etc. Car traffic of tourists accounts for almost half of the transport in the Alpine area (Elsasser and Messerli, 2001) and causes considerable noise pollution. This problem was addressed at the 2004 Alpine Convention conference. Measures to reduce car traffic in the area by offering attractive alternatives in public transport

([43]) Source: Malta's first national communication to the UNFCCC (http://unfccc.int/resource/docs/natc/mlt_nc01.pdf).

also mitigate greenhouse gas emissions (BMU, 2004).

There is scope to develop policies to facilitate the implementation of such 'win-win' adaptation measures, particularly in the transport and energy sectors. Policies leading to the reduction in vulnerability as well as in greenhouse gas emissions are of particular interest.

5.2.4 'No-regret' strategies

'No-regret' measures are those that would be justified under all plausible climate futures, which include the absence of man-made climate change. No-regret decisions have benefits today and should increase adaptive capacity. An example of a no-regret action would be a company that has relocated, and has avoided areas that are potentially vulnerable to flooding and/or also avoided buildings that are prone to over-heating in summer. Other examples of no-regret decisions include:

- policies requiring water supply utilities to reduce water loss from the supply network;
- insurance company investments in high resolution digital elevation models, postcode and flood level mapping. Thus, they aim to manage their exposure to flood risk damage claims and set premiums according to flood risk.

Such strategies may require investments but overall are likely to be cost neutral as far as climate risks are concerned (West and Gawith, 2005a, b).

In many countries, the link between climate change adaptation and sustainable development has been mentioned. That is, by adapting to adverse and/or beneficial impacts of climate change, other development goals (e.g. environment protection, higher economic growth/lower losses, stable community life etc.) can be achieved at the same time. In the Netherlands, the focus of climate change adaptation is on mainstreaming and 'no-regret' strategies. No adaptation measures are taken for the sake of adaptation only. In the water sector, climate change adaptation measures are strongly integrated into the policy agenda. Here, emphasis is placed on 'no-regret' strategies. Through water management agreements, it has also been integrated into other policy areas. For example, the spatial implications of the Dutch Cabinet's position on water management and the associated adaptation measures have been incorporated into the Dutch Spatial Policy. Inclusion in the policy for rural areas offers an opportunity to combine the implementation of measures for increased safety and flood prevention in rural areas with other measures. These have objectives such as improving water quality, combating dropping water tables, reconstructing rural areas and improving the ecological infrastructure. In Ireland, the guiding principles of 'no regrets', 'precautionary principle' and 'inter-generational equity' have been taken as touchstones for national climate policy development.

6 Conclusions

6.1 Scientific and technical capacity in support of adaptation planning

Despite the considerable efforts being devoted to research on various aspects of climate change science in Europe, there is limited confidence in the magnitude and rate of climate change (including variability and extremes) at scales relevant to adaptation (see Sections 3.3.2, 5.1.1 and 5.1.2). Knowledge on the potential impacts of such changes on natural and human systems is not yet detailed enough to enable meaningful adaptation planning particularly at operational level (Eisenreich, 2005). Research into the theory and practices of adaptation is still in its infancy and is not yet in the position to guide the adaptation decision process. Hence, further efforts are required to strengthen the scientific and technical capacity for adaptation. In particular, the following areas deserve attention.

6.1.1 Scenario data for in-depth impacts, vulnerability and adaptation assessments

High quality scenario data for climatic and non-climatic variables are central to in-depth assessment of potential climate risks in the future. Specifically, efforts are needed to improve the spatial and temporal resolution of climate scenarios. This would enable more location-specific assessment and assessment of potential risks of extreme weather and climate events. The EU FP6 project ENSEMBLES ([44]) aims to produce, for the first time, objective probability climate scenarios at a range of time scales for applications in vulnerability and adaptation assessment from 2007. Although progress is being made in regional climate modelling in Europe through concerted efforts, much more needs to be done in:

- interpreting and communicating model results in order to make them more accessible to wide ranging end-users (including research community, decision makers and the general public);
- better characterizing extreme events under a changing climate;
- developing other environmental (e.g. air quality, land use) and socio-economic scenarios consistent with climate scenarios.

6.1.2 Comprehensive and quantitative assessments

Although many countries have completed their national assessments through the process of national communications to the UNFCCC, such assessments are rarely comprehensive in their coverage of sector/system and geographic domains. Indeed, hindered by the inadequacy of quality scenario data and technical capacity, assessments are often of a descriptive and sensitive analytical nature. They often lack a systematic quantification of future climate risks for natural and human systems and the capacity to cope with such risks. The latter appears to be desirable for better adaptation planning. In particular, current assessments fall short in characterizing vulnerability and adaptation in the sectors/issue of water resources, ecosystems and public health. Research priority areas for adapting the water resources sector to climate change are suggested by a recent study on climate change, and the water dimension in Europe (see Box 8).

6.1.3 Integrated assessment

It is important for climate change assessments to consider the interaction and feedback between systems/sectors (i.e. horizontal integration, such as linkages between water resources, agriculture and human health), and processes at different scales (i.e. vertical integration, such as the effects of global GHG emissions propagating through regional climate regimes to local manifestation of climate change and sea level rise). Such integrated assessments are relevant to supporting decision making on adaptation to climate change. In this regard, the approach taken by the ATEAM project (see Box A1) could be used by future assessments.

([44]) http://www.ensembles-eu.org.

Box 8 Quantitative assessments on impacts and vulnerability are recommended for the water sector to adapt to climate change impacts in Europe (Eisenreich, 2005)

- Quantify at the European and river basin scale the impacts of climate change on *water quality* of surface water and ground water, and water classification for river basin management by coupling river basin — coastal zone models in a climate changed world;
- Quantify at the European and river basin scale the impacts of climate change on *water quantity*, its spatial-temporal distribution including extreme weather events such as floods and droughts, and availability of surface and ground water under different scenarios and uses, and the associated costs of adaptation;
- Evaluate the effectiveness of different protection measures in trans-national river basins with hydrological models as a response to possible increase in extreme weather events;
- Evaluate the impacts of climate change on the re-mobilization, redistribution and emission of contaminants (chemical and microbiological) as a result of warming and extreme weather events;
- Establish long term monitoring at the pan-European scale of marine and coastal systems using earth observing satellites and other tools of those parameters sensitive or indicative of climate change (sea surface temperature , sea level rise, biomass, primary productivity, carbon cycles, wind fields and trophic state).

Source: Eisenreich, 2005.

6.1.4 Research on the theory and practices of adaptation

As discussed in previous sections, very limited efforts have been devoted to understanding the theory and practices of adaptation up till now. In practical terms, research efforts need to address questions such as, 'How does adaptation decision take place?' 'What are the roles of different stakeholders in decision making for adaptation?' 'What hinders and encourages adaptation actions?' 'What are the criteria to evaluate adaptation options?' 'How to measure the success and failure of adaptation measures?' etc. Without such key questions being resolved, adaptation planning is unlikely to be robust and its implementation successful or sustainable. The growing number of adaptation decisions being made and actions being taken across Europe could provide valuable cases for focused adaptation studies.

Currently, much of the science and technical capacity tends to be concentrated in the west and northwest European countries, with relatively less expertise in eastern and southern countries. This can be seen from the distribution of major research programmes among EU countries (i.e. a concentration of EU funded projects in western and northwest countries — see Table 5). To bridge this gap, the EU could adjust its research and development policy to facilitate development and enhancement of scientific and technical capacity in eastern and southern European countries.

6.2 Communication, information exchange and experience sharing

The existence of knowledge and capacity does not guarantee that adaptation takes place (Burton, 1996). To turn scientific knowledge into adaptation action, it is essential that scientific knowledge is effectively communicated to all involved. This includes governmental organisations at different levels, the business community, environmental NGOs, the research community and the general public. Communication does not only convey the scientific ideas and findings to a wide range of audience. It is also a tool to raise public awareness and thus could potentially be part of the solution to the challenge of climate change by affecting behavioural change of well-informed citizens. Based on this notion, the UK Department for the Environment, Food and Rural Affairs (DEFRA) launched a communications campaign. It announced a GBP 12 million package of funding over three years as the first part of a new climate change communications initiative to change public attitude towards climate change ([45]).

At a more operational level, knowledge, information and experience also need to be shared among scientists, decision makers and practitioners within and between countries. This could take varying forms, such as the establishment of thematic and interest groups, workshops, partnerships between research and policy communities and roundtable discussions. Such exchange of knowledge,

([45]) Source: DEFRA press release, 16 February 2005, ref. 71/05.

experience and know-how among stakeholders could lead to the opening of a web-based database of experiences and case studies on adaptation, classified by sectors, systems and regions.

There are an increasing number of good practices in this regard. For example, the ESPACE project ([46]) (see Table 5) brings together a wide variety of representatives from the science and decision making communities to work in partnership in developing strategies and practical guidance for adapting spatial planning to projected climate change and its impacts in Europe.

The Alpine Convention facilitates information exchange and experiment sharing on a variety of sustainability issues (e.g. adapting to climate change) among stakeholders from member countries.

The ERA-Net CIRCLE (Climate Impact Research Coordination for a Larger Europe) provides comprehensive information on major research programmes at the national level of the EU Member States and beyond. Its aim is to facilitate information and experience share among the 18 member countries and to identify common research needs and gaps which will flow into a joint CIRCLE research agenda providing joint calls for proposals among the CIRCLE partner countries and programmes. All this is to support the development of a European Research Area (ERA) for Climate Change (König *et al*., 2005).

Within the Dutch national research programme 'Climate changes Spatial Planning' ([47]), partners from the government, private enterprises and scientific institutes collaborate in research.

Moreover, information sharing and experience exchange between countries is considered to be effective in enhancing and sustaining adaptive capacity, particularly if it is directed towards addressing a specific regional issue. For example, countries of the Mediterranean with similar climate but contrasting socio-economic conditions could benefit from knowledge sharing to address drought risk. Similarly, countries facing similar climate risks (e.g. flooding) could learn from each other in preventing and managing such risks.

Finally, there are significant synergies between climate risk management and natural hazard prevention/management. Therefore, expertise and experience on hazard prevention and management from the natural hazard community should be more fully utilised in climate change adaptation planning (Purvis and Busby, 2004).

6.3 Adaptation planning and implementation

Due to the cross-sector and cross-boundary linkages in managing natural resources (e.g. water, land, biodiversity) and human wellbeing (e.g. public health), adaptation planning and implementation require institutional coordination and collaboration.

To enhance cross-sector linkages, national government departments should develop coherent cross-sector adaptation policies and implementation plans with adequate consideration of interactions and feedback mechanisms between sectors. For example, in adapting the public health sector to increasing risk of heat waves, closer coordination and collaboration is required between the health and meteorology communities and civil protection agencies. They provide timely and authoritative early warnings of potential heat wave risks and civil protection agencies offer contingency services in times of adversity (WHO European Centre for Environment and Health, 2004).

There are also cases where international coordination and collaboration are required to ensure effective adaptation. For example, given the close linkage between water resource in the Netherlands and Germany, water resource management authorities in both countries need to work in partnership. This partnership would ensure that a strategy for adapting the water resource in one country is coherent with that in the other country. In general such coordination should take place within the development of plans for river catchments in Europe.

To achieve and maintain favourable conservation status of species and habitats in the face of climate change and to ensure the ecological connectivity, international coordination and collaboration are essential for establishing cross-border ecological corridors between the EU and neighbouring states ([48]).

([46]) See: http://www.espace-project.org.
([47]) BSIK-KvR: http://www.falw.vu.nl/bsik.
([48]) Source: http://europa.eu.int/comm/environment/nature/biodiversity/develop_biodiversity_policy/malahide_conference/index_en.htm.

6.4 Policy frameworks for adaptation

Adaptation, as opposed to mitigation, as a policy response to climate change is still in its early stages of development. At present, there is no EU level adaptation policy framework, although a discussion has started end of 2005 within the second phase of the European Climate Change Programme. With the need for adapting to inevitable climate change becoming increasingly evident, an EU adaptation strategy could set out the guiding principles, provide broad policy guidance and mechanism for implementation of national adaptation policies in Member States. Moreover, climate change impacts are not yet integrated into EU environmental directives (e.g. the Water framework directive or the Habitats Directive) and other policies (e.g. the CAP). Although work has started to explore implications of climate change for the implementation of environmental directives, further mainstreaming of climate change adaptation into EU-wide environment protection, resource management, and economic and social development in Europe would be needed.

At national and sub-national level, adaptation policy frameworks and strategies are needed to guide the planning, implementation and evaluation of adaptation. There is progress on the development of national adaptation strategies in a number of countries. However, most adaptation measures are triggered by the loss of extreme weather/climate events over recent years rather than addressing long-term climate change impacts. There is a need for national adaptation plans to be put in place to prevent and/or manage climate risk in a more cost-effective and sustainable manner.

Appendix 1 Case studies

Vulnerability and adaptation differs across sectors, regions or different ecosystem goods and services as a whole. There is a need for a multi-sectoral investigation and the implementation of adaptation measures in the private and the public sector. Authorities at different levels (e.g. local, regional, national and Pan-European) should be involved. Changes in river discharge, for example, affect agricultural activities, the transport sector, energy production and flood protection.

To highlight the multi-dimensional feature of vulnerability and adaptation to climate change in Europe, three different case studies have been selected to represent trends in vulnerability of:

(1) a system (natural ecosystems) across Europe;
(2) a particular region (the Alps) to different aspects of climate change;
(3) a sector (water resources) to one specific aspect of climate change (change in rainfall patterns) in one particular region (the Mediterranean).

Each case study describes key vulnerability issues and their underlying drivers, data sources and methodologies applied to identify these issues and links to policies.

The first case study describes the vulnerability of natural ecosystems across Europe, demonstrating how climate change and other pressures affect ecosystem function and biodiversity. Although natural ecosystems have become increasingly affected by various pressures like land-use changes, many ecosystems are highly vulnerable to climate change. This case study identifies the most threatened natural ecosystems in Europe and assesses the possible consequences of climate change.

The Alpine region was selected as the subject of the regional case study in order to illustrate the interaction between different drivers in different sectors, and the need for integrated vulnerability assessments and climate risk management. The natural environment and human society in the Alpine region are already exposed to various stresses due to its mountainous character with high elevations and slopes. Climate change will have major impacts on the Alpine region and exacerbates the current vulnerability of its natural ecosystems and socio-economic sectors to a variety of pressures. This case study emphasises the need for well interlinked adaptation measures. Much of the consideration about the Alps could be applied to other European mountainous areas, such as Pyrenees, the Carpathian and so on.

The third case study deals with the vulnerability of the Mediterranean basin to increased drought risk.

Key messages, case study 1 — system vulnerability: natural ecosystems in Europe

1. There is compelling evidence that the observed changes in average climate and weather extremes have affected species and ecosystems adversely, and as a result, biodiversity in various parts of Europe is threatened.

2. The most vulnerable natural ecosystems in Europe are arctic and mountain ecosystems, coastal wetlands and ecosystems in the Mediterranean region.

3. Links between climate change and ecosystems have been made in the UN Framework Convention on Climate Change. However, EU and national policies explicitly directed towards adapting ecosystems to potential climate change impacts are yet to be developed. As a first step, habitats and species most at risk under climate change in Europe are to be identified by 2007. The aim is to develop appropriate management plans and to support the establishment of coherence within the Ecological network as defined under the Natura 2000.

An increase risk of drought in the Mediterranean represents an important impact of climate change on society in Europe. Currently water scarcity already threatens ecosystems and social well-being in some southern European regions. This case study highlights the multidimensional consequences of reduced water availability and the need for adaptation actions to address such adverse impacts.

These case studies neither cover the full range of key vulnerability issues in Europe nor do they necessarily reflect any hierarchy of importance. Rather, they are intended to provide a balanced selection of examples to illustrate the different aspects of the complexity of vulnerability to climate change and associated impacts in Europe.

A1.1 Case study 1 — system vulnerability: natural Ecosystems in Europe

Natural ecosystems are an important part of the European landscape. As shown in Table A1, natural ecosystems provide a wide range of goods and services, which are vital to sustain the natural environment and human well-being. In particular, terrestrial ecosystems play an important role in the global carbon cycle since they store about three times the amount of carbon in the atmosphere and the surface layer of the ocean, and exchange rates with the atmosphere are fast (Prentice *et al.*, 2001). Furthermore, natural ecosystems are important for their role in preserving biodiversity. In this respect, biodiversity is defined as the genetic and species variation within ecosystems and the variation of ecosystems in a region. An increase in species richness is often associated with an increase in biodiversity and more stable ecosystems. This is, however, not necessarily the case if an environmental change results in the introduction of new species.

Table A1 Goods and services of natural ecosystems

Function	Goods and services
Production	Wood and fuel
Biogeochemical cycles	C, N and P cycle Carbon sinks Affecting global radiation balance
Soil, and water conservation	Flood and storm control Erosion control Clear water and air Water availability for irrigation
Animal-plant interactions	Biodiversity Landscape connectivity Recreation/tourism

Source: Gitay *et al.*, 2001.

Climate is considered to be an important determinant of large-scale distribution of natural ecosystems (see Table A2) because species can only successfully reproduce and grow within specific ranges of climatic conditions. Furthermore, climatic conditions (e.g. drought, high temperature and strong wind) are closely linked to ecosystem disturbances such as forest fires. There is a host of evidence that the observed changes in climate have already affected species and ecosystems both directly through the climate effect and indirectly through disturbances. If climatic conditions change, plant species have either to adapt or to migrate. This response is species specific and results in differences within ecosystems. If both types of responses are not feasible, species could become extinct. This case study reviews the impacts of climate change on natural ecosystems and identifies the most vulnerable ecosystems in Europe.

A1.1.1 Data and methodology

Studies investigating vulnerability of natural ecosystems to climate change vary widely with respect to methodological approaches, tools applied, and scales of the assessment. All studies assess, for example, the sensitivity of natural ecosystems to climate change, whereas only the ATEAM project considered the issue of adaptation (Metzger and Schröter, 2004). The ATEAM project explored how society adjusts to changes in ecosystem goods and services, and suggests that planned adaptation is a function of the type of ecosystem, time (e.g. because of multiple stresses) and the scenarios used (see Box A1). Secondly, some studies assessed the vulnerability of natural ecosystems on a global scale (e.g. Smith and Hitz, 2003), others only for Europe (e.g. AIR-CLIM, ATEAM). A third difference is that some studies assess vulnerability of individual ecosystems (e.g. alpine meadows) whereas others undertake more aggregated assessments (e.g. AIR-CLIM considered natural land-cover types). Although the differences in approaches are likely to affect the outcomes, these studies have arrived at largely consistent conclusions on the most vulnerable natural ecosystems across Europe. Finally, studies differ with respect to the consideration of adaptation.

These assessments also share a set of similarities in their methodological framework. Firstly, these studies include a detailed understanding of ecosystems responses with some broad-scale assumptions, expert knowledge (e.g. based on stakeholder

Table A2 Temperature increases and possible impacts on ecosystems and biodiversity

Global mean temperature increase (above pre-industrial)	**Example of possible impacts**
< 1 °C	• Limited ecosystem shifts • Suffering of and initial losses in hotspots like coral reefs, and wetlands • Suffering of plant and animal species in arctic regions
1–2 °C	• Severe losses of area and species in some protected areas and mountain regions • Severe harm on wildlife in arctic ecosystems • Large impacts on wetland ecosystems • Losses of coral reefs without possible recovery • Melt of permafrost with varying consequences on environment and societies.
> 2 °C	• > 20 % shifts of ecosystems • > 10 % loss of coastal wetlands • Severe disruptions and losses of coral reefs • High risk of loss of protected areas • Large-scale losses of species, e.g. in mountain summits

Source: Arnell *et al.*, 2002; Gitay *et al.*, 2002; WBGU, 2003; ACIA, 2004; Leemans & Eickhout, 2004; Toth, 2002.

workshops) and multiple scenarios. Secondly, most studies assessed vulnerability in terms of sensitivity and exposure to global mean temperature increase and changes in average precipitation. An exception to this was the WWF (2004) study which also considered vulnerability to extreme weather events and suggested that assessments without considering extreme events result in an under-estimation of ecological impacts. To make projection of natural ecosystem exposure to future climate risk, vulnerability assessments usually combine empirical knowledge with modelling tools. Models used in these assessments differ in complexity. Some of the studies simply use published model results whereas others (i.e. AIR-CLIM, ATEAM, OECD) conduct modelling exercises themselves.

Climate scenarios were mostly constructed from outputs of the HadCM2/3 climate and/or the ECHAM 3/4 model experiments. The AIR-CLIM and ATEAM projects compared the final results of using different climate model outputs. Socio-economic futures are largely derived from the IPCC Special Report of Emission Scenarios (Nakicenovic *et al.*, 2000). This improves the comparability of the results from different assessments and allows for the exploration of uncertainties associated with emission scenarios and climate models.

A1.1.2 Key pressures

Most natural ecosystems in the world and the biodiversity within them are already exposed to multiple pressures other than climatic constraints. Many ecosystems in the world, including Europe, suffer, for example, already from land-use changes, air pollution, landscape fragmentation and habitat destruction (Kundzewicz *et al.*, 2001). These pressures have led to the degraded functioning and species extinction that is at a rate 100–1 000 times greater than is considered normal over history (Hare, 2003).

Regarding climate change, natural ecosystems are relatively vulnerable compared to other systems like agriculture (Smith and Hitz, 2003). This is due to

- High level of sensitivity and susceptibility

The high level of sensitivity and susceptibility of natural ecosystems to climate change can be

Box A1 Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM, http://www.pik-potsdam.de/ateam/ateam.html) Project

Funded under the EU's 5th Framework Programme, ATEAM's main objective is to assess the vulnerability of human sectors relying on ecosystem services with respect to global change. A set of internally consistent socio-economic, climate, land-use and nitrogen deposition scenarios were developed and applied in a comprehensive modelling framework for projecting the dynamics of ecosystem services provided by European terrestrial ecosystems at a regional scale. The ability of human sectors to implement planned adaptation measures was considered using indicators of adaptive capacity. Stakeholders were engaged in the assessment through dialogues right from the start of the project in order to provide applicable results to the management of natural resources in Europe. It was concluded that the provision of essential ecosystem services will change significantly with global change during the 21st century. Specific vulnerability of sectors and/or regions can be reduced by specific adaptation strategies.

Source: Schröter *et al.*, 2005.

illustrated by the changes in distribution of various bird, plant, lichen, insect, spider and fungi species that have already been observed in Europe and other parts of the world. The alteration of species ranges is especially relevant because species will not move to the same extent or at the same rate. This could result in the loss of entire ecosystems. In some cases, ecosystems are forced into conditions they have never experienced. Regarding the latter, small additional changes in climate can have significant consequences before the complete distortion of the ecosystem becomes visible (WWF, 2004).

- Changes in average and extreme climate conditions

An increase in the frequency of ecosystem fires and changed birth rates has been observed. Various observed changes are (partly) attributable to recent changes in average and extreme climate (EEA, 2004b; WWF, 2004). For example, a northward extension of thermophilic (warmth demanding) plant species has been observed in the Netherlands (Tamis *et al.*, 2001), the United Kingdom (Preston *et al.*, 2002), and Central Norway (Often and Stabbetorp, 2003).

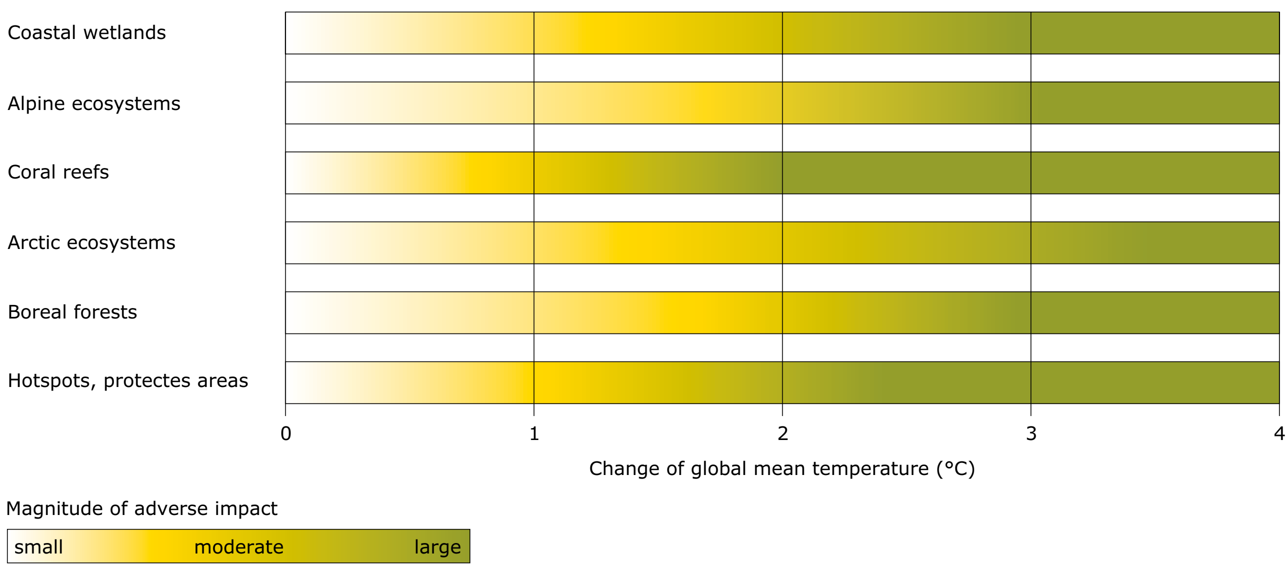
- Low level of adaptive capacity

Managed systems such as agriculture can adapt to climate change, e.g. by changing crop types on a regular base. However, natural ecosystems such as natural forests are adapted to long-term relatively constant climate periods and are therefore vulnerable to significant and fast changes of their environment. Furthermore, most ecosystems have narrow ranges of environmental conditions in which they exist (i.e., environmental envelopes). Current rate of change is likely to exceed tolerance ranges of various species (Smith and Hitz, 2003).

A1.1.3 Key vulnerability issues

Vulnerability of natural ecosystems differs between ecosystems, regions, indicators and time. Globally, the most vulnerable ecosystems are coral reefs and mountain regions with retreating glaciers and changing plant species composition, wetlands and dry communities, and arctic regions (see Figure A1). For Europe WBGU (2003) identified four vulnerable ecosystem regions (see Table A3). Sensitivities of species distributions in Europe are illustrated in Figure A2. Vulnerability of these regions is discussed in detail below.

Figure A1 Visualisation of climate change impacts on selected vulnerable ecosystem types



Note: Visualisation of climate change impacts on some ecosystem types. The risk of adverse impacts due to different climate-related parameters increases with the magnitude of climate change. Global mean temperature rise since 1861–1890 is used as proxy. The figure presents a global summary of expected adverse impacts upon some examples of global ecosystem types. This takes the form of a highly aggregated conceptualisation. Regional impacts may be more or less severe than the global averages shown. The figure does not reflect a quantitative approach but a fuzzy assessment of risks based on case studies and reviews. The assessment takes into account only the magnitude of climate change and not the rate of change.

Source: WBGU, 2003.

Table A3 Regions vulnerable to climate change in Europe

Regions	Example impacts that affect ecosystems
Arctic regions (especially Greenland)	Loss of endemic plant species Thawing of permafrost Reduced habitats and changed food sources for endemic animals
Mountain regions	**Loss of endemic plant species**
Coastal zones and wetlands	Changes in water quality due to algal blooms Changes in distribution of marine species More landward intrusion of sea water (i.e. salinity)
Mediterranean region	More frequent droughts and fires Land degradation due to salinity Loss of wetlands (e.g. due to sea level rise and climate extremes)

Arctic regions

Ecosystems in arctic regions are highly vulnerable to climate change because observed and projected climate change is among the greatest in Arctic regions, and the adaptive capacity is relatively low. Consequently, arctic mammals, for example, might suffer from a global temperature increase of 1.7–2.2 °C . Likewise, substantial (up to 50 %) area of tundra ecosystems might be replaced by boreal forests under a 1.3–3.8 °C rise in global average temperature. The latter, in turn, can have global implications because tundra vegetation reflects more solar radiation than forested areas. A conversion of tundra into boreal forest could therefore enhance global warming.

Numerous impacts of climate change on nature and local societies have been observed in arctic regions. Winter temperature in some parts has already increased by 3–4 °C over the last century (ACIA, 2004; EEA, 2004b). Impacts of these climatic changes are, for example, increased areas of tree growth and a decrease in the Greenland Ice sheet and sea-ice extent. These changes might have devastating consequences for marine mammals.

Climate models show that a 2 °C increase of the global average temperature implies an increase of 3.2–6.6 °C for the arctic region. Therefore projected temperature increases in the range of 4–7 °C are likely by the end of the 21st century (ACIA, 2004; Gitay *et al.*, 2002; Gitay *et al.*, 2001). Possible consequences of such temperature rise include:

- *Decline of permafrost* (12–22 % by 2050). This will affect infrastructure and hydrological cycle.
- *Reduction of sea ice extent.* By 2050, sea-ice extent might be reduced by up to 80 % compared to the same area in the mid-20th century, and might completely disappear by the summer season of 2100 (Johannessen and Bengtsson, 2002).
- *Increased soil decomposition* (the net effect on carbon balance depends on increased productivity of ecosystems).
- *Changes in plant and animal species composition.* This will result from a northwards shift in extension of some species (various tree and shrub species). Tundra area could shrink by two-third and be replaced by forests.

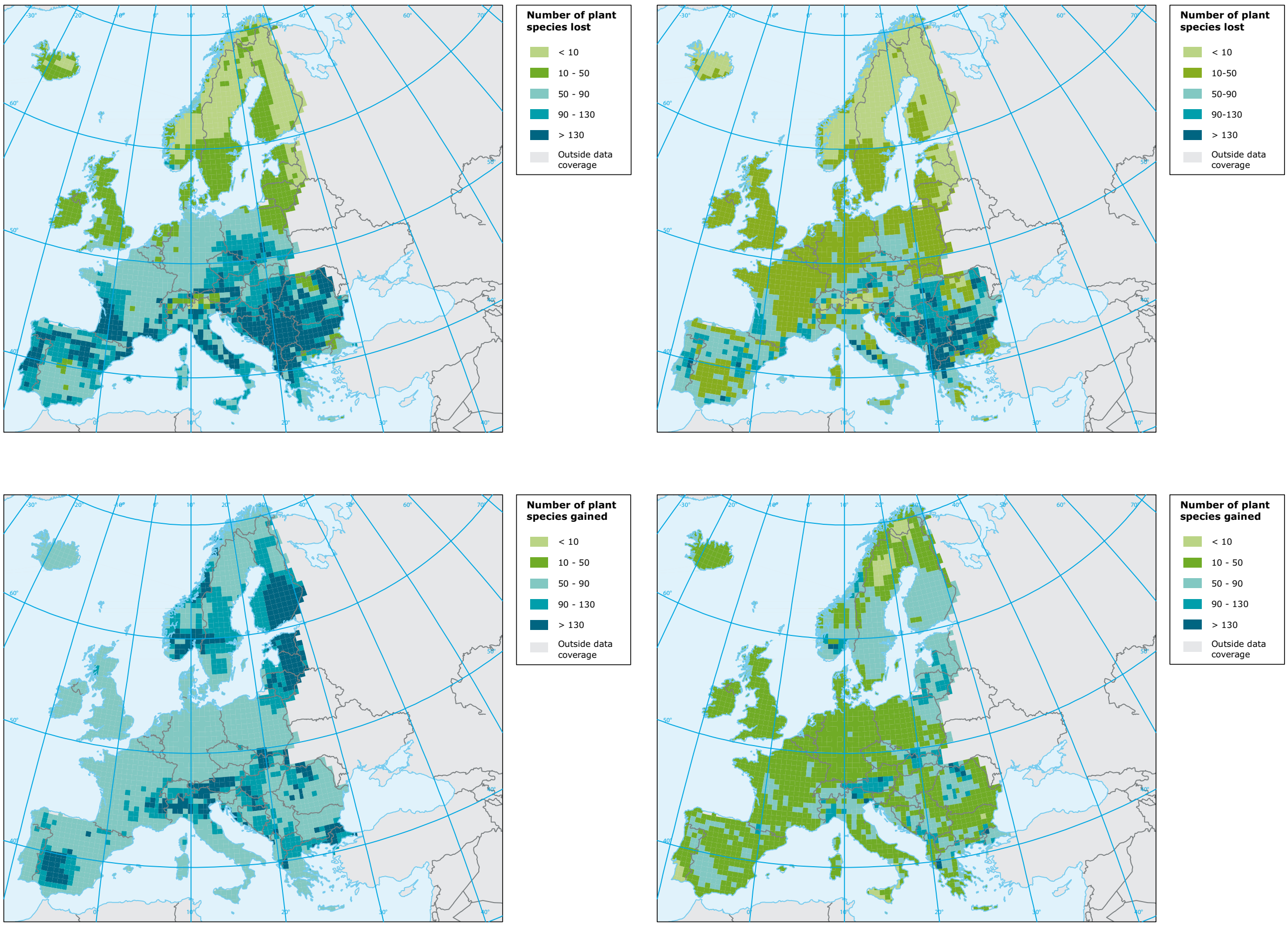
Mountain regions

Mountain regions like the Alps, Pyrenees, Iberian System, Apennines and Carpathians mountains are important reservoirs of biological diversity in Europe. The functioning and distribution of biodiversity within these mountain ecosystems are in general governed by changes in land-use. But climate change plays an important role in undisturbed mountain summits. Species in these regions are in general able to cope with a local warming of 1–2 °C. But some species, especially endemic species, might face problems under such limited changes in temperature because they are unable to compete with immigrating species and are not able to migrate (Gitay *et al.*, 2002). Extinction of more than 90 % of species is expected by temperature increases above 3 °C.

Observed changes in temperature and longer growing seasons associated with climate change have created suitable growing conditions for plant species that have migrated upwards and which now compete with endemic species (Gottfried *et al.*, 1999: Grabherr *et al.*, 1994). The net effect on species richness varies from region to region and even within single regions. In some cases, like at some summits in the Alps, it has led to an increased species richness, compared to 50–100 years ago (Grabherr *et al.*, 2002; Motta and Masarin, 1998; Theurillat and Guisan, 2001).

Future climate change is projected to affect species distribution in mountain regions considerably.

Figure A2 Changes in plant species distribution in Europe due to climate change



Note: The left figure shows the number of plant species lost (top) and gained (bottom) under a baseline scenario in 2100. The right figure shows the same for a limited climate change scenario (i.e. global temperature increase remains below 2 °C).

Source: EEA, 2005.

A specific model application showed that a 1 °C additional warming would result in the loss of 40 % of the potential range of 62 endemic mountain species in the Alps, whereas a 4–5 °C warming would imply a 90–97 % loss (Hare, 2005; Pauli *et al.*, 2001). Endemic species suffer especially, because they will be unable to adapt to the changed environment, can not migrate to more appropriate locations and can not compete with immigrating (shrub and tree) species. In the lower Alps the treeline is projected to climb and the competition from Norway spruce is likely to adversely affect the growing conditions of endemic plant species (Theurillat and Guisan, 2001). Likewise, EEA (2004b) showed that some species (e.g. mountain bladder fern, *Cystopteris montana*) will disappear in considerable parts of their current habitats. Finally, a 40–60 % loss of the current area of mountain vegetation is projected for Scandinavia (Holten and Carey, 1992).

Coastal wetlands

Coastal zones in Europe support a mixture of ecosystems that provide important habitats and sources of food. These ecosystems are vulnerable to climate change for two reasons: Firstly, because many of these regions are below sea level or frequently flooded. Therefore increasing sea-level and more frequent storms could have devastating impacts. These events may not only affect the presence of the ecosystems but also the functioning (e.g. increasing salinity reduces the production). A key factor is the tidal range. In general, the smaller the tidal range, the greater the susceptibility to increasing sea level (Kundzewicz *et al.*, 2001). The Mediterranean and Baltic coastal wetlands, which have low tidal ranges, are therefore considered to be more vulnerable than wetlands in the Atlantic and North Sea. Secondly, many marine ecosystems in coastal regions are vulnerable to climate change because many of them occur at or close to their temperature tolerance limits. In general, the risk of damage is low for most but not all ecosystems in coastal regions with less than 1 °C of global average temperature increase. Nevertheless, some changes in species composition in marine eocystems has been observed under the current climate trend (Edwards *et al.*, 2005). More serious impacts are expected at 2–3 °C of global warming. Such an increase might, for example, result in about 50 % habitat loss in Mediterranean and Baltic coastal wetlands (Hare, 2003).

Projected climate change will intensify the already observed effects due to the high vulnerability, especially if the change in average climate is accompanied by changes in storms and surges. The largest losses in Europe have been projected for the wetlands along the Baltic and Mediterranean coasts. Estimates vary between 84–98 % and 31–100 %, respectively (Gitay *et al.*, 2002; Kundzewicz *et al.*, 2001).

Mediterranean region

Various studies (e.g. Körner *et al.*, 2003; Schröter *et al.*, 2005; van Minnen *et al.*, 2002) concluded that Mediterranean ecosystems are among the most vulnerable ecosystems in Europe. Multiple potential impacts on a number of sectors were projected and combined with low adaptive capacity. Various ecosystems in the Mediterranean are close to the environmental limits, for example with respect to their ability to cope with drought stress (see AI.3). Slight temperature rise and precipitation reduction could have therefore severe consequences on various species. These species could be replaced by more drought resistant tree species (Hare, 2003). However, this will lead to reduced species richness in Mediterranean ecosystems (Gitay *et al.*, 2002). Likewise, experiments show that for Mediterranean-type scrubland communities, drought and warming over 4 consecutive years have decreased the species richness (Lloret *et al.*, 2004). Even without changes in species richness, increasing drought risk could reduce the productivity and carbon sequestration of Mediterranean ecosystems (Körner *et al.*, 2003; van Minnen *et al.*, 2002). In addition, increasing temperatures and reduced precipitation will further increase fire risk in the Mediterranean region (see AI.3). Disturbances such as fire risk are a crucial determinant for the survival of various species, and an increase in such risks may reduce the species richness (Kundzewicz *et al.*, 2001). An additional threat to Mediterranean ecosystems is the projected sea level rise that endangers Mediterranean wetlands (Gitay *et al.*, 2002; Kundzewicz *et al.*, 2001).

A1.1.4 Policy linkages

As stated in *Article 2* of the UNFCCC, the ultimate objective of the Convention is to '*.achieve the stabilisation of greenhouse gas concentrations in the atmosphere.. within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, .*'. This means that there is within the UNFCCC a clear link between climate change and the conservation of nature, ecosystem goods and services and biodiversity. Links between biodiversity and climate change have also been made in the UN Convention on Biological Diversity (UNCBD). An expert group has, for example, been established to assess the climate change impacts on biodiversity in different ecosystems and to define possible adaptation options (CBD, 2003). Likewise, the CBD is seeking collaboration with other UN organisations (including the UNFCCC) to address the link between biodiversity and climate change at the national, regional and international levels. Such explicit integration between climate change and the adaptation of natural ecosystems has, however, rarely been included in EU or national policy plans and directives. Plans and directives regarding the adaptation to climate change are seldom directed towards the protection of natural ecosystems and vice versa. They more often address the water issue or coastal protection. Climate change concern has often been raised to strengthen the need to implement the existing policies that aim to protect natural ecosystems.

On the one hand, targets such as those included in the EU Habitat and Bird Directives can only be achieved if opportunities are created for adapting to environmental changes like climate change. Although there is a lack of understanding about the 'autonomous adaptation' of natural ecosystems to climate change, one clear direction is to migrate towards new, more appropriate regions. The EU Natura 2000 initiative might be an effective instrument to improve migration possibilities and therefore strengthen the adaptive capacity of ecosystems, albeit climate change is not explicitly mentioned. Natura 2000 is a comprehensive ecological network of valuable habitats in the EU. The Member States of the EU have so far proposed about 15 000 areas with a total area of about 420 000 km^2 (i.e. 15 % of total EU-territory) to be part of Natura 2000. This includes all protected regions that fall under the Habitat and Bird Directives. The numbers are likely to increase in coming years since some countries have not yet nominated the areas in their territory. Unfortunately, at this moment the Natura 2000 is still merely a collection of fragments with little connectivity, which covers the species' ecological needs for breeding, staging and wintering. This puts habitats and species contained in the designated areas at risk. Improved connectivity of ecological areas in Europe and the promotion of ecological coherence, could strengthen the resilience of ecosystems to climate change. The promotion of ecological coherence is mentioned in art. 10 of the Habitat directive and stresses the maintenance of various ecosystems features. These ecological corridors are, for example, stimulated within the pan European Ecological Network (PEEN, www.ecnc.nl) and also included in documents of a stakeholder conference held in 2004 in Malahide on vulnerability and adaptation of habitats and species to climate change (Malahide, 2004). Member states like the Netherlands incorporated the information of the Natura 2000 in policy plans and regulations in order to create 'green corridors' that connect the ecological hot spots and as such should strengthen the resilience of ecosystems to climate change.

The national ecological plans are often implemented by:

(i) providing subsidies to farmers, land owners and others that protect nature areas;
(ii) explicitly making links to other policy objectives, this increases the likelihood of success (see Section 4). In the Netherlands, for example, synergies between water management and agriculture are sought to optimize land use, for example, nature development in flood prone areas in combination with flood retention.

On the other hand, a high level of biodiversity has been considered as a boundary condition for natural ecosystems to adapt to climate change (CBD ad hoc group). Likewise, the EU common agricultural policy (CAP) includes explicit links between the protection of biodiversity and achieving sustainable development goals.

Despite the lack of explicit consideration of ecosystem in relation to climate change in EU and in many national policy plans, various initiatives have recently been taken to identify options for natural ecosystems to adapt to climate change. The revision process of the EU biodiversity strategy is an example. The aforementioned stakeholder conference held in Malahide, which explicitly dealt with the issue on climate change, assessed vulnerable habitats and species, and defined adaptation strategies for ecosystems. Various member countries expressed their concern regarding the vulnerability of ecosystems and the willingness to support adaptation to climate change impacts. Afforestation and conservation of existing forests, for example, have been considered by southern European countries and the European Commission in the context of combating future risk of desertification. More detailed discussions on adaptation measures in member countries are presented in Section 4 of this report.

A1.2 Case study 2 — regional vulnerability: the Alpine Region

The Alps cover an area of 190 000 km². The range is 1 100 km long and 170 km wide. 14.2 million people live in the territory of its eight countries: Austria, France, Germany, Italy, Liechtenstein, Monaco, Slovenia, and Switzerland. The ridges have an average elevation of 2 500 m above sea level with a maximum up to 4 800 m. They are a barrier for atmospheric circulation. The alpine ridge separates maritime temperate from Mediterranean climate and creates its own regional climatic conditions. The combination of complex orography and climatic gradients leads to a great variety of environmental conditions with strong gradients over short distances. The higher parts are rarely affected by direct human activities like climbing, hiking or

Key messages, case study 2 — regional vulnerability: the Alpine region

1. The Alps are particularly vulnerable to climate change and already suffering from higher increases in temperature than the European average.
2. Climate change is already affecting biodiversity and discharge of alpine rivers and is increasing natural hazards. It leads to economic losses in winter tourism especially in areas at lower altitudes. These trends are projected to be exacerbated under enhanced climate change.
3. Non — climatic pressures, which includes competition for the limited land from urbanisation and construction of infrastructure and trans-alpine transport, enhance the vulnerability in the area.
4. In contrast to most European regions, the Alps are covered by a convention to protect the environment in place (the Alpine Convention and its protocols). This convention could become a powerful instrument to implement trans-national strategies for adaptation to climate change and sustainable development in the region.

skiing. Such activities only exist in moderate heights. In contrast, valleys are often densely populated with high pressure on the very limited land due to competing needs for settlements, infrastructure, agriculture and recreation.

The Alps provide important services for the surrounding low-lands as well. They ensure continuous water supply, ecosystem goods and services, such as wood products or hydro-power, and serve as sources of inspiration and recreation. Furthermore, the Alps are an important reservoir of biological diversity. About 15 % of the 2 500 high alpine species living above the tree-line are endemic (UBA, 2004). A large variety of traditional land-use forms increases the diversity of ecosystem types. High altitude pastures have been created and have been managed for 2 000 years, depressing the tree-line by about 300 m. These human activities formed the current landscapes, which helped make the region an attractive tourist destination (Paulsch *et al.*, 2003).

Currently around 60 million people visit the Alpine area for holidays. The area accommodates 370 million stays per year with more than 60 million people making day trips, especially to areas close to major cities and along roads (UBA, 2004). This generates an annual revenue of about 50 billion euros for the region (BMU, 2004). Tourist activities are concentrated in 10 % of the local communities only. This provides about 10–12 % of the jobs in the alpine region (Bätzing, 2003). In some areas like Zermatt, Switzerland, tourism represents the single most important source of income.

However, increasing pressures are arising from changes in socio-economic conditions, land-use and land-management practices, resource exploitation, increase in traffic on transit routes and increased tourism (GLP, 2003).

A1.2.1 Data and methodology

Various international, national, and sub-national activities were initiated to investigate the risk arising from natural hazards for economic development in the Alps. Adaptation and vulnerability to climate change are seldom mentioned explicitly but the notion is embedded in the objectives of these studies to reduce risks and promote sustainable development within specific sectors and/or regions (e.g. 'Future of the Alps' — Programme ([49])). Focus for assessing vulnerability and adaptation in the Alpine region is on tourism and natural hazards.

There are only few studies that deal explicitly with adaptation to climate change. Detailed analyses are available, e.g. the impacts of climate change on winter tourism in the Alpine region (e.g. Abegg, 1996; Bader and Kunz, 1998; Beniston, 2000). Multi-sectoral studies were undertaken for Austria (Steininger *et al.*, 2005) and Switzerland (Bader and Kunz, 1998) using either a mix of national assessments and case studies (Switzerland) or analysing adaptation on national strategic level (Austria). The final report of the working group, 'environmental targets and indicators' of the Alpine Convention (UBA, 2004), provides a comprehensive overview of available data in the region.

Assessments reviewed in this case study employ a wide variety of data, methods and tools. Climate, ecosystem and hydrological models were used in various impact assessments. Observed climate data were analysed to detect trends in climate and extreme events (e.g. AustroCLIM ([50]); Bader and Kunz, 1998). There are relatively few assessments using climate change scenarios. In most cases outputs from global circulation models (GCMs) and down-scaling methods are used for interpreting temperature changes (Bürki, 2000). In some studies detailed climate change scenarios were created for various time periods (e.g. BayFORKLIM ([51]), ProClim ([52])).

A1.2.2 Key pressures

The combination of current changes in environmental and economic conditions results in a spatially heterogeneous pattern of stresses within the alpine area. Key environmental pressures in the Alps can be summarised as follows:

- Changes in temperature affect snow-cover, snow pack and biodiversity. Temperature changes in the Alps are more significant than global or hemispheric average (Beniston, 2004). Minimum temperatures increased by about 2 °C in the last century. Increase in maximum temperature is closer to the hemispheric average (Beniston, 2004). The warming experienced since the early 1980s is, however, of far greater magnitude. This is in line with the global and European trend.

([49]) http://www.cipra.org.
([50]) http://www.austroclim.at.
([51]) http://www.bayforklim.uni-muenchen.de/.
([52]) http://www.proclim.unibe.ch.

For the Säntis station in Switzerland (2 490 m) and the Sonnblick station in Austria (3 106 m) for example, last century's warming exceeded 1.5 °C, which is more than twice the global average warming (Auer and Böhm, 2004; Diaz and Bradley, 1997). Warmer winter and extreme weather events already increased in frequency and intensity (Beniston, 2004).
- Changes in precipitation patterns, particularly extreme weather events (droughts and floods) affect tourism, transport and natural hazards. Land-slides and flash-floods already cause more and more damages to infrastructure and settlements (Bader and Kunz, 1998; Steininger and Weck-Hannemann, 2002).
- Changes in the wind regimes with the foëhn effect associated in leeward sides can affect the snow and vegetation distribution and human health.
- Land-use changes and conflicts arise from urbanisation and competition between different sectors.

There is growing urbanisation in major valleys and areas close to European centres like Marseille, Milano, Munich, Ljubljana, Zürich, and other major cities. This affects around 26 % of the alpine area as it bears around 60 % of the population (Kanatsching and Weber, 1998). Growing demand on land increases the competition for the very limited resource (UBA, 2004). Areas at higher risk of flooding and land-slides are now used for housing and infrastructure. Warmer winters lead to an upward shift of skiing resorts. Tourism competes with nature protection in high elevation areas, especially on glaciers.

In more remote areas people migrate due to lack of income. Three hundred ski-resorts are concentrated in 600 of almost 6000 local communities. Here, there is potential for further concentration. 19 % of the area faces increasing economic problems. For 18 % of the area, the economy, settlements and cultural heritage are breaking down as people leave (Bätzing, 2003; Kanatsching and Weber, 1998). This is particularly the case in southern France, some parts of Italy (e.g. Piemont) and Slovenia. Only tourism can reverse this trend but the number of tourists visiting the Alps has either been constant or decreasing since the 1980s. In these areas forests move into grassland and the area becomes less attractive for tourism (Bader and Kunz; 1998).

- Increase in air and noise pollution on transit routes, major roads and in cities affect human health.

Traffic for tourism and transportation causes high levels of air and noise pollution, which affects residents along the transit routes across the Alps. In Austria, France and Switzerland, for example, around 6 % of the overall annual cases of death are attributable to air pollution from traffic (UBA, 2004). Annual total transport services in the alpine area currently stands at 100 billion km and is projected to increase significantly.

A1.2.3 Key vulnerability issues

The following vulnerability issues are identified under the pressures discussed above:

- Increasing risks of economic losses in winter tourism due to warmer winter and less snow-cover, especially in lower altitudes (e.g. less than 1 500 m).

Winter tourism is highly dependent on snow cover and is therefore very sensitive to changes in climate conditions. Tourist resorts need snow at the right time (e.g. starting in late December) for landscape attractiveness and the right snow pack for outdoor activities (Elsasser and Messerli, 2001). Too much snow causes severe damage. This results from both avalanches and closed lifts and roads, which prevent tourists from reaching their destinations. This happened, for example in the winter of 1999 in Switzerland (Elsasser and Messerli, 2001; Nöthiger, 2003). Over the past years both the number of tourists and accommodation have been constant or slowly declining (UBA, 2004). Consequently, there is increasing competition between tourist resorts and the pressure for new investments (e.g. snow making facilities, wellness and higher standards in infrastructure) to make the destinations more attractive and profitable. Due to changing climate conditions, the overall number of lifts in the Alps is slightly decreasing and in areas at low altitudes ski-resorts are already closed or will be closed in the near future (Güthler, 2003). Therefore, resort managers are under pressure to adjust their strategy (e.g. diversify their services, relocate their business, invest in new facilities) in order to maintain the viability of their businesses.

- Increasing vulnerability of settlements and infrastructure to natural hazards, such as flash-floods, avalanches, land-slides, rock fall and mudflows (Beniston, 2004) due to heavy rain- and snowfalls and the upward shift of the permafrost line (UBA, 2004)

Warmer climate also leads to an upward shift of the permafrost line, which causes a widespread reduction in stability of formerly glacierized or perennially frozen slopes. It also increases the risk of land-slides and sediment loads in rivers and lakes (Haeberli and Beniston 1998; Haeberli *et al.*, 1998). Retreat of permafrost also destabilises the infrastructure in high altitudes like lodges, lifts and top stations. Hence, this increases the need for additional avalanche protection (Bader and Kunz, 1998; Keller, 2005) and the risk of damages and accidents by rock-falls. There is a need for public investments to improve the protection of settlements and infrastructure from natural hazards like floods, avalanches and landslides due to decreasing slope stability and dangerous ice- and moraine-dammed lakes (Haeberli and Beniston, 1998; UBA, 2004). This is especially pertinent to tourist resorts and in areas where urbanisation is currently taking place. This increases the public costs for avalanche barriers and flood protection facilities.

- Changes in biodiversity and stability of ecosystems

Alpine species are in danger of being out-competed either by other grassland species or by trees and shrubs migrating upwards under increasing temperature, atmospheric CO_2 concentration and land-use change (reforestation of pastures) (Bader and Kunz, 1998; Beniston, 2004). The number of forest fires is increasing due to rises in temperature, reforestation and immigration of species from warmer climates. Changing climate threatens the stability of forest ecosystem, especially in planted forests which are not even adequately adapted to current site conditions (e.g. 25–30 % of Swiss forest sites) (Bader and Kunz, 1998) (see also AI.1 for discussion on vulnerability of natural ecosystems).

- Changes in water balance

Due to the combination of glacier retreat and reduction in snow-cover and snow-pack, the water balance is likely to change in the important water exporting regions. This will also have adverse impacts on summer skiing and makes the landscape less attractive for summer tourists. Watersheds with glaciers have more water flow in summer with a higher risk of floods due to warm weather and heavy rainfalls. In basins without glaciers, the amplitude of water discharge is higher with flow reduction during summer. Impacts on hydro-power, water supply, power stations and navigation in the surrounding low-lands are also expected (Beniston, 2003; Braun and Weber, 2002; EEA, 2004b).

- Increasing vulnerability of human health and tourism due to heat waves (e.g. Beniston, 2004), flash floods (e.g. BMU, 2004) and to higher air pollution from traffic and energy consumption (UBA, 2004).

A1.2.4 Policy linkages

Environmental constraints in the alpine region are addressed by several national and international organisations (Mountain Research Initiative (MRI), Mountain Forum, Commission Internationale pour la Protection des Alpes (CIPRA), Greenpeace), alpine regional corporations (ARGE Alp, ARGE Alpen-Adria) and national NGOs (German and Austrian Alpenverein, Swiss Alpenklub, etc.).

The legislative framework for sustainable development in the Alps is constituted and regulated in the 'Alpine Convention' (BMU, 2004). The convention is binding for the 'Alpine space' (the territory of 5.934 communities) and to all parties according to international law. General targets are set in the Framework Convention. The practical execution of the convention targets is regulated in protocols. Nine protocols are in force since 18 December 2002. These are: 'regional planning and sustainable development', 'nature protection and landscape conservation', 'mountain agriculture', 'mountain forests', 'tourism', 'energy', 'soil protection', 'traffic', and 'settlement of disputes'. Further protocols for 'population and culture', 'water supply', 'clean air', and 'waste management' are planned (Mohr, 2002). All protocols were ratified by Austria, Germany, Liechtenstein and Slovenia. France and Monaco have ratified some. Switzerland will ratify several protocols in the near future. Italy and the EU have signed but not ratified (BMU, 2004). The Alpine Convention implements the principle of sustainable development into international environmental law according to the UN Conference for Environment and Development (Rio-Conference, 1992). It is the only framework worldwide established in a mountain area (BMU, 2004) and may serve as a very effective instrument to transform sustainable targets into measures and regulations. The challenge is not only to find a political consensus on sustainable development for the Alpine region (see also BMU, 2004; Güthler, 2003; Wessely and Güthler, 2004) but also to rise awareness among people on the problems of sustainable development under global climate change. This needs communication of both mitigation of climate change and adaptation to some unavoidable changes projected to take place in the next few decades.

National organisations in the region also attach increasing significance to the vulnerability of the

Key messages, case study 3 — sectoral vulnerability: droughts in the Mediterranean Basin

1. Environmental state, economic development and social wellbeing in the Mediterranean region are currently under multiple pressures such as desertification, water shortage and persistent urbanisation.
2. Projected temperature rise and decrease in precipitation will result in a reduction in water availability in the Mediterranean region. At the same time, water demand in the region will increase with a growing need for irrigation under a changing climate, changing lifestyle, rising demand for tourism, energy production and other economic activities. Hence, the currently already acute water shortage problem in the Mediterranean region will be exacerbated under projected climate change.
3. With the wide ranging adverse impacts of climate change and the relatively low level of adaptive capacity, the Mediterranean region is among the most vulnerable regions in Europe. Climate change will also pose a threat to the ecosystem and human well-being in the region.
4. Although legislation and processes exist to promote sustainable water resource management in the Mediterranean, policies and plans explicitly directed to address in the challenge of climate change impacts on water resources in the region have not been developed yet.

Alps to projected climate change. A wide range of adaptation measures are being developed and implemented to adapt the region to a changing climate. Details on specific adaptation measures and actions by national and sub-national organisations are discussed in Section 4 of this report.

A1.3 Case study 3 — sectoral vulnerability: droughts in the Mediterranean Basin

The Mediterranean basin is 3 800 km long and 400 to 740 km wide. It takes 90 years for the water in this sea to be completely renewed. Hence, it is especially susceptibility to pollution. The population is between 150 and 250 million depending on whether just the actual coastal strip is taken into account or the drainage basin of the Mediterranean. This population is growing mainly in the southern and eastern Mediterranean countries due, in particular, to growth in the urban population. The population along the north Mediterranean coast has more or less stabilised despite the attraction of the Mediterranean coastline, which produces an increase in population as a result of internal immigration.

The Mediterranean climate is characterised by the rainfall pattern. The maximum rainfall is in the autumn or winter, but rainfall is always low in summer when the heat is greatest. Vegetation is therefore particularly capable of adapting to periods of drought. From the north to the south this period of drought increases. It ranges from one to more than six months, and the average annual rainfall declines from 600 mm to less than 200 mm towards Libya. Finally, the erratic nature of the rainfall is another essential aspect. The area experiences very dry years which cause disasters, especially in the south.

The total amount of water available per capita per year, i.e. rainfall less evapotranspiration, depends on these two parameters, climate and population. As demand for water for agriculture, tourism or general population needs is greatest in summer and is growing in the southern and eastern countries, water scarcity will be virtually inevitable in some of the countries if present trends continue ([53]).

This case study focuses on vulnerability of the water sector as represented by an *increasing drought risk in the European Mediterranean/Southern Europe* under a changing climate. As described above, water availability in the Mediterranean is highly sensitive to changes in climate conditions (Bolle, 2003; Karas, 1997). In the last century the Mediterranean basin has experienced up to 20 % reduction in precipitation (Eisenreich, 2005). Such a trend is expected to worsen with increasing demand for water and reduction in rainfall in the region (Arnell, 2004; Rosato and Giupponi, 2003), see also Section 3.1.6).

A1.3.1 Data and methodology

A review of existing studies on the vulnerability of an increasing drought risk showed that most assessments focus on vulnerability of a single sector/

([53]) Source: http://www.europeangreens.org/peopleandparties/networks/med.narbonne.html.

aspect of the natural or human systems affected by droughts in the Mediterranean, such as:

- Hydrology: Several studies take a long-term view of Europe's future water resource (Arnell, 1999; Brando and Rodrigues, 2000; Henrichs and Alcamo, 2001). The MEDIS project follows an interdisciplinary research strategy investigating the vulnerability of the water sector.
- Agricultural production: The impacts of droughts including an increasing drought stress on agricultural production are investigated in numerous studies (Iglesias *et al.*, 2000; Iglesias *et al.*, 2003; Olensen and Bindi, 2002; Rizza *et al.*, 2004).
- Biological implications: Biological implications of and the vulnerability of ecosystems to droughts are explored in projects like VULCAN and studies such as Reichstein *et al.*(2002) and Lloret *et al.*(2004).
- Tourism: Perry (2003) provides a study of adaptation to drought conditions in the tourism sector, which is highly dependent on water resources and represents an important economic factor in the Mediterranean area.

A comprehensive assessment describing potential impacts of climate change for the Mediterranean region was conducted by Greenpeace (Karas, 1997). Examples of national integrated vulnerability assessments of possible changes induced by climate change are for Portugal the project SIAM and for Spain the project ECCE ([54]). A European wide vulnerability assessment was conducted under the ATEAM project (see Box A1). Multiple, internally consistent scenarios were developed, analysing potential impacts on and vulnerability of agriculture, forestry, carbon storage, water, nature conservation and mountain tourism in the 21st century. These were assessed and mapped for Europe (Schröter *et al.*, 2004).

There are a number of studies on the development and implementation of an integrated water resource management, which support the water framework directive (AQUADAPT, WaM-Me, WaterStrategyMan, MEDROPLAN, RICAMARE). These studies mostly do not explicitly consider climate change, vulnerability or adaptation, but take into account the issue of sustainability. These studies build networks and institutions that enable the enforcement of adaptation measures. The basic reference units for most of these studies are watersheds. These studies cover the European Mediterranean region — some of them including the Middle East and North Africa — or single Mediterranean countries or islands.

Nearly all of the vulnerability studies include stakeholder involvement. In most cases stakeholders are engaged as reviewers and/or end-users of the projects final products. Only few projects implement a continuous stakeholder dialogue during the entire duration of the study from the identification of future research and policy development. These projects invite a wide range of stakeholder from regional and local water administration bodies, representatives of major water users, water management scheme developers, NGOs which deal with water, farmers and farming cooperatives, tourism enterprises and operators, and residents/communities in need for water. An example of a systematic approach of stakeholder selection is to invite representatives for three main groups: decision makers from the public sector, business decision makers and opinion holders such as environmental journalists.

The majority of the studies investigating the vulnerability of an increasing drought risk in the Mediterranean require scenario data. Climate scenarios derived from global circulation models (GCM) form the basis for most assessments. The sources for the climate scenarios for the reviewed studies are mostly the results of the HadCM 2/3 (Gordon *et al.*, 2000; Jones *et al.*, 2001) and/or ECHAM 3/4 (Röckner *et al.*, 1996) models. Results from other GCMs (e.g PCM, CSIRO2, CGCM2, CCGG and CCGC) are used sometimes. Only few studies use other, more 'bottom-up' approaches (Lloret *et al.*, 2004).

The majority of the studies use climate scenario data as an input to impact models such as hydrological models (Arnell, 1999), water use models (Lehner and Döll, 2000), farm scale simulation models of agricultural production (Olensen and Bindi, 2002), crop models (Iglesias *et al.*, 2003) and economic models (Martinez *et al.*, 2003).

A1.3.2 Key pressures

To identify key vulnerability issues in the water sector, it is important to investigate the pressures from both the supply and demand sides. The balance between water supply and demand is

([54]) See: A Preliminary General Assessment of the Impacts in Spain Due to the Effects of Climate Change. http://www.mma.es/oecc/en_impactos2.htm.

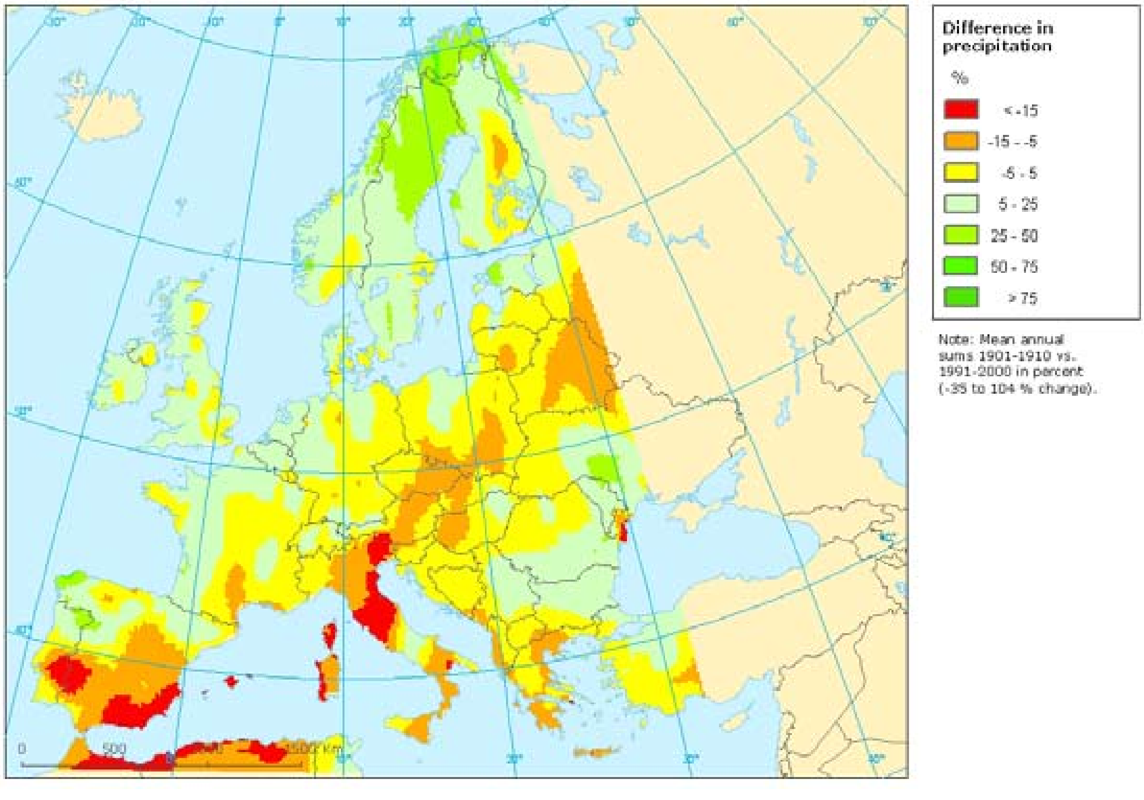
important in order to assess the vulnerability of a region facing an increasing drought risk. Assuming a constant demand, the environmental and socio-economic situation will worsen because water use is currently not sustainable in large parts of the Mediterranean (Karas, 1997).

- Supply side pressures

The supply of water is provided by terrestrial and aquatic ecosystems as an ecosystem service. Direct drivers of changes in water supply in the Mediterranean area include the amount of precipitation, evapotranspiration and river discharges:

- Precipitation: For the Mediterranean region, the majority of climate change projections suggest an increase in temperature and a decrease in precipitation (see Figure A3). This results in an increased drought risk (Eisenreich, 2005). The severity and location of the decrease in precipitation differs between climate models used. Alcamo *et al.*, (2001) suggested that there could be a decrease in precipitation by more than 25 % in parts of Iberian Peninsula and Turkey in 2070. Jacobeit *et al.*, (2005) project the largest decrease in precipitation for south-eastern Europe in this century.
- Rising evapotranspiration: An increase in warming-induced evapotranspiration and consequently a decrease in water supply is a further consequence of climate change. As a result, the risk rises for salinisation of the soils and surface water bodies. A reduction in water supply without a reduction in demand increases the risk of overexploitation of other water resources with negative consequences, such as saltwater intrusions into groundwater reservoirs.
- Declining river discharge and aquifer replenishment: The net result of the discharge is often used as an indicator assessing future water availability (Brando and Rodrigues, 2000; de Cunha *et al.*, 2002; Santos *et al.*, 2002: Schröter *et al.*, 2004). The results of ATEAM show that there is a broad consistency in the pattern of changes. There will be reductions in runoff in southern Europe and increases in northern Europe (Schröter *et al., 2004).* The aquifer replenishment is highly sensitive to changes in quantity and seasonality of precipitation and evapotranspiration.

Figure A3 Trend in mean annual rainfall during 1900~1998 over the Mediterranean region



Note: The numerical values in the grids indicate the rainfall changes in percent when the evolution follows a significant trend (P < 0.01).

Source: Hulme, 1999.

In addition, water supply is related to water storage capacity of the landscape. Landscape degradation, which influences both water quality and quantity, is a key supply side, non-climatic driver for vulnerability of the water sector in the Mediterranean.

Apart from the ecosystem service, the engineering supply of water resources is also an issue to address. The leakage from urban distribution networks and irrigation systems currently results in an enormous loss of water on the supply side. Without maintenance and repair of the pipelines, more water will be needed in the future because more arable land will be equipped with irrigation systems. Consequently, there will be more network systems with a risk of leaking. The construction of artificial water reservoirs often comes into conflict with nature conservation plans because they are placed in natural ecosystems and can disturb nature's unmanaged character.

- Demand side pressures

Direct drivers for changes in water use are public consumers, agriculture and industries:

- Rising public consumption: Population growth and changes in lifestyle are drivers of the increase in public water consumption. Especially in the new Member States life styles are rapidly changing due to the economic restructuring process, which is expected to lead to an increase of water consumption (Lehner *et al.*, 2001).
- Growing demand for irrigation: At present already 40 % of all food is produced by irrigated agriculture (Chmielewski, 2005). Due to growing population and climate change, the agricultural production will intensify its management including irrigation (CEDEX, 1998; EEA, 2003). This would also imply that the agricultural sector will experience increasing production costs (Martinez *et al.*, 2003).
- Increasing demand from industries: industries in the economically advanced countries have significantly increased the water use efficiency during the last decades (Scheele and Malz, 2005). By contrast, however, in countries with economies in transition — such as eastern European countries — the level of water recycling and wastewater treatment is much lower and the intensive use of available water resources can cause severe degradation in water quality and severe competition between water users (Alcamo *et al., 2001).*

A1.3.3 Key vulnerability issues

The following vulnerability issues of the natural environment to increased drought risk are identified:

- dehydration of terrestrial ecosystems, particularly the water dependent wetland environments. Currently 50 % of the major wetlands in Europe are already endangered (EEA, 2002);
- deficiency of water in fresh water ecosystems (rivers, lakes and reservoirs); and
- decline of groundwater tables caused by a lack of recharge.

A growing drought risk also poses secondary impacts on ecosystems:

- fires threatening ecosystems as well as society: the 2003 drought resulted in 25000 reported heath and forest fires in Europe (Eisenreich, 2005);
- desertification: hotter and drier conditions will enhance the process of desertification including erosion, salinization and reductions of soil quality (Baumhauer, 2005; Karas, 1997);
- environmental degradation of ecosystems including a loss of species (Karas, 1997);
- acceleration of groundwater decline, which includes an increasing risk of saltwater intrusion, caused by an overexploitation of the existing water resources (EEA, 2003);
- deterioration of water quality through higher concentration of pollution in rivers, lakes and reservoirs. This is caused by increased abstraction;
- eutrophication as a consequence of higher water temperatures. This includes an increase in the demand for oxygen and consequently anaerobic conditions in the water body, which ultimately endangers fresh water wildlife (Hupfer and Kleeberg, 2005).

At the same time, drought conditions have wide ranging implications for the socio-economic sectors and activities:

Droughts in the Mediterranean cause water shortages for domestic, agricultural and industrial water use and low flows for hydropower and cooling water. The use of alternative resources and their overexploitation could increase the risk of water quality deterioration. Sub-standard drinking water endangers human health through cholera and dysentery (Casimiro *et al.*, 2002). Water deficiency for agricultural production can lead to increases in irrigated cultivation or increased harvest failures

(Martinez *et al.*, 2003). Many economic activities, especially in Southern Europe (e.g. tourism), depend on available water. Shortages in water availability directly affect the economic performances.

The already acute challenge of water shortages in the Mediterranean will be exacerbated by more frequent and severe droughts projected under a changing climatic regime (Schröter *et al.*, 2005). For Southern Europe, model results show increased water stress under changing climate conditions (Arnell, 1999; Henrichs and Alcamo, 2001; Schröter *et al.*, 2004). Meanwhile, water demand is expected to increase as a result of population growth, changes in lifestyles and agricultural production. Vulnerability to drought is therefore increasing (Eisenreich, 2005). Hence, adaptation measures to address these adverse impacts are important in the Mediterranean region.

A1.3.4 Policy linkages

Many international and national policies and measures exist aimed at sustainable water resource management in Europe. These include, in particular, the Water Framework Directive (WFD) (2000/60/EC). The United Nations Convention to Combat Desertification UNCCD is a worldwide approach to foster sustainable development of countries affected by drought and desertification. The WFD aims to protect inland surface waters, transitional waters, coastal waters and groundwater. It requires an assessment of the ecological status of rivers, lakes, transitional and coastal waters. Drought is one issue the WFD aims to address. As a Europe wide policy, the EU's common agricultural policy (CAP) aims to preserve of the rural environment (Olensen and Bindi, 2002). The implementation measures under the CAP could indirectly address the challenge of drought. In particular, measures that provide improvements for water retention capacity will help to improve water availability and alleviate droughts. Drought is not mentioned in European energy policies despite impacts on water supplies for hydropower and the restrictions on consumer electricity consumption during hot summers (Eisenreich, 2005).

In the Mediterranean, water is a priority in the majority of relevant regional processes, e.g. the Euro-Mediterranean Partnership, Barcelona Convention, MCSD, the Blue Plan etc. As shown by the Mediterranean Information Office for Environment Culture and Sustainable Development (MIO-ECSDE), measures to tackle climate change have so far focused on mitigation. Measures addressing 'adaptation' to climatic changes are scarce and far from systematic or operational. There is no common European drought policy or institutional frameworks to address drought situations (Vogt and Somma, 2000). There is a lack of European approaches for 'best practice' to reduce vulnerability to droughts (Eisenreich, 2005).

There are also initiatives to mitigate desertification processes such as the Desertification National Action Plan in Greece. While drought planning in some Member States is at an advanced level, the extent and effectiveness of drought management procedures vary greatly between EU Member States (Eisenreich, 2005). Progress is being made to reduce leakage losses in some countries. In Malta, leakage control policies have been introduced to reduce leakage rates by 55 % from 1995 to 2001 (EEA, 2003). More country-specific adaptation measures are discussed in Section 4.

Appendix 2 Summary of country-by-country sectoral vulnerability issues ([55])

Country	Agriculture	Water	Coastal zones	Human health	Ecosystems	Fisheries	Others
Austria	√	√		√ (Possible malaria incidence)	√		Cryospere and winter tourism
Belgium	√ (Including horticulture)	√ (Likely increase in the frequency and intensity of flooding and low water levels)			√ (Forestry)		Soils
Bulgaria	√ (Maize)	√			√ (Based on Holdridge model)		Soils
Cyprus							
Czech Republic	√ (Spring barley)	√			√ (Forestry — stress from drought)		
Denmark	Direct impacts of climate change are thought to be modest and could be countered by suitable ongoing adaptation.						
Estonia	√		√				
Finland	√ (To pest and disease patterns)				√ (Forestry are most vulnerable at the timberline; but the timber-producing capacity may increase substantially; risk of new insects and pests)		
France (*)	√	√			√		Power generation
Germany					√ (Forestry)		Soils
Greece (**)							
Hungary	Increased drought is perceived to be a potential risk.						
Iceland				√ (Mild adverse impacts from severe storms)			
Ireland		√	√		√		
Italy	√	√	√		√ (Alpines)		Tourism
Latvia	Current vulnerability of coastal zone and vegetation to climate variability was discussed. In spite of the public awareness on the impacts of climate change on environment and national economy, there is very little research in this area.						
Liechtenstein	√	√			√ (The Alps)		Insurance
Lithuania			√		√ (Biodiversity; terrestrial, freshwater, wetlands ecosystems)		
Luxembourg							
Malta	√	√	√		√	√	
Netherlands			√				
Norway	√ (difficulty of spring farming and harvesting due to intense precipitation; pests and diseases)				√ (Terrestrial, freshwater, and marine ecosystems: Possible adverse impacts but not quantified ; Forestry: benefits from higher temperature and CO2 concentration might be offset by damage from wind, pests and diseases)	√	Transport
Poland		√	√				

([55]) Reported in national communications to UNFCCC or in national assessments (as available up to mid 2005).

Country	Agriculture	Water	Coastal zones	Human health	Ecosystems	Fisheries	Others
Portugal	√ (Dependence on water availability will increase, further conditioning crop productivity)	√ (A general decrease in water availability is expected, as well as an increase of seasonal and spatial asymmetries; Increase of flood risk; Increase of water quality problems; Groundwater level, thus influencing water resources availability)	√ (Drowning and flooding of lowlands; Increased erosion of presently receding coastal ribbons and wide spreading of erosion in others; Risk of land loss has been found along 67% of the coastal length in association with erodible bedrock or low lying coasts)	√ (Heat-related mortality, air pollution related health effects, health effects associated with floods and drought and water and food-borne diseases are expected increase)	√ (Projected increase in frequency of extreme events, fire risks, water deficits could result in a possible decline in forest productivity in most of the mainland territory)	√ (Significant changes in temperature, upwelling or turbulence may alter optimal production, yield and levels of stocks)	Energy (changing rainfall patterns affect hydropower production)
Romania	√	√			√ (Forestry)		
Slovakia		√					
Slovenia	√ (Increased insect infestations, crop damage from extreme heat, increased soil erosion, increased weed growth, increased moisture stress and droughts)	√ (Assessment took into account agriculture and hydrology)					
Spain	√	√ (Decreased water availability and increased irrigation need)	√ (Most vulnerable parts are delta's/wetlands & confined beaches various non-climatic effects have at least similar impacts. Most likely changes in extremes (e.g. storms) have larger impacts than SLR)	√ (Extreme temperatures, storms, air pollution, water & food diseases, vector borne diseases)	√ (Terrestrial and aquatic nature, forestry, biodiversity)	√ (Inland fisheries)	Natural hazards, energy, tourism, insurance
Sweden	√ (To pests)	√ (Particularly in the southern areas)	√	√ (Possible adverse impacts but the country is considered to have the resources to prevent many of the epidemic diseases that may become more widespread)	√ (Ecosystems; forestry — from risk of pests and diseases)	√ (In Swedish lakes and the Baltic Sea)	Infrastructure (from storms etc.), land and soil
Turkey							
United Kingdom		√		√	√		Economy, Built environment

(*) It is noted that the most vulnerable regions and zones in France are the overseas territories (frequent tropical cyclones and infectious diseases), the Mediterranean South (as a consequence of increased drought periods), and areas in the northern half of the country that are most exposed to storms and/or flooding.

(**) Presentation on recent trends in Mediterranean climate, and possible changes in the future, no quantitative impact assessment.

Appendix 3 Template for information on climate change vulnerability and adaptation

A3.1 Climate change impacts and vulnerability assessments

Which climate change impacts and vulnerability assessments form the background for climate change adaptation initiatives in your country? *[On which international/national/regional scenarios on climate impacts and vulnerability are adaptation initiatives based? How are potential options for adaptation identified and appraised? Which criteria lead to the selection and implementation of adaptation initiatives?]*

A3.2 Policy framework

Is climate change adaptation formally on the national climate policy agenda in your country? [If so, which government ministry, organisation has the lead responsibility? Please also briefly describe what has been done at national level on adapting to climate change. If not, please briefly explain whether it is indirectly addressed in the context of other policy agendas.]

A3.3 Recent/on-going adaptation initiatives

For each major climate change adaptation initiative in your country, please provide details on the following (or else supply the name and contact details of the relevant people managing the initiative):

- Title/name of the initiative
- Overall objectives of the initiative
- Sectors (e.g. water resources, public health, agriculture, forestry etc.), region (e.g. mountains, water catchments, etc.), and social groups (e.g. elderly, women, children, etc.), and time horizon the initiative deals with
- Stakeholders (e.g. policy-makers at national, regional, and local levels from both public and private sectors, academics, local communities, NGOs, funding agencies, etc.) involved in the Initiative
- Roles (e.g. management, overall policy guidance, scientific and technical assistance, insights into various stages of the project cycle, funding, etc.) of these different stakeholders in the planning, design, implementation, evaluation and managing of the Initiative
- Major challenges and obstacles encountered (so far) in developing and implementing the initiative
- Major opportunities arising from the process
- Major achievements and lessons learnt.

If the above information is contained in a report or can be obtained via a web site, we would appreciate it very much if you could provide us with this report or web address.

References

Abegg, B., 1996: *Klimaänderung und Tourismus — Klimafolgenforschung am Beispiel des Wintertourismus in den Schweizer Alpen*. Schlussbericht NFP 31. Vdf Zürich.

ABI, 2004: *A changing climate for insurance: A summary report for chief executives and policy makers.* Associate of British Insurers, 24. http://www.abi.org.uk/Display/File/Child/239/climatechange2004.pdf

ACIA, 2004: *Impacts of a Warming Artic: Artic Climate Impacts Assessment*. Cambridge University Press, Cambridge and New York, 139 pp.

Adger, WN; Huq, S; Brown, K; Conway, D and M Hulme, 2003: Adaptation to climate change in the developing world. *Progress in Development Studies* 3 (3): 179–195.

Alcamo, J., P. Doll, T. Henrichs, and B. Lehner, 2001: Summing up Eurowasser: an integrated assessment of climate change impacts on Europe's water resources. *EuroWasser: model-based assessment of European water resources and hydrology in the face of global change*, B. Lehner, T. Henrichs, P. Doll, and J. Alcamo, Eds., Center for Environmental Systems Research, University of Kassel, Germany.

Alcamo, J., P. Doll, T. Heinrichs, F. Kaspar, B. Lehner, T. Rösch, and S. Siebert, 2003: Global estimates of water withdrawals and availability under current and future business-as-usual conditions. *Hydrological Sciences Journal*, 48, 339–348.

Alpenverein, 2004: Fachabteilung Raumplanung — Naturschutz: Gletscherschutz. http://www.alpenverein.or.at/naturschutz/Alpine_Raumordnung/Gletscherschutz/index.shtml.

Arnell, W. N., 1999: The effect of climate change on hydrological regimes in Europe: a continental perspective. *Global Environmental Change*, Vol. 9, 5–23.

Arnell, N.W., Cannell, M.G.R., Hulme, M., Kovats, R.S., Mitchell, J.F.B., Nicholls, R.J., Parry, M.L. Livermore, M.T.J. and White, A. (2002): The consequences of CO_2 stabilisation for the impacts of climate change, *Climatic Change* 53, 413–446.

Arnell, W.N., 2004: Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environmental Change*, Vol. 14, 31–52.

Auer, I. and R. Böhm, 2004: *Der Sonnblick*; ZAMG; Austria.

Bader, S. and P. Kunz, 1998: Climat et risques naturels. La Suisse en mouvement. *Rapp. Sci. Final Progr. Nat. Rech*, 31**,** 312S.

Bätzing, W., 2003: *Die Alpen-Geschichte und Zukunft einer europäischen Kulturlandschaft.* München, 431 S.

Baumhauer, R., 2005: Beschleunigung der Desertifikation. *Warnsignal Klima: Genug Wasser für alle?* J. L. Lozan, H. Graßl, P. Hupfer, L. Menzel, and C.-D. Schönwiese, Eds., Geo-Wissenschaftliche Auswertungen, 216–220.

Bello, G., N. Casavola, and E. Rizzi, 2004: *Aliens and visitors in the Southern Adriatic Sea: effects of tropicalisation.* Rapport du 37e Congres de la Commission Internationale pour l' Exploration Scientifique de la Mer Méditerranée CIESM Congress Proceedings, Monaco: CIESM, 491 only.

Beniston, M., R.S.J. Tol, R. Delcolle, G. Hörmann, A. Iglesias, J. Innes, A.J. McMichael, A.J.M. Martens, I. Nemesova, R.J. Nicholls, and F.L. Toth, 1998: Europe. In: The Regional Impacts of Climate Change: An Assessment of Vulnerability. *Special Report of IPCC Working Group II*, R. T. Watson, M. C. Zinyowera, and R. H. Moss, Eds., Cambridge University Press, 149–185.

Beniston, M., 2000: *Environmental Change in Mountains and Uplands*. Arnold Publishers, London, and Oxford University Press, New York, 172 pp.

Beniston, M., 2003: Climatic change in mountain regions: A review of possible impacts. *Climatic Change*, 59**,** 5–31.

Beniston, M., 2004: *Climatic Change and its Impacts — An overview focusing on Switzerland. Advances in global change research Vol. 19*. Kluwer Academic Publishers. Dordrecht, the Netherlands, 286 pp.

Beniston, M. and H.F. Diaz, 2004: The 2003 heat wave as an example of summers in a greenhouse climate? observations and climate model simulations for basel, switzerland. *Global and Planetary Change*, 44, 73–81.

Bindi, M. and M. Moriondo, 2005: Impact of a 2 °C global temperature rise on the Mediterranean region:Agriculture analysis assessment. *Climate change impacts in the Mediterranean resulting from a 2 °C global temperature rise*, C. Giannakopoulos, M. Bindi, M. Moriondo, and T. Tin, Eds., WWF, 54–66.

BMU, 2004: Alpenkonvention konkret — Ziele und Umsetzung. Alpensignale 2. *Bundesministerium für Umwelt Naturschutz und Reaktorsicherheit, Berlin und Ständiges Sekretariat der Alpenkonvention*, Innsbruck, 62.

Bolle, H.-J., 2003: Climate, Climate Variability, and Impact in the Mediterranean area: an overview. *Mediterranean climate — variability and trends*, H.-J. Bolle, Ed., Springer Verlag, 5–86.

Bradshaw, H.M., B.H. Holmqvist, S.A. Cowling, and M.T. Sykes, 2000: The effect of climate change on the distribution and management of Picea abies in southern Scandinavia. *Canadian Journal of Forest Research*, 30, 1992–1998.

Brando, C. and R. Rodrigues, 2000: Hydrological Simulation of the International Catchment of Guadiana River. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere*, 25, 329–339.

Braun, L. N. and M. Weber, 2002: *Droht im nächsten Sommer Hochwasser vom Gletscher?* Rundgespräche der Kommission für Ökologie der BAdW, 22 pp.

Brooks, Nick, W. Neil Adger, and P. Mick Kelly, 2005: The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, 15, 151–163.

Bürki, R., 2000: *Klimaänderung und Anpassungsprozesse im Wintertourismus.* Ostschweizerische Geographische Gesellschaft NF H. 6, St. Gallen. 206 pp.

Burton, I., 1996: The growth of adaptation capacity: practice and policy. *Adapting to climate change: an international perspective*, J. Smith, N. Bhatti, G. Menzhulin, R. Benioff, M. I. Budyko, M. Campos, B. Jallow, and F. Rijsberman, Eds., Springer-Verlag, 55–67.

Burton, I., Huq, S., Lim, B., Pilifosova, O., Schipper, E.L., 2002: From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy 2*, 145–159.

Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka, 1994: *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. London: University College and Japan: Centre for Global Environmental Research, 59 pp.

Casimiro, E., J.M. Claherios, and S. Dessai, 2002: Human Health. *Climate change in Portugal: scenarios, impacts and adaptation measures — SIAM*, F. D. Santos, K. Forbes, and R. Moita, Eds., 241–301.

CBD, 2003: *Linkages between biological diversity and climate change and the advice on the intregration considerations into the UNFCCC and its Kyoto Protocol*. Report no 17.

CEDEX, 1998: *Demadas de aqua en la union Europea y en los paises condidatos. informe technico para ETC/IW*, Madrid.

Ceron, J-P. and G. Dubois, 2004: The potential impacts of climate change on French tourism. *Tourism and the Natural Environment: Inter-relationships, Impacts and Management Issues*, P. Burns, Ed.

Chmielewski, F.-M., 2005: Wasserbedarf in der Landwirtschaft. *Warnsignal Klima: Genug Wasser für alle?* J. L. Lozan, H. Graßl, P. Hupfer, L. Menzel, and C.-D. Schönwiese, Eds., Geo- Wissenschaftliche Auswertungen.

Colombo, A.F., D. Etkin, and B.W. Karney, 1999: Climate variability and the frequency of extreme temperature events for nine sites across Canada: Implications for power usage. *Journal of Climate*, 12, 2490–2502.

COPA-COGECA, 2003: *Assessment of the impact of the heat wave and drought of the summer 2003 on agriculture and forestry*. http://www.copa.be/pdf/pocc_03_78i4_1e.pdf.

Defra, 2003: *Supplementary note on climate change considerations for flood and coastal management.* (www.defra.gov.uk/environ/fcd/pubs/pagn/Climatechangeupdate.pdf).

de Cunha, L.V., R. Oliveira, and V. Nunes, 2002: The Watersector. *Climate change in Portugal: scenarios, impacts and adaptation measures — SIAM project*, F. D. Santos, K. Forbes, and R. Moita, Eds., Gradavia, 133–172.

de Roo, Ad, G.Schmuck, V. Perdigao, J. Thielen, and, 2003: The influence of historic land use change and future planned land use scenarios on floods in the Oder catchment. *Physics and Chemistry of the Earth, Parts A/B/C*, 28**,** 1291–1300.

Dessai, S. and Schipper, E.L., 2003: The Marrakesh Accords to the Kyoto Protocol: Analysis and Future Prospects. *Global Environmental Change* 13:149–153.

Diaz, H.F. and R.S. Bradley, 1997: Temperature variations during the last century at high elevation sites. *Climatic Change*, 36**,** 253–279.

Diaz, H. F., M. Grosjean, and L. Graumlich, 2003: Climate variability and change in high elevation regions: past, present and future. *Climatic Change*, 59**,** 1–4.

Döll, P., 2002: Impact of Climate Change and variability on Irrigation Requirements: A Global Perspective. *Climate Change*, 54**,** 269–293.

Downing, T. E. and A. Patwardhan, 2005: Assessing Vulnerability for Climate Adaptation. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, B. Lim, E. Spanger-Siegfried, I. Burton, E. Malone, and S. Huq, Eds., Cambridge University Press, Cambridge and New York, 67–90.

European Commission, 2000: Energy in Europe — 1999 Annual Energy Review. Special Issue January 2000. *Directorate-General for Energy*.

European Commission, 2004a: *EU emissions trading: An open scheme promoting global innovation to combat climate change*. European Commission, 24 pp.

European Commission, 2004b: *Statistical and economic information 2004 on Agriculture in the European Union*. http://europa.eu.int/comm/agriculture/agrista/2004/table_en/

European Commission, 2005: *Winning the Battle Against Global Climate Change*, Brussels, 9.2.2005. COM(2005) 35 final.

Eckhardt, K. and U. Ulbrich, 2003: Potential impacts of climate change on groundwater recharge and streamflow in a central European low mountain range. *Journal of Hydrology*, 284, 244–252.

Edwards, M., P. Licandro, A.W.G. John, and D.G. Johns, 2005: *Ecological status report: results from the CPR survey.* Technical Report 2.

EEA, 2002: *Europe's Biodiversity — biogeographical regions and seas*. EEA.

EEA, 2003: *Europe's water: An indicator-based assessment*. Topic report, European Environment Agency, 99 pp.

EEA, 2004a: *Impacts of Europe's changing climate: an indicator-based assessment*, EEA Report No 2/2004, 107 pp.

EEA, 2004b: *EEA Signals 2004: A European Environmental Agency update on selected issues*. 31 pp.

EEA, 2005: *European Environmental Outlook*. EEA Report No. 4/2005, 85 pp.

EEA, 2006 (forthcoming): State of Coasts in Europe, EEA report.

Eisenreich, S.J., (coordinating author), 2005: *Climate and the European Water Dimension*. European Commission — Joint Research Centre.

Eitzinger, J., M. Stastna, Z. Zalud, and M. Dubrovsky, 2003: A simulation study of the effect of soil water balance and water stress in winter wheat production under different climate change scenarios. *Agricultural Water Management*, 61, 195–217.

Elsasser, H. and P. Messerli, 2001: The Vulnerability of the Snow Industry in the Swiss Alps. In: *Mountain Research and Development* Vol. 21 No 4 Nov 2001, S. 335–339. http://www.giub.unibe.ch/wg/English/Aktuell/mrdsnow.pdf http://sinus.unibe.ch/wg/Aktuell/mrdsnow.pdf.

Elsasser, H. and R. Burki, 2002: Climate change as a threat to tourism in the Alps. *Climate Research*, 20, 253–257.

Entec UK Ltd, 2003: *The potential impacts of climate change in the West Midlands* — technical report. Sustainability West Midlands, 244 pp.

ETC/ACC, 2005: *Technical paper for EEA on scenarios for Adaptation: scenario exercises in the context of climate change adaptation in Europe*, 60 pp.

Gabriel, I., Pirjo Kuuppo, Markku Rummukainen, BertJan Heij, Sandor Szalai, Jean-Claude André, Ulrich Katenkamp, and Martin König, 2005: SSA CIRCLE Climate Impact Research Coordination for a Larger Europe, Deliverable 1.2.1: *Report on the scientific programme contents of those programmes represented in CIRCLE.*

Gajic-Capka, M., 2004: *Changes in snow parameters in Croatian Highland.* NATO Publication.

Giannakopoulos, C. and B.E. Psiloglou, 2004: *Trends in energy load demand for Athens, Greece: Weather and non-weather related factors.* Climate Dyn.

Gitay, H., S. Brown, W.E. Easterling, B. Jallow, J. Antle, M. Apps, R. Beamisch, T. Chapin, W. Cramer, J. Frangi, J. laine, L. Erda, J. Magnuson, I. Noble, J. Price, T. Prowse, T.L. Root, E.-D. Schulze, O. Sirotenko, B. Sohngen, and J. Soussane, 2001: *Ecosystems and their goods and services*, Chapter 5 WGII, 235–342 pp.

Gitay, H., A. Suárez, R.T. Watson, O. Anisimov, F.S. Chapin, R.V. Cruz, M. Finlayson, W.G. Hohenstein, G. Insarov, Z. Kundzewicz, R. Leemans, C. Magadza, L. Nurse, I. Noble, J. Price, N.H. Ravindranath, T.L. Root, B. Scholes, A. Villamizar, and X. Rumei, 2002: *Climate change and biodiversity*. IPCC Technical Paper V, 77 pp.

GLP, 2003: Global Land Project. Science Plan. Cross-Cutting Themes: *Mountain Research Initiative* http://www.glp.colostate.edu/plan.htm.

Gordon, C., C. Cooper, C.A. Senior, H. Banks, J.M. Gregory, T.C. Johns, J.F.B. Mitchel, and R.A. Wood, 2000: The simulation of the SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics*, Vol. 16**,** 147–168.

Gottfried, M., H. Pauli, K. Reiter, and Georg Grabherr, 1999: A fine-scaled predictive model for changes in species distribution patterns of high mountain plants induced by climate warming. *Div. Distr.*, 5**,** 241–251.

Grabherr, G., M. Gottfried, and H. Pauli, 1994: Climate effects on mountain plants. *Nature*, 369**,** 448–448.

Grabherr, G., M. Gottfried, and H. Pauli, 2002: Okologische Effekte an den Grenzen des lebens. *Spektrum der Wissenschaft*, 1**,** 84–89.

Güthler, A., 2003: *Aufrüstung im alpinen Wintersport*. CIPRA Deutschland alpMedia Hintergrundbericht, Februar 2003, 15. S. http://www.alpmedia.net/.

Gruber, S., M. Hoelzle, and W. Haeberli, 2004: Permafrost thaw and destabilization of Alpine rock walls in the hot summer of 2003. *Geophys. Res. Lett.*, 31**,** 4.

Haeberli, W. and M. Beniston, 1998: Climate change and its impacts on glaciers and permafrost in the Alps. *Ambio*, 27(4)**,** 258–265.

Haeberli, W., M. Wegmann, and D. Von der Mühl, 1998: Slope stability problems related to glacier shrinkage and permafrost degradation in the Alps. *Ecolog. Geol. Helv.*, 90**,** 407–414.

Haeberli, W. and C. R. Burn, 2002: Natural Hazards in Forests: Glacier and Permafrost Effects as Related to Climate Change. *Enviromnental change and geomorphic Hazards in Forest, IUFRO Research Series*, R. C. Slide, Ed., CABI Publishing, Wallingford/New York, 167–202.

Hajat, S., Kovats, R.S., Atkinson, R.W., Haines, A. , 2002: Impact of hot temperatures on death in London: a time series approach. *Journal of Epidemiology and Community Health*, 56**,** 367–372.

Hantel, M., M. Ehrendorfer, and A. Haslinger, 2000: Climate sensitivity of snow cover duration in Austria. *Int. J. Climatol*, 20, 615– 640.

Hare, W., 2003: *Assessment of knowledge on impacts of climate change-Contribution to the specification of Art. 2 of the UNFCCC*. Background report to the WBGU special report 94., 106 pp.

Hare, B., 2005: *Relationship between increases in global mean temperature and impacts on ecosystems, food production, water and socio-econimc systems* (http://www.stabilisation2005.com/58_Bill_Hare.pdf). International Symposium on the Stabilisation of Greenhouse Gases.

Harris, C., D. V. Mühll, K. Isaken, W. Haeberli, J. L. Sollid, L. King, Per Holmlun, F. Dramis, M. Guglielmin, and D. Palacios, 2003: Warming permafrost in European mountains. *Global Planet Change*, 39**,** 215–225.

Henrichs, T. and J. Alcamo, 2001: Europe's Water Stress Today and in the Future. *Eurowasser — Model-Based Assessment of European Water Resources and Hydrology in the Face of Global Change*, B. Lehner, T.

Henrichs, P. Döll, and J. Alcamo, Eds., Kassel World Water Series.

Holten, Jarle I. and P.D. Carey, 1992: *Responses of natural terrestrial ecosystems to climate change in Norway.* NINA Forskningsrapporter 0802-3093; 82-426-0198-4.

Hulme, M., 1999: An historical monthly precipitation dataset for global land areas from 1900 to 1998, gridded at 2.5° latitude by 3.75° longitude resolution ('gu23wld0098.dat', version 1.0), http://iri.ldeo.columbia.edu/.

Hupfer, P. and A. Kleeberg, 2005: Zustand und Belastung limnischer Ökosysteme — Warnsignale einer sich verändernden Umwelt. *Warnsignal Klima: Genug Wasser für alle?* J. L. Lozan, H. Graßl, P. Hupfer, L. Menzel, and C.-D. Schönwiese, Eds., Geo-Wissenschaftliche Auswertungen, 115–121.

Huq, S., 2002: The Bonn-Marrakesh agreements on funding. *Climate Policy*, 2**,** 243–246.

Huq, S. and I. Burton, 2003: *Funding adaptation to climate change: what, who and how to fund?* Sustainable development opinion paper. IIED, London.

IEA, 2004: *World Energy Outlook 2004 Edition*, IEA, Paris.

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

Iglesias, A., C. Rosenzweig, and D. Pereira, 2000: Agricultural impacts of climate change in Spain: developing tools for a spatial analysis. *Global Environmental Change*, Vol. 10**,** 69–80.

Iglesias, A., M.N. Ward, M. Menendez, and C. Rosenzweig, 2003: Water availability for agriculture under climate change: understanding adaptation strategies in the Mediterranean. *Climate Change in the Mediterranean*, C. Giupponi and M. Shechter, Eds., Edward Elgar, 75–93.

Izmerov, N.F., B.A. Revich, and E.I. Korenberg, Eds., 2004: *Climate Change and Public Health in Russia in the XXI century: Proceeding of a workshop, Apr. 2004, Moscow*. 260 pp.

Jacobeit, J., A. Dünkeloh, and E. Hertig, 2005: Die Niederschlagsentwicklung im mediterranean Raum und ihre Ursachen. *Warnsignal Klima: Genug Wasser für alle?* J. L. Lozan, H. Graßl, P. Hupfer, L. Menzel, and C.-D. Schönwiese, Eds., Geo-Wissenschaftliche Auswertungen.

Johannessen, O.M. and L.B. Bengtsson, 2002: *Arctic Climate Change- Observed and Modeled Temperature and Sea Ice Variability.* Technical Report 218.

Jones, R., J. Murphy, D. Hassell, and R. Taylor, 2001: *Ensemble mean changes in a simulation of the European climate of 2071–2100 using the new Hadley Centre regional modelling systems HadAM3H/HadRM3H*. Haldey Centre, Met Office Bracknell, United Kingdom.

Jones, R., 2003: *Managing climate change risks*. OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers.

Kanatsching, D. and G. Weber, 1998: *Nachhaltige Raumentwicklung in Österreich*. Wien 1998.

Karas, J., 1997: *Desertification — Climate Change and the Mediterranean Region*.

Keller, F., 2005: Die Pioniergemeinde Pontresina im Umgang mit Lawinen, Muren und Permafrost. Presentation at Aqua Alta, Munich 2005.

Kime, D.E., 1995: The effects of pollution on reproduction in fish. *Reviews in Fish Biology and Fisheries*, 5**,** 52–96.

Koppe, C., S. Kovats, G. Jendritzky, and B. Menne, 2004: *Heat-waves: risks and responses*. World Health Organisation. Regional Office for Europe. Health and Global Environmental Change, Series No. 2, 123 pp.

König *et al.*, 2005: Climate Impact Research Coordination for a Larger Europe, CIRCLE ERA-NET, Country report.

Körner, Ch., W. Cramer, and U Fritsch, 2003: Vulnerability of Europe ecosystems facing an increasing drought risk. *International workshop of the EU concerted action of AVEC*, Samos, Greece, 10.

Kundzewicz, Zbigniew W., Martin Parry, W. Cramer, J.I. Holten, Z. Kaczmarek, P. Martens, R.J. Nicholls, M. Öquist, M.D.A. Rounsevell, and J. Szolgay, 2001: Europe. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel* *on Climate Change*, J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Docken, and K. S. White, Eds., Cambridge University Press.

Lapin, M. and K. Hlavcova, 2003: *Changes in Summer Type of Flash Floods in the Slovak Carpathians due to Changing Climate*. The International Conference on Alpine Meteorology and MAP2003 Meeting, 19.–23.V.2003, Brig, Switzerland, Publ. of MeteoSwiss, 105–108.

Lasch, P., M. Linder, M. Erhard, F. Suckow, and A. Wenzel, 2002: Regional impact assessment on forest structure and functions under climate change — the Brandenburg case study. *Forest Ecology and Management*, 162**,** 73–86.

Laternser, M. and M. Schneebeli, 2003: Long-term snow climate trends of the Swiss Alps (1931– 1999). *Int. J. Climatol*, 733–750.

Lehner, B. and P. Döll, 2000: Europe's droughts today and in the future. *Eurowasser: an integrated assessment of climate change impacts on Europe's water resources*, J. Alcamo, P. Döll, T. Henrichs, and B. Lehner, Eds.

Leemans, R. and Eickhout, B. (2004): Another reason for concern: regional and global impacts on ecosystems for different levels of climate change, *Global Environmental Change* 14, 219–228.

Lehner, B., Gregor Czisch, and Sara Vassolo, 2001: Europe's hydropower potential today and in the future. *EuroWasser: model-based assessment of European water resources and hydrology in the face of global change*, B. Lehner, T. Henrichs, P. Doll, and J. Alcamo, Eds., Center for Environmental Systems Research, University of Kassel, Germany.

Lim, Bo, Erika Spaner-Siegfried, Ian Burton, Elizabeth Malone, and Saleemul Huq, Eds., 2005: *Adaptation policy frameworks for climate change: developing strategies, policies and measures*. Cambridge University Press, 258 pp.

Linder, M., 2000: Developing adaptive forest management strategies to cope with climate change. *Tree Physiology*, 20, 299–307.

Lindgren, E. and T.G.T. Jaenson, 2004: *Lyme borreliosis in Europe: influences of climate and climate change, epidemiology, ecology and adaptation measures.* WHO: Health and Global Environmental Change Series.

Lisø, Kim Robert, Guro Aandahl, Siri Eriksen, and Knut H. Alfsen, 2003: Preparing for impacts of climate change in Norway's built environment. *Building Research & Information*, 31 (3–4)**,** 200–209.

Lloret, Francisco, Josep Penuelas, and Marc Estiarte, 2004: Experimental evidence of reduced diversity of seedlings due to climate modification in a Mediterranean-type community. *Global Change Biol*, 10, 248–258.

Ludwig, W., P. Serrat, L. Cesmat, and J. Dracia-Esteves, 2003: Evaluating the impact of the recent temperature increase on the hydrology of the Tét River (Southern France). *Journal of Hydrology*, 289**,** 204–221.

MA, 2005: *Millennium Ecosystem Assessment Synthesis Report, Final Draft*. 219 pp.

MAFF, 1999: *Flood and Coastal Defence Project Appraisal Guidance — Economic Appraisal: FCDPAG3*. MAFF.

MAFF, 2001: *Flood and Coastal Defence Project Appraisal Guidance — Overview: CDPAG1*. MAFF.

Maish, M., 2000: The long-term signal of climate change in the Swiss Alps: Glacier retreat since the end of the Little Ice Age and future ice decay scenarios. *Geogr. Fis. Dinam. Quat.*, 23**,** 139–151.

Majithia, S., 2003: *Switched on to demand*. http://www.earthed.info.

Maladide 2004. Message from the Malahide stakeholder conference 'Halting the decline of biodiversity- Priority objectives and targets for 2010. 27 May 2004. http://www.jncc.gov.uk/PDF/Final-message-from-Malahide.pdf

Maracchi, G., O. Sirotenko, and M. Bindi, 2004: Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. *Climatic Change*, 70(1)**,** 117–135.

Martin, E., G. Giraud, Y. Lejeune, and G. Boudart, 2001: Impact of climate change on avalanche hazard. *Ann. glaciol.*, 32**,** 163–167.

Martinez, E.I., A. Gomez-Ramos, and A. Garrido-Colmenero, 2003: Economic impacts of hydrological droughts under climate change scenarios. *Climate Change in the Mediterranean*, C. Giupponi and M. Shechter, Eds., Edward Elgar, 108–129.

Martinka, K. and K. Poprendova, 2003: Flood Warning and Forecasting System — Slovak Republic (POVAPSYS). Environment (Zivotne prostredie) (in Slovak), 37(3), 213–214.

McCarthy, I.D. and D.F.H. Houlihan, 1997: The effect of temperature on p r otein metabolism in fish: the possible consequences for wild Atlantic salmon (Salmo salar) stocks in Europe as a result of global warming. *Global Warming: Implications for Freshwater and Marine Fish*, C. M. Wood and D. G. McDonald, Eds., Cambridge University Press, 51–77.

Metzger, M. and D. Schröter, 2004: Concept for a spatial explicit and quantitative vulnerability assessment of Europe. *Regional Environmental Change*, submitted.

Mimikou, M.A., E. Baltas, E. Varanou, and K. Pantazis, 2000: Regional impacts of climate chang on water resources quantity and quality indicators. *Journal of Hydrology*, 234, 95–109.

Mindas, J. and J.Slovak Skvarenina, Eds., 2003: *forests and global climate change*. EFRA Zvolen, FRI Zvolen, in Slovak, 129 pp.

Ministry of Transport, Public Works and Water Management, 2000: *Water Policy in the 21st century* [Waterbeleid in de 21e eeuw], the Hague. www.minvenw.nl

Ministry of Housing, Spatial Planning and the Environment, 2004: *Spatial Plan* [Nota Ruimte], www.minvrom.nl.

Mohr, A., 2002: *The Staus Quo of the Alpine Convention. — Jahrbuch des Verein zum Schutz der Bergwelt e.V.*, special edition in English, München.

Motta, R. and F. Masarin, 1998: Strutture e dinamiche forestali di popolamenti misti di pino cembro (Pinus cembra L.) e larice (Larix decidua Miller) in alta valle Varaita (Cuneo, Piemonte). *Archivio Geobotanico*, 2, 123–132.

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E. Emilio la Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H.-H. Rogner, A. Sankovski, M.E. Schlesinger, P.R. Shukla, S. Smith, R.J. Swart, S. van Rooyen, N. Victor, and Z. Dadi, Eds., 2000: *IPCC Special Report on Emissions Scenarios*. Cambridge University Press, 599 pp.

Nicholls, R.J. and R.J.T. Klein, 2004: Climate change and coastal management on Europe's coast. In: *Managing European Coasts: Past, Present and Future. Environmental Science Monograph Series*, J. E. Vermaat, L. Ledoux, R. K. Turner, and W. Salomons, Eds., Springer, Berlin, Germany.

Nicholls, Robert J. and Richard J.T. Klein, 2003a: *Adaptation frameworks for sea-level rise impacts.* http://www.survas.mdx.ac.uk/pdfs/romepap.pdf.

Nicholls, Robert J. and Richard J.T. Klein, 2003b: *Climate change and coastal management on Europe's Coast.* EVA Working Paper No.3.

Nöthiger, C. J., 2003: *Naturgefahren und Tourismus in den Alpen — Untersucht am Lawinenwinter 1999 in der Schweiz.* SLF Eidgenössisches Institut für Schnee- und Lawinenforschung, Davos. pp. 245.

ODPM, 2001: Planning Policy Guidance 25: *Development and Flood Risk*. ODPM.

Often, A. and O.E. Stabbetorp, 2003: *Landscape and biodiversity changes in a Norwegian agricultural landscape.*

Olensen, J.O. and M. Bindi, 2002: Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy*, Vol. 16, 239–262.

Parry, M., Ed., 2000: *Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project*. Jackon Enviornment Institute, University of East Anglia, Norwich, United Kingdom, 320 pp.

Parry, M.L. and T.R. Carter, 1998: *Climate Impact and Adaptation Assessment: A Guide to the IPCC Approach.* Earthscan, 166 pp.

Paul, F., A. Kääb, M. Maish, T. Kellengerger, and W. Haeberli, 2004: Rapid disintegration of Alpine glaciers observed with satellite data. *Geophys. Res. Lett.*, 31, L21402, doi:10.1029/2004GL020816.

Pauli, H., M. Gottfried, and G. Grabherr, 2001: High summits of the Alps in a changing climate. The oldest observation series on high mountain plant diversity in Europe. *Fingerprints of Climate Change' — Adapted Behavior and Shifting Species Ranges*, G.-R. Walther, C. A. Burga, and P. J. Edwards, Eds., Kluwer Academic Publisher, 139–149.

Paulsch, A., C. Dziedzioch, and T. Plän, 2003: *Umsetzung des Ökosystemaren Ansatzes in*

Hochgebirgen Deutschlands: Erfahrungen mit der Alpenkonvention. Bundesamt für Naturschutz. BfN-Skripten 85, Bonn. 62 S. http://www.bfn.de/09/090203.htm.

Perry, A., 2003: Impacts of climate change on tourism in the Mediterranean: adaptive responses. *Climate change in the Mediterranean*, C. Giupponi and M. Shechter, Eds., Edward Elgar, 279–288.

Prentice, I.C., M.J.R. Farquah, M.J.R. Farham, M.L. Goulden, M. Heinmann, V.J. Jaramillo, H.S. Kherghi, C. Le Quere, R.J. Scholes, and D.W.R. Wallance, 2001: *The carbon cycle and atmospheric carbon dioxide,* Chapter 3 WGI, 193–237 pp.

Preston, C.D., M.G. Telfer, H.R. Arnold, P.D. Carey, J.M. Cooper, T.D. Dines, M.O. Hill, D.B. Roy, and S.M. Smart, 2002: *The changing flora of the United Kingdom*, 36 pp.

Purvis, N. and J. Busby, 2004: *The Security Implications of Climate Change for the UN System', Environmental Change and Security Project Report no. 10*. Woodrow Wilson International Center for Scholars.

Randolph, S.E., 2004: Evidence that climate change has caused 'emergence' of tick borne diseases in Europe? *Int. J. Med. Microbiol.*, 293, 5–15.

Reichstein, M., J.D. Tenhunen, J.M. Ourcival, J.M. Rambal, F. Miglietta, A. Peressotti, M. Pecciari, G. Tirone, and R. Valentini, 2002: Severe drought effects on ecosystem CO2 and H2O fluxes in three Mediterranean evergreen ecosystems: revision of current hypotheses? *Global Change Biology*, Vol. 8**,** 999–1017.

Reilly, J., 1996: Agriculture in a changing climate: impacts and adaptation. *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, R. T. Watson, M. C. Zinyowera, and R. H. Moss, Eds., Cambridge University Press, 429–467.

Reiter, P., C.J. Thomas, P.M. Atkinson, S.I. Hay, S.E. Randolph, D.J. Rogers, G.D. Shanks, R.W. Snow, and A.J. Spielman, 2004: Global warming and malaria: a call for accuracy. *The LANCET Infectious Diseases*, 4, 323–324.

Reynard, N.S., C. Prudhomme, and S.M. Crooks, 2001: The flood characteristics of large U.K. rivers: potential effects of changing climate and land use. *Climatic Change*, 48, 343–359.

Rigg, K., A. Salman, D. Zanen, M. Taal, J. Kuperus, and J. Lourens., 1997: *Threats and Opportunities in the Coastal Areas of the European Union: a Scoping Study*.

Rizza, F., F.W. Badeck, L. Cattivelli, O. Lidestri, N. Di Fonzo, and A.M. Stanca, 2004: Use of water stress index to identify barley genotypes adapted to rainfed and irrigated conditions. *Crop Science Society of America*, Vol. 44.

Röckner, E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L: Dümenil, M. Esch, M. Giorgetta, U. Schlese, and U. Schulzweida, 1996: *The atmospheric general circulation model ECHAM-4: Model description and simulation of present day climate.* MPI-Report No.218, MPI für Meteorologie.

Rosato, P. and C. Giupponi, 2003: What future for Mediterranean agriculture? A proposal to integrate socio-economics in climate change. *Climate Change in the Mediterranean*, C. Giupponi and M. Shechter, Eds., Edward Elgar, 133–158.

RSPB, British Trust for Ornithology, Wildfowl and Wetlands Trust, English Nature, Scottish Natural Heritage, and Countryside Council for Wales and Environment and Heritage Service (Northern Ireland), 2005: *The State of the United Kingdom's Birds*. 27 pp.

Rummukainen, M., S. Bergström, G. Persson, and E. Ressner, 2005: *Anpassning till klimatförändringar. Kartläggning av arbete med sårbarhetsanalyser, anpassningsbehov och anpassningsåtgärder i Sverige till framtida klimatförändring*. SMHI Reports Meteorology and Climatology No. 106. SMHI, SE-601 76 Norrköping, Sweden, 44 pp.

Sailor, D.J., 2001: Relating residential and commercial sector electricity loads to climate evaluating state level sensitivities and vulnerabilities. *Energy*, 26, 645–657.

Sanchez-Arcilla, A., J. Jimenez, and H.I. Valdemoro, 1998: The Ebro delta: morphodynamics and vulnerability. *Journal of Coastal Research*, 14, 754–772.

Santos, F.D., K. Forbes, and R. Moita, Eds., 2002: *Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures — SIAM Project.* Gradiva, Lisbon, Portugal.

Schär, C., P.L. Vidale, D. Lüthl, C. Frei, C. Häberli, M.A. Liniger, and C. Appenzeller, 2004: The role of increasing temperature variability in European summer heatwaves. *Nature*, 427**,** 332–336.

Scheele, U. and S. Malz, 2005: Wassernutzung und Eingriffe des Menschen in den Wasserhaushalt. *Warnsignale Klima: Genug Wasser für alle?* J. L. Lozan, H. Graßl, P. Hupfer, L. Menzel, and C.-D. Schönwiese, Eds., GEO — Wissenschaftliche Auswertungen.

Schneeberger, C., O. Albrecht, H. Blatter, M. Wild, and R. Hock, 2001: Modelling the response of glaciers to a doubling in atmospheric CO2: a case study of Storglaciaren, northern Sweden. *Climate Dyn.*, 17, 825–834.

Schneider, C., 2004: *Wandern statt wedeln*. Süddeutsche Zeitung 25.10.2004. http://www.presse.teletour.info/sueddeutsche/251004/wandern.html.

Schröter, D, W. Cramer, R. Leemans, I.C. Prentice, M.B. Araújo, A.W. Arnell, A. Bondeau, H. Bugmann, T. Carter, C.A. Gracia, A.C. de la Vega-Leinert, M. Erhard, F. Ewert, M. Glendining, J.I. House, S. Kankaanpää, R. J. T. Klein, S. Lavorel, M. Lindner, M. Metzger, J. Meyer, T. D. Mitchell, I. Reginster, M. Rounsevell, S. Sabate, S. Sitch, B. Smith, J. Smith, P. Smith, M.T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, S. Zähle, B. Zierl, 2005: Ecosystem Service Supply and Vulnerability to Global Change in Europe, *Science* 310: 1333–1337

Schröter, D., L. Acosta-Michlik, A.W. Arnell, M.B. Araújo, F. Badeck, M. Bakker, A. Bondeau, H. Bugmann, T. Carter, A.C. de la Vega-Leinert, M. Erhard, G.Z. Espiñeira, F. Ewert, U. Fritsch, P. Friedlingstein, M. Glendining, C.A. Gracia, T. Hickler, J. House, M. Hulme, S. Kankaanpää, R.J.T Klein, B Krukenberg, S. Lavorel, R. Leemans, M. Lindner, J. Liski, M.J. Metzger, J. Meyer, T. Mitchell, F. Mohren, P. Morales, J.M. Moreno, I. Reginster, P. Reidsma, M. Rounsevell, E. Pla, J. Pluimers, I.C. Prentice, A. Pussinen, A. Sánchez, S. Sabaté, S. Sitch, B. Smith, J. Smith, P. Smith, M.T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, G. van der Werf, J. Vayreda, M. Wattenbach, D.W. Wilson, F.I. Woodward, S. Zaehle, B. Zierl, S. Zudin, and W. Cramer, 2004: *ATEAM Final Report*. Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany, 139 pp.

Smit, B., O. Pilifosova, I. Burton, B. Challenger, S. Huq, R.J.T. Klein, and G. Yohe, 2001: *Adaptation to Climate Change in the Context of Sustainable Development and Equity*. Climate Change 2001: Impacts, Adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White, Eds., Cambridge University Press, Cambridge and New York.

Smith, J.B. and S. Hitz, 2003: *Estimating global impacts from climate change*. Background paper to OECD workshop on the benefits of climate policy: Improving information for policy makers, 100 pp.

Steininger, K. W. and H. Weck-Hannemann, Eds., 2002: *Global Environmental Change in Alpine Regions: Recognition, Impact, Adaptation and Mitigation.* Edward Elgar Publishing Inc., Cheltenham, United Kingdom. 271 pp.

Steininger, K.W., C. Steinreiber, and C. Ritz, 2005: *Extreme Wetterereignisse und ihre wirtschaftlichen Folgen. Anpassung, Auswege und politische Förderung betroffener Wirtschaftsbranchen*. Springer Verlag Berlin, Heidelberg, 246 pp.

Stieglitz, M., S. J. Déry, V.E. Romanovsky, and T. E. Osterkamp, 2003: The role of snow cover in the warming of the arctic permafrost. *Geophys. Res Lett.*, 30(13), 1721.

Stuczyinski, T., G. Demidowicz, T. Deputat, T. Gorski, S. Krasowicz, and J. Kus, 2000: Adaptation scenarios of agriculture in Poland to future climate changes. *Environ. Monit. Assess.*, 61, 133–144.

SYKE, 2004: FINADAPT: *Assessing the Adaptive Capacity of the Finnish Environment and the Society under a Changing Climate*. FINADAPT Consortium, http://www.miljo.fi/download.asp?contentid=15919&lan=en.

Szolgay, J., K. Hlavcova, M. Lapin, and R. Danihlik, 2003: Impact of climate change on mean monthly of runoff in Slovakia. *Slovak Meteorological Journal*, VI(3), 9–21.

Tamis, W.L.M., M. Van het Zelfde, and R. Van der Meijden, 2001: Changes in vasular plant biodiversity in the Netherlands in the 2oth century explained by climatic and other environmental characteristics. *Long-term effects of climate change on biodiversity and ecosystem processes*, H. Oene, W. N. Ellis, M. M. P. D. Heijmans, D. Mauquoy, W. L. M. Tamis, A. J. H. van Vliet, F. Berendse, B. van Geel, R. van der Meijden, and S. A. Ulenberg, Eds., Dutch National Research Programme on Global Air Pollution and Climate Change, 23–51.

Theurillat, J.P. and A. Guisan, 2001: Potential impact of climate change on vegetation in the European Alps: A review. *Climatic Change*, 50**,** 77–109.

Toth, F.L. Bruckner, Th. Fussel, H.M., Leimbach, M., Petschel-Held, G., and Schellnhuber, H.J. (2002): A new analytical framework for exploring options for global climate policy. *Environment* 44(5), 23–34.

UBA, 2004: *Die Veränderungen des Lebensraums Alpen dokumentieren — Indikatorensystem und Konzept für einen Alpenzustandsbericht. Abschlußbericht der Arbeitsgruppe 'Umweltziele und Indikatoren' der Alpenkonvention (3. Mandatsphase)*, Oktober 2004. Report. Umweltbundesamt Berlin.

UNEP/DEWA, 2004: *Impacts of summer 2003 heat wave in Europe*. http://www.grid.unep.ch/product/publication/download/ew_heat_wave.pdf.

UNEP/MAP/MED/POL, 2003: Riverine transport of water, sediments and pollutants to the mediterranean sea. *MAP Technical Reports Series No. 141*, UNEP/MAP Athens, 19–34.

Valor, E., V. Meneu, and V. Caselles, 2001: Daily air temperature and electricity load in Spain. *J. of Appl. Meteor.*, 40(8), 1413–1421.

van Minnen, J.G., J. Onigkeit, and J. Alcamo, 2002: Critical climate change as an approach to assess climate change impacts in Europe: development and application. *Environmental Science and Policy*, 5**,** 335–347.

Vincent, C., 2002: Influence of climate change over the 20th Century on four French glacier mass balance. *J. Geophys. Res.*, 107.

Viner, D. and M.D. Agnew, 1999: *Climate Change and its Impacts on Tourism.*

Vogt, J.V. and F. Somma, 2000: Introduction. *Drought and Drought Mitigation in Europe*, J. V. Vogt and F. Sommma, Eds., Kluver Academic Publishers, 3–5.

Vojtek, M., P. Faško, and P. Šťastný, 2003: Some selected snow climate trends in Slovakia with respect to altitude. *Acta Meteorologica Universitatis Comenianae*, 32, 17–28.

WBGU, 2003: *Climate Protection Strategies for the 21st Century: Kyoto and beyond*. Special Report 2003, 89 pp.

Wessely, H. and A. Güthler, 2004: *Alpenpolitik in Deutschland — Anspruch und Realität*. Bund Naturschutz Forschung Nr. 8. Report Nürnberg, November 2004. pp 151.

West, C.C. and Gawith, M.J. Eds., 2005a: *Measuring progress: Preparing for climate change through the UK Climate Impacts Programme*. UK Climate Change Impacts Programme Technical Report.

West, C. C. and M.J. Gawith, Eds., 2005b: *The UKCIP Integration Report*. UK Climate Change Impacts Programme, 110 pp.

WHO European Centre for Environment and Health, 2004: *Extreme weather and climate events and public health responses: Report on a WHO meeting Bratislava, Slovakia, 09–10 February 2004*. 48 pp.

Wigley, T.M.L., 2005: The Climate Change Commitment. *Science*, 307**,** 1766–1769.

Willows, R. and R. Connell, Eds., 2003: *Climate adaptation: risk, uncertainty and decision-making*. UKCIP Technical Report. Oxford: UKCIP.

Wood, C.M. and D.G. McDonald, Eds., 1997: *Global Warming: Implications for Freshwater and Marine Fish*. Cambridge University Press.

WWF, 2004: *Extreme weather:does nature keep up?* 60 pp.

Zebisch M., Grothmann T., Schröter D., Hasse C., Fritsch U., and W. Cramer, 2005: *Klimawandel in Deutschland. Vulnerabilität und Anpassungsstrategien klimasensitiver Systeme Forschungsbericht 201 41 253*. Climate Change 08/05. Dessau. http://www.umweltbundesamt.de.

European Environment Agency

Vulnerability and adaptation to climate change in Europe

2006 — 79 pp. — 21 x 29.7 cm

ISBN 92-9167-814-7

TH-AK-06-002-EN-N

ISBN 92-9167-814-7

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99

Web: www.eea.eu.int
Enquiries: www.eea.eu.int/enquiries

Publications Office

European Environment Agency