

Impacts of Europe's changing climate — 2008 indicator-based assessment

Joint EEA-JRC-WHO report

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Foreword

Climate change and its associated impacts require immediate action in order to safeguard the economy and environment of Europe and the rest of the world. This indicator report shows how temperature is increasing, sea levels are rising, glaciers, ice sheets and sea ice are melting, precipitation is changing, and the intensity and frequency of weather extremes in many regions is increasing. It also underlines the cascade of consequences including an increased risk of floods and droughts, losses of biodiversity (marine, freshwater and terrestrial), threats to human health, and damage to economic sectors such as energy, transport, forestry, agriculture, and tourism.

We are already experiencing a global average temperature increase of almost 0.8 °C above pre-industrial levels, and even higher increases in Europe and northern latitudes. There is an urgent need to stabilize the climate below a 2 °C increase above pre-industrial levels, so as to avoid major irreversible impacts on society and ecosystems. To achieve this we need both global greenhouse gas emission reductions and actions to adapt to climate change.

For the past decade the European Union has tackled climate change through international agreements under the United Nations Framework Convention on Climate Change. What is now needed is a massive scale-up in renewable energy technology development and transfer, investment in energy and resource efficiency, adaptation actions and efforts to reduce deforestation, increase the resilience of ecosystems and reduce effects on human health. A global post-2012 regime, hopefully agreed by the end of 2009, will need to include all these elements.

Tackling the climate change problem requires numerous relevant institutions to work towards the same goal. This report was prepared jointly by the European Environment Agency, including its European Topic Centres, the Joint Research Centre of the European Commission, and World Health Organization Regional Office for Europe. It builds on results of recent national and EU-wide research activities, the fourth assessment of the

Intergovernmental Panel on Climate Change (IPCC) and the Arctic Climate Impact Assessment. We consider the report a successful example of an inter-institutional collaboration.

The report highlights that more action is needed towards halting biodiversity loss and maintaining the resilience of ecosystems because of their essential role in regulating the global climate system. Enhancing ecological coherence and interconnectivity of the EU Natura 2000 network is key to the long-term survival of many species and habitats, for them to be able to adapt to a changing climate.

Climate change is also a significant and emerging threat to public health, and changes the way we must look at protecting vulnerable populations. The large number of additional deaths during the 2003 heat wave highlighted the need for adaptation actions, such as heat health action plans. A number of vector-borne, water- and food-borne and other diseases are expected to increase. The possible spread of such diseases is highly dependent on early detection and having preventive measures in place.

The report highlights that vulnerable regions and sectors vary widely across Europe. Key economic sectors, which will need to adapt through integration within sectoral policies at European and (sub-) national levels, include energy supply, health, water management, agriculture, tourism and transport. The report shows that there is a lack of information on good practices in adaptation actions and their costs.

The report shows there is a need for improved international monitoring and reporting mechanisms by countries and international organisations. A European Clearing House on climate change impacts, vulnerability and adaptation will make information widely available to users across Europe. It will be underpinned by the EU Shared Environmental Information System (SEIS), the services to be generated by the EU Kopernikus programme on global monitoring for environment and security and the WHO Climate, Environment

and Health Information System (CEHAIS). Our institutes are committed to contribute to the further development of these systems and services.

The report was prepared at a time when the European Commission was discussing ideas for a European strategy on adaptation in its Green Paper on Adaptation (2007). More concrete policy actions have been developed in its White Paper on Adaptation (due at the end of 2008). This report will provide a valuable resource in the implementation phase of the White Paper and for the development of national adaptation plans by member countries. Our three organizations are committed to providing the appropriate data and information to support the efforts of European policy makers and society to develop and implement both adaptation and mitigation actions.

Hereby we would like to thank all staff that worked hard on finalizing the report, from EEA, and its European Topic Centres on Air and Climate Change, on Water and on Biological Diversity, JRC and WHO Europe, as well as the many external

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Executive summary

Introduction

Background and objective

This report is an update and extension of the 2004 EEA Report *Impacts of Europe's changing climate*. Since 2004, there has been much progress in monitoring and assessing the impacts of climate change in Europe. The objectives of this report are to present this new information on past and projected climate change and its impacts through indicators, to identify the sectors and regions most vulnerable to climate change with a need for adaptation, and to highlight the need to enhance monitoring and reduce uncertainties in climate and impact modelling. To reflect the broadening of coverage of indicators and make use of the best available expertise, the report has been developed jointly by EEA, JRC and WHO Regional Office for Europe.

Developments in science and policy

The Intergovernmental Panel on Climate Change (IPCC), in its 4th Assessment report (2007) reconfirmed and strengthened earlier scientific findings about key aspects of climate change. Increased monitoring and research efforts have enhanced understanding of climate change impacts and vulnerability. European research on impacts and vulnerability in national and EU programmes has advanced considerably, making a major contribution to international assessments of the IPCC, the Arctic Climate Impact Assessment (2004), the UNEP Global Outlook for Ice and Snow (2007) and WHO reports.

At the 2007 UN Framework Convention on Climate Change (UNFCCC) Bali conference, the urgency of responding effectively to climate change through both adaptation and mitigation activities was recognised by a larger number of countries than ever before. The EU has proposed a target of a maximum global temperature increase of 2 °C above the pre-industrial level and a number of EU mitigation targets and actions by 2020. A post-Kyoto regime that would include both adaptation and mitigation is expected to be agreed by end of 2009. There has been progress in implementing the UNFCCC

work programme on impacts, vulnerability and adaptation to climate change, developed to help countries improve their understanding of climate change impacts.

This report

The main part of this report summarises the relevance, past trends and future projections for about 40 indicators (from 22 in the 2004 report). The indicators cover atmosphere and climate, the cryosphere, marine systems, terrestrial systems and biodiversity, agriculture and forestry, soil, water quantity (including floods and droughts), water quality and fresh water ecology, and human health. The report also addresses adaptation and the economics of climate change impacts and adaptation strategies and policies, and data availability and uncertainty.

Key messages

Atmosphere and climate

Recent observations confirm that the **global mean temperature** has increased by 0.8 °C compared with pre-industrial times for land and oceans, and by 1.0 °C for land alone. Europe has warmed more than the global average (1.0 and 1.2 °C, respectively), especially in the south-west, the north-east and mountain areas. Projections suggest further **temperature increases in Europe** between 1.0–5.5 °C by the end of the century, which is also higher than projected global warming (1.8–4.0 °C). Whether the EU's goal of less than 2 °C global warming (compared with pre-industrial levels) will be exceeded will depend on the effectiveness of international climate policy regarding global greenhouse gas emission reductions. More frequent and more intense **hot extremes** and a decreasing number of **cold extremes** have occurred the past 50 years and this trend is projected to continue.

Changes in **precipitation** show more spatially variable trends across Europe. Annual precipitation changes are already exacerbating differences

between a wet northern part (an increase of 10 to 40 % during the 20th century) and a dry southern part (a decrease of up to 20 % in some parts of southern Europe). The intensity of **precipitation extremes** such as heavy rain events has increased in the past 50 years, and these events are projected to become more frequent. Dry periods are projected to increase in length and frequency, especially in southern Europe.

No clear trend in the frequency and intensity of **storms** has yet been observed, but the strength of the heaviest storms is projected to increase, albeit with slightly lower frequency. Uncertainties for projected annual precipitation and frequency and the intensity of extreme events continue to be larger than those for annual temperature. Climate variability and change have contributed to an increase in **ozone concentrations** in central and south-western Europe, which is projected to continue. This may result in current ozone abatement policies becoming less effective.

Cryosphere

The cryosphere (the frozen world) is important since it is affected by climate change, while changes in the cryosphere itself have a major effect on the climate system. **European glaciers** are melting rapidly: those in the Alps have lost two thirds of their volume since 1850, with loss accelerating since the 1980s, and they are projected to continue their decline. **Snow cover** has decreased by 1.3 % per decade during the past 40 years, with the greatest losses in spring and summer, and decreases are projected to continue. These various changes will cause natural hazards and damage to infrastructure and changes in river flows and seasonality, thus substantially affecting the hydrological cycle in river catchment areas.

The reduction in **Arctic sea ice**, especially in summer, has accelerated the past five decades, with a record low extent in September 2007 of about half the normal minimum in the 1950s. Arctic sea ice may even disappear at the height of the melting season in the coming decades, creating a feedback that will further increase climate change because dark open water reflects much less sunlight than white snow-covered surfaces. Species specialised for life in the ice are threatened. Less ice will ease access to the Arctic's resources. Oil and gas exploration, shipping, tourism and fisheries will offer new economic opportunities, but also increase risks to the Arctic environment.

Also **mountain permafrost** is reducing due to increasing temperatures, which is already increasing natural hazards and damage of high-mountain

infrastructure. The **Greenland ice sheet** has lost ice since the 1990s, probably at an increasing rate. Hence its contribution to global sea-level rise has increased in the past decades. Accelerated flow of outlet glaciers to the sea accounts for more of the ice loss than melting. No reliable predictions of the future of the ice sheets in Greenland and Antarctica can yet be made. The processes causing the faster movement of the glaciers are poorly understood and there is a lack of long-term observations.

Marine biodiversity and ecosystems

According to satellite observations, the rate of global mean **sea-level rise** has increased to 3.1 mm/year in the past 15 years (compared with a global average of 1.7 mm/year in the 20th century). Because of ocean circulation and gravity effects, sea-level rise is not uniform but varies across European seas. An acceleration of **sea surface temperature** increases has also been observed in recent decades. Projections suggest that sea level and sea surface temperature of some European seas could rise more than the global average. IPCC (2007) sea-level rise estimates (up to 0.59 m by 2100) may be too low because of the risks of more rapid changes than so far assessed in the Greenland ice sheet (and partly in the Antarctic ice sheet). Sea-level rise can cause flooding, coastal erosion and the loss of flat and low-lying coastal regions. It increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands.

Changes in the **timing of seasonal biological phenomena (phenology)** and distribution of **marine species** have been observed, including earlier seasonal cycles (by 4–6 weeks) and **northward movements**, by up to 1 100 km over the past 40 years, which seems to have accelerated since 2000. These changes will affect marine ecosystems, biodiversity and affect fisheries, including increasing the vulnerability of North Sea cod stocks to over-fishing and a decline in seabird populations. Sub-tropical species are occurring with increasing frequency in European waters, and sub-Arctic species are receding northwards. The rate of northward movement of a particular species, the sailfin dory, has been estimated at about 50 km/year. Changes in the geographic distribution of fish may affect the management of fisheries. Fisheries regulations in the EU include allocations of quotas based on historic catch patterns, and these may need to be revised.

Water quantity, river floods and droughts

Climate change, including changes in temperature, precipitation, glaciers and snow cover, is intensifying

the hydrological cycle. However, other factors such as land-use changes, water management practices and extensive water withdrawals have considerably changed the natural flows of water, making it difficult to detect climate change-induced trends in hydrological variables. In general, annual **river flows** have been observed to increase in the north and decrease in the south, a difference projected to exacerbate. Strong changes in seasonality are projected, with lower flows in summer and higher flows in winter. As a consequence, **droughts** and water stress will increase, particularly in the south and in summer.

Europe has been affected by several major droughts in recent decades, such as the catastrophic drought associated with the summer 2003 heatwave in central parts of the continent and the 2005 drought in the Iberian Peninsula. The regions most prone to an increase in drought hazard are southern and south-eastern Europe, but minimum river flows will also decrease significantly in many other parts of the continent, especially in summer.

In the past, the recorded number of **river floods** has been strongly influenced by improved monitoring and reporting systems. For example since 1990, 259 major river floods have been reported in Europe, of which 165 have been reported since 2000. For the coming decades, however, floods are projected to occur more frequently in many regions, particularly in winter and spring, although estimates of changes in flood frequency and magnitude remain uncertain.

Projected climate-induced changes in the hydrological cycle will aggravate the impact of other stresses (such as land-use and socio-economic changes) on water availability, freshwater ecosystems, energy production, navigation, freshwater supply and use (in agriculture, households, industry) and tourism. Adaptation actions will be needed such as improving water efficiency to mitigate water stress and enhancing retention to reduce flood risk.

Freshwater quality and biodiversity

Increased **temperatures of lakes and rivers** (by 1–3 °C during the 20th century) have resulted in decreases in **ice cover on lakes and rivers** by 12 days on average in the last century in Europe. These changes can be at least partly attributed to climate change, and partly to other causes such as freshwater use for cooling processes (e.g. power plants). Lake and river surface water temperatures are projected to increase further with increasing air temperatures. Warming of surface water can have several effects on **water quality** and hence

on human use and **aquatic ecosystems**. Changes include movement of freshwater species northwards and to higher altitudes, changes in life-cycle events (phenology), for example spring phytoplankton and zooplankton blooms up to one month earlier than 30–40 years ago. Climate change may thus favour and stabilise the dominance of harmful cyanobacteria in phytoplankton communities, resulting in increased threats to the ecological status of lakes and enhanced health risks, particularly in water bodies used for public water supply and bathing. This may counteract nutrient load reduction measures. Further monitoring is needed to confirm and better analyse these changes.

Terrestrial ecosystems and biodiversity

Climate change, in particular milder winters, is responsible for the observed **northward and uphill distribution shifts** of many European **plant species**. By the late 21st century, plant species are projected to have shifted several hundred kilometers to the north, forests are likely to have contracted in the south and expanded in the north, and 60 % of mountain plant species may face extinction. The rate of change will exceed the ability of many species to adapt, especially as landscape fragmentation may restrict movement. The **timing of seasonal events in plants (phenology)** is changing, for example the average advance of spring and summer between 1971 and 2000 was 2.5 days per decade. The pollen season starts on average 10 days earlier and is longer than 50 years ago. Changes in seasonal events are projected to continue.

Birds, insects, mammals and other **animal groups** are also **moving northwards and uphill**. A combination of the rate of climate change, habitat fragmentation and other obstacles will impede the movement of many animal species, possibly leading to a progressive decline in European biodiversity. Distribution changes are projected to continue. Suitable climatic conditions for Europe's breeding birds are projected to shift nearly 550 km north-eastward by the end of the century, with the average range size shrinking by 20 %. Projections for 120 native European mammals suggest that, assuming no migration, up to 9 % risk extinction during the 21st century.

Climate change has caused advancement in the **life cycles of many animal groups (phenology)**, including frog spawning, bird nesting and the arrival of migrant birds and butterflies, and these trends are projected to continue. Populations may explode if the young are not exposed to normal predation pressures. Conversely, populations may

crash if the emergence of vulnerable young is not in synchrony with their main food source or if shorter hibernation times lead to declines in body condition.

Soil

Information on the impacts of climate change on soil and the various related feedbacks is very limited. Indicators with full European coverage are absent and there is a need for the establishment of appropriate monitoring schemes. Changes in the bio-physical nature of soil are likely due to projected rising temperatures, changing precipitation intensity and frequency and more severe droughts. Such changes can lead to a future decline in **soil organic carbon** stocks and a substantial increase in CO₂ emissions. Adapted land-use and management practices could be implemented to counterbalance these impacts. Projected increased variations in rainfall pattern and intensity will make soils more susceptible to **erosion**. Projections show significant reductions in summer soil moisture in the Mediterranean region, and increases in the north-eastern part of Europe. Maintaining **water retention capacity** is important, e.g. through adaptation measures. Climate change alters the habitat of soil biota, which affects the diversity and structure of species and their abundance. Ecosystem functioning is modified consequently, but quantified knowledge of these impacts is limited. Soil degradation is already intense in parts of the Mediterranean and central-eastern Europe and, together with prolonged drought periods and increased numbers of fires, is already contributing to an increased risk of desertification. In many cases, desertification is irreversible, leading to adverse social, economic and environmental effects. Projected risks for future desertification are the highest in the same areas.

Agriculture and forestry

In both agriculture and forestry, climate change affects the **growing season** and average yields while also key relevant land-use and management changes occur, making it difficult to detect climate change-induced trends. The length of the growing season of several agricultural crops has increased at northern latitudes, favouring the introduction of new species that were not previously suitable. However, there has been a shortening of the growing season locally at southern latitudes. The flowering and maturity of several species in Europe now occurs two or three weeks earlier than in the past with consequent higher risk of frost damage from delayed spring frosts. Changes in the growing season and the **timing of the cycle of agricultural crops (agrophology)** are projected to continue.

Since the beginning of the 21st century, the **variability of crop yields** has increased as a consequence of extreme climatic events, e.g. the summer heat of 2003 and the spring drought of 2007. Since extreme events are projected to increase in frequency and magnitude, crop yields will become more variable. Increases in **water demand** for agriculture (by 50–70 %) has occurred mainly in Mediterranean areas and this is projected to continue, thus increasing competition for water between sectors and uses. There is a need for adaptation of farm practices and land management to reduce or avoid adverse impacts. Some of the adaptation options such as irrigation may however increase emissions because of increased energy consumption.

In much of continental Europe, the majority of **forests** are growing faster now than in the early 20th century, due to advances in forest management practices, increased nitrogen deposition, and reduced acidification by air pollution (sulphur dioxide) and also increasing temperatures and atmospheric CO₂ concentrations. Projected climate change will favour certain species in some forest locations, while making conditions worse for others, leading to substantial shifts in vegetation distribution. Changes in distribution and the timing of seasonal events of both pests and pollinators will further change forests, although the types of change are difficult to project. Periods of drought and warm winters are increasing pest populations and further weakening forests. Projected temperature increases will increase the **danger of forest fires** and lead to more area being burned, more ignitions and longer fire seasons, especially in southern and central Europe. Adaptation actions will also be needed in the forestry sector to limit the adverse effects.

Human health

Increased temperatures can have various effects on human health. The large number of additional deaths during the 2003 (more than 70 000 excess deaths reported in 12 European countries) **heat wave** highlighted the need for adaptation actions, such as heat health action plans. Such heat waves are projected to become much more common later in the century as the climate continues to change, with mortality risk increases by between 0.2 and 5.5 % for every 1 °C increase in temperature above a location-specific threshold. There is some evidence that winter mortality in Europe has decreased, but this could have other causes, particularly improved housing and the prevention of winter infections. A number of

vector-borne diseases are expected to increase in the near future. The tiger mosquito, a transmitter of a number of viruses, has extended its range in Europe substantially over the past 15 years and is projected to extend even further. Ticks and the associated Lyme disease and tick-borne encephalitis are moving into higher altitudes and latitudes. There is a risk of additional outbreaks of Chikungunya (a virus that is highly infective and disabling but not transmissible between people) and a potential for localised dengue to re-appear. Changes in the geographic distribution of the sandfly vector are occurring in several European countries and there is a risk of human Leishmania cases further north. The possible spread of these diseases is very dependent on early detection and the preventive measures in place. Some **water- and food-borne disease** outbreaks are expected to become more frequent with rising temperatures and more frequent extreme events. The risk is very dependent on human behaviour and the quality of health care services and their ability to detect early and act.

Adaptation to climate change

To limit adverse impacts and benefit from some positive changes, adaptation is needed. Europe has to adapt and should also assist developing countries as they are most vulnerable in terms of communities, economic sectors and ecosystems.

Adaptation involves all levels of decision-making, from municipalities to international organisations. It is a cross-sectoral and transboundary issue which requires comprehensive integrated approaches. Economic sectors that are particularly concerned with adaptation include energy supply, health, water management, agriculture, tourism and transport. **Integration of adaptation into sectoral policies** at European and national levels is important in order to reduce, in the long term, the vulnerability of ecosystems, economic sectors, landscapes, health and communities to climate change impacts.

The European Commission adopted a Green Paper 'Adapting to climate change in Europe — options for EU action' in June 2007 and is planning to publish a White Paper framing a European adaptation strategy and options for adaptation in late 2008. National adaptation strategies have been or are being developed and implemented in many member countries, usually on the basis of impact and vulnerability assessments, and/or because of the urgency deriving from extreme weather and climate events.

Economic impacts

Economic costs and potential benefits of climate impacts have been quantified in some studies, but factors other than climate change often have a dominant effect, making assessments uncertain. Furthermore the costs of adaptation actions are poorly understood for both the current situation and the future.

However, about 90 % of all natural disasters that occurred in Europe since 1980 are directly or indirectly attributable to weather and climate, representing about 95 % of the economic losses caused by catastrophic events. Overall losses resulting from weather- and climate-related events have clearly increased during the past 25 years. Even though **social change and economic development** are the main factors responsible for this increase, there is evidence that **changing patterns of weather disasters** are also drivers. However, it is still not possible to determine the proportion of the increase in damage that might be attributed to anthropogenic climate change.

Economic losses as a consequence of extreme flood events in recent years have been substantial. For example, the estimated losses in central Europe in 2002 were EUR 17.4 billion. In addition, the economic costs of coastal flooding (assuming no adaptation) are estimated in the range of 12 to 18 billion EUR/year for Europe in 2080. Adaptation could significantly reduce these costs to around 1 billion EUR/year.

The hot summer of 2003 in Europe is estimated to have led to EUR 10 billion of economic losses to farming, livestock and forestry from the combined effects of drought, heat stress and fire.

Work undertaken in the context of the initiative 'The Economics of Ecosystems and Biodiversity' tentatively indicates that at a global level the cumulative welfare losses due to loss of ecosystem services, with climate change being one of the causes, could be equivalent to 7 % of annual consumption by 2050. However, little is currently known either ecologically or economically about the impacts of future biodiversity loss, and further assessment and methodological work is needed.

Projections suggest significantly reduced space-heating demand in northern Europe and increased space-cooling demand in southern Europe, with associated costs and benefits. Hydropower production is projected to increase in northern Europe and decrease in the south. With

more severe summer droughts, the availability of cooling water for power plants could be limited.

Changes in climate are starting to reduce the attractiveness of major tourist resorts in mountain areas and the Mediterranean, while improving it in other regions. The suitability of the Mediterranean for tourism is projected to decline during the key summer months, although there will be an increased suitability during spring and autumn. This can produce shifts in the major flows of tourism within the EU, which will be very important in regions where tourism is a dominant economic sector. Adaptation responses such as economic diversification will be critical to limit economic losses.

Key future challenges

Improved monitoring and reporting

In recent decades the availability of observed and projected data and information on climate change impacts across Europe has improved. However, for many impacts the information availability differs very considerably between regions. There are some national monitoring and data collection programmes for a number of the 'Essential Climate Variables' defined by WMO as part of GCOS (Global Climate Observing System), with regular international reporting obligations to the UNFCCC. Also satellite data are increasingly being used for tracking these variables. Some data depend on voluntary work by non-governmental organisations. However for many indicators the data result from a limited number of local or regional projects and national or EU-wide research projects. There are no regular Europe-wide monitoring programmes for many of the indicators presented in this report. More spatially detailed information is needed to develop adequate adaptation strategies. Through coordinated efforts by countries and the Commission, monitoring and reporting systems can be improved in a way consistent with the Shared Environmental Information System for Europe SEIS (EC, 2008). GMES (Global Monitoring and Environmental Security, EC, 2004) projects could fill key data and information gaps, along with the Environment and Health Information system (EHIS). The INSPIRE Directive will help to improve inter-operability, harmonisation and access to data. It would be useful to have a European agreement on the definition of key climate change indicators, including extreme weather events (for example 'floods' and 'droughts') and to define operational ways of tracking impacts through multiple sectors, over a variety of time and geographic scales.

Improved attribution methods for impact assessments

Even if many of the observed changes in various natural and societal systems are consistent with observed climate changes, other factors also influence system behaviour. Disentangling the climate change factor from other (e.g. societal) factors and separating anthropogenic from natural forcing for different indicators often remains a challenge (IPCC, 2007). There is a need to improve in this area, in order to have better projections of impacts and develop more focused adaptation actions.

Improved understanding of socio-economic and institutional aspects of vulnerability and adaptation

Many of the research and assessment activities to date have focused on the climatological, physical and biological aspects of climate change impacts. A better understanding of the socio-economic and institutional aspects of vulnerability and adaptation, including costs and benefits, is urgently needed. Very few studies have assessed the effectiveness of adaptation measures over a variety of time scales; today's adaptation measures may not be effective in future decades if, for example, extreme weather events become more frequent and intense.

Improved and coordinated scenario analysis of impacts and vulnerability

The scenarios for the climate change impacts and vulnerability indicators presented in this report are based mainly on global scenarios and contain spatially detailed European information for only few indicators. They are also incomplete and differ between indicators. Regular interaction is needed between the climate modelling community and the user community that is analysing impacts, vulnerability and adaptation in order to develop high-resolution, tailor-made climate change scenarios for the regional and local level at a level that is needed to define appropriate adaptation measures. It would be useful if European research projects were to adopt the same contrasting set of climate scenarios for global development, such as those used by IPCC, and make use of regional climate projections as soon as they become available. There will be a need both for explorative research for the very long term (centuries) and for analysis of climate-change impacts in the medium term (decades) for which better adaptation actions urgently need to be developed. However, despite uncertainties in existing climate change scenarios, stakeholders will have to make decisions, which could then be further improved as more detailed scenarios become available.

More information on good practices and avoiding mal-adaptation

Understanding of how to implement integration of adaptation into sectoral policies should be further improved, particularly with regard to water management, energy supply, biodiversity protection, health and agriculture. Good practices should also be developed to address the cross-sectoral and transboundary nature of adaptation, in synergy with mitigation actions, in order to enhance resilience across European countries, sectors, landscapes and communities. Future activities should also consider European neighbouring countries and overseas territories. In addition, it is important to better understand mal-adaptation e.g. by developing criteria (including social, environment, health and economic aspects). Substantial work should also be undertaken on better assessment of adaptation costs across all sectors.

increasing amount of data and information on climate change impacts, vulnerability and adaptation. A European clearing house on climate change impacts, vulnerability and adaptation could make this information widely available to potential users across Europe. The information could include data on observed and projected climate changes, information on vulnerable systems, indicators, tools for impacts assessments, and good practice adaptation measures. Such a clearing house should be developed and made consistent with the existing European environmental data centres (on climate change, water, land use, biodiversity and air) and information systems (European Community Biodiversity Clearinghouse) that are currently managed by EEA, by JRC (data centres on forestry and soil), and the WHO (Climate, Environment and Health Action and Information system, CEHAIS). This clearing house could also effectively provide important European information to international organisations such as UNFCCC.

Develop information exchange mechanisms

Planned research programmes both at the national and the European level will result in a rapidly

Table S.1 Observed (obs) and projected (scen) trends in climate and impacts for northern (Arctic and boreal), temperate (maritime climate, central/eastern) and southern (Mediterranean) regions of Europe

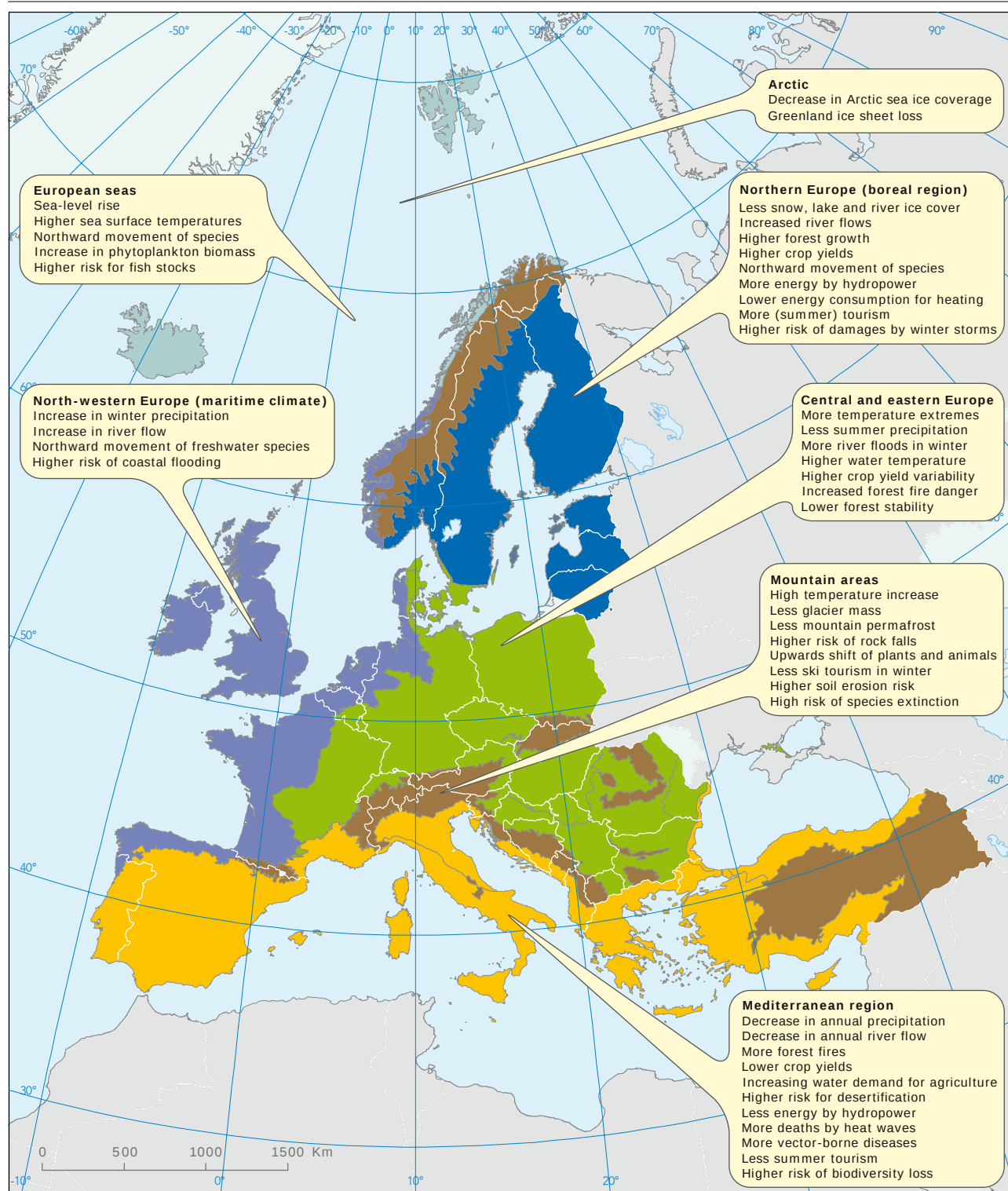
Section	Indicator	Northern	Temperate		Southern
		Arctic and boreal	Maritime climate	Central/eastern	Mediterranean
		obs/scen	obs/scen	obs/scen	obs/scen
5.2 Atmosphere and climate					
5.2.2	Global and European temperature	+/+	+/+	+/+	+/+
5.2.3	European precipitation	+/+	+/0	0/0	-/-
5.2.4	Temperature extremes in Europe				
	Heat waves in Europe	+/+	+/+	+/+	+/+
	Number of days with frost	-/-	-/-	-/-	-/-
5.2.5	Precipitation extremes in Europe	+/+	+/+	+/+	+/+
5.2.6	Storms and storm surges in Europe	0/0	0/+	0/0	0/0
5.2.7	Air pollution by ozone	0/+	+/+	+/+	+/+
5.3 Cryosphere					
5.3.2	Glaciers	-/-	n.a./n.a.	-/-	-/-
5.3.3	Snow cover	-/-	-/-	0/-	+/-
5.3.4	Greenland ice sheet	-/-	n.a./n.a.	n.a./n.a.	n.a./n.a.
5.3.5	Arctic sea ice	-/-	n.a./n.a.	n.a./n.a.	n.a./n.a.
5.3.6	Mountain permafrost	-/-	-/-	-/-	-/-
5.4 Marine biodiversity and ecosystems					
5.4.2	Sea-level rise	+/+	+/+	+/+	+/+
5.4.3	Sea surface temperature	+/+	+/+	+/+	+/+
5.4.4	Marine phenology	+/+	+/+	n.a./n.a.	n.a./n.a.
5.4.5	Northward movement of marine species	+/n.a.	+/n.a.	n.a./n.a.	n.a./n.a.

Table S.1 Observed (obs) and projected (scen) trends in climate and impacts for northern (Arctic and boreal), temperate (maritime climate, central/eastern) and southern (Mediterranean) regions of Europe (cont.)

Section	Indicator	Northern	Temperate		Southern
		Arctic and boreal	Maritime climate	Central/eastern	Mediterranean
		obs/scen	obs/scen	obs/scen	obs/scen
5.5	Water quantity, river floods and droughts				
5.5.2	River flow	+/+	o/+	o/+	-/-
5.5.3	River floods (number of events)	o/-	+/+	+/+	o/+
5.5.4	River flow drought	o/-	o/+	o/-	o/+
5.6	Freshwater quality and biodiversity				
5.6.2	Water temperature	+/+	+/+	+/+	+/+
5.6.3	Lake and river ice cover	-/-	-/-	-/-	-/-
5.6.4	Freshwater biodiversity and water quality (north and upward shift of species)	+/+	+/+	+/+	+/+
	Water quality	n.a./-	n.a./-	n.a./-	n.a./-
5.7	Terrestrial ecosystems and biodiversity				
5.7.2	Distribution of plant species (north-/upward shift)	+/+	+/+	+/+	+/+
5.7.3	Plant phenology	+/+	+/+	+/+	+/+
5.7.4	Distribution of animal species (north-/upward shift)	+/+	+/+	+/+	+/+
5.7.5	Animal phenology	+/+	+/+	+/+	+/+
5.7.6	Species-ecosystem relationships	-/-	-/-	-/-	-/-
5.8	Soil				
5.8.2	Soil organic carbon	n.a./n.a	n.a./n.a	n.a./n.a	n.a./n.a
5.8.3	Soil erosion by water	n.a./n.a	n.a./n.a	n.a./n.a	n.a./n.a
5.8.4	Water retention	n.a./+	n.a./-	n.a./-	n.a./-
5.9	Agriculture and forestry				
5.9.2	Growing season for agricultural crops	+/+	+/+	+/+	+/+
5.9.3	Timing of the cycle of agricultural crops (agrophology)	+/+	+/+	+/+	+/+
5.9.4	Crop-yield variability	+/+	+/+	+/+	+/+
5.9.5	Water requirement	n.a./n.a.	-/n.a.	-/n.a.	+/n.a.
5.9.6	Forest growth	+/+	+/+	+/+	+/+
5.9.7	Forest fire danger	-/+	-/+	+/+	+/+
5.10	Human health				
5.10.2	Heat and health	+/+	+/+	+/+	+/+
5.10.3	Vector-borne diseases (case study)	+/+	+/+	+/+	+/+
5.10.4	Water- and food-borne diseases	n.a./+	+/+	+/+	+/+
7	Economic consequences of climate change				
7.2	Direct losses from weather disasters	+/+	+/+	+/+	+/+
7.3	Normalised losses from river flood disasters	+/-	+/+	+/o	+/o
7.4	Coastal areas (floods)	n.a./+	n.a./+	n.a./+	n.a./+
7.5	Public water supply and drinking water management	n.a./o	-/-	n.a./o	-/-
7.6	Agriculture and forestry (yield)	n.a./+	n.a./-	n.a./o	n.a./-
7.7	Biodiversity and ecosystem goods and services (welfare losses)	n.a./+	n.a./+	n.a./+	n.a./+
7.8	Energy				
	Heating and cooling demand	n.a./-	n.a./o	n.a./o	n.a./+
	Hydropower production	n.a./+	n.a./-	n.a./-	n.a./-
7.9	Tourism and recreation (comfort index)	n.a./+	n.a./-	n.a./-	n.a./-
7.10	Health (impacts)	n.a./+	n.a./+	n.a./+	n.a./+
7.11	The costs of climate change for society	n.a./+	n.a./+	n.a./+	n.a./+

+ = increasing; - = decreasing; o = no significant changes (or diverging trends within the region); n.a. = not available

Map S.1 Key past and projected impacts and effects on sectors for the main biogeographic regions of Europe



Main biogeographic regions of Europe (EEA member countries)

Arctic	North-western Europe	Mountain areas
Arctic — Greenland (not EEA member)	Central and eastern Europe	Mediterranean region
Boreal region		

Source: IPCC, 2007; EEA.