IPCC WGII Fourth Assessment Report – Draft for Expert Review

Chapter 12: Europe

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Contents

Executive Summary *(provisional)*

New studies of the instrumental record confirm the 20th century warming trend throughout Europe, as well as trends of increasing precipitation in Northern Europe and decreasing precipitation in Southern Europe.

New research results have established a clear connection between the North Atlantic Oscillation (NAO) and European climate. The NAO has been found to be correlated in particular with the magnitude of winter precipitation and frequency of extreme rainfall events in different parts of Europe.

New analyses using regional climate models are providing a more detailed picture of climate change and its impacts in Europe. Regional models have a spatial resolution higher than the global models previously relied upon for climate estimates and therefore provide a finer picture of the spatial variability of climate changes. Although results from regional models have unavoidable uncertainties, some results are robust as noted in the following point.

Results from regional and global climate models agree on a substantial decrease in summer precipitation in Southern Europe and parts of Central Europe, and an increase in winter precipitation in Northern Europe for a range of scenarios up to the end of the 21st century. Consequences of these changes could be a shift of cropping and natural vegetation zones throughout Europe, an increase in flood occurrence in Northern Europe, a decrease in water availability in Southern Europe, and a shift in location and timing of tourism.

Some, but not all, climate modelling results point to an increased frequency and/or intensity of extreme climate events. Longer and more frequent dry periods are expected especially in Southern Europe, and higher maximum seasonal temperatures and one-day precipitation are anticipated for many parts of Europe.

Recent extreme climate events have provided "case studies" of possible impacts of climate change on Europe. The Elbe flood of 2002, the European heat wave of 2003, and Iberian forest fires of 2005 provide examples of the possible consequences of future extreme climate events on nature and society in Europe. These events need to be further studied to extract lessons for adaptation to climate change.

Current thinking about adaptation to extreme climate events has moved away from reactive disaster relief, towards more proactive risk management. Although an essential part of disaster planning is preparing for a quick *reaction* to disasters, increasing emphasis is being put on *proactive* measures to avert climate-related disasters. Examples of recent proactive measures include the adoption of heat wave warning systems in 15 European cities since the heat waves of 2003. Another example is the increasing attention given to establishing new river flood warning systems and incorporating "flood-ways" in land use plans.

Greater efforts are being taken to factor in climate change impacts in environmental planning. The European climate research community has recognized that a key to adaptation to climate change is the integration of proactive planning into existing planning institutions. For example, scenarios of sea level rise are being considered more often in local and regional coastal management plans. Another example is that water supply planning is beginning to incorporate a possible change in the frequency of extreme climate events.

Adaptation strategies are beginning to take into account other expected physical and institutional changes in Europe. Recent work has shown that adaptation strategies could be more feasible if they factor in other expected changes in Europe. One example is linking adaptation strategies for natural ecosystems with the expected abandonment of agricultural land stemming from agricultural policies of the European Union. This newly available land is being seen as an opportunity to reserve new habitat for plant and animal species endangered by climate change.

12.1 Summary of knowledge in TAR

Climate Trends in the 20th Century. During the 20th century, most of Europe experienced increases in average annual surface temperature (average increase over the continent 0.8°C), with strongest warming over the Iberian Peninsula and Northwestern Russia, and in winter rather than summer. The 1990s were the warmest in the instrumental record. Precipitation trends in the 20th century showed an increase in Northern Europe (10-40%) and decrease in Southern Europe (up to 20% in some parts of Southern Europe).

Climate Change Scenarios. The most recent climate model results available to the TAR showed an increase in annual temperature in Europe of 0.1 – 0.4°C per decade over the 21st century. It is very likely that the intensity and frequency of summer heat waves will increase throughout Europe. The models show a widespread increase of precipitation in the north, smaller decreases in the south, and small or ambiguous changes in Central Europe. It is likely that intense precipitation events will increase, especially in winter.

Current Sensitivities to Climate. With regards to its current sensitivities to climate, Europe was found to be most sensitive to the following conditions:

- extreme seasons, in particular exceptionally hot and dry summers and mild winters
- short-duration events such as windstorms and heavy rains
- slow, long term changes in climate leading to coastal squeeze.

Variability of Impacts in Regions and on Social Groups. Impacts of climate change will vary substantially from region to region, and from sector to sector within regions. More adverse impacts are expected in regions with lower economic development and therefore lower adaptive capacity, e.g., the Balkans. Climate change will have different impacts on different on different social groups (age classes, income groups, occupations and genders).

Economic effects. The TAR identified many climate impacts on Europe's economy:

- for shipping reasons, industry in Europe has traditionally been located on its coastlines. These industries will have to adapt to seal level rise.
- increasing CO_2 concentrations are expected to increase agricultural yields, although this may be counteracted by decreasing water availability in Southern and Eastern Europe.
- preferences for recreation are likely to change (more outdoor activity in Northern Europe less in Southern Europe).
- the insurance industry may be confronted with increased claims due to climate-related events.
- warmer temperatures and higher CO_2 levels may increase potential timber harvest in Northern Europe, while increasing the risk of forest fire risk in the Southern Europe.

12.2 Current sensitivity/vulnerability

12.2.1 Climate factors and trends

Europe has an area of 10.5 millions km². Extending from the Atlantic Ocean in the west, to the Ural Mountains, the River Ural and the Caspian Sea in the east, and from the Arctic Ocean in the north to the Mediterranean Sea, Black Sea and Caucasus Mountains in the south. Climatic conditions vary greatly over this territory. Europe's climate is primarily influenced by the Icelandic Low over the North Atlantic Ocean, which stems from stationary waves in the atmosphere. This low, together with the Azorean high, determines the mean position and direction of airflow across Europe (Bolle, 2003). Synoptic-scale circulation spinning off from the stationary waves determines European weather and climate. High mountains barriers such as the Alps and Pyrenees interact with (or help to generate) these systems (e.g. Genoa cyclones in the bow of the Alps). Strong precipitation gradients occur in these regions. At smaller scales, temperature gradients induced by the land-sea interface or orographic flows modify the climate patterns. The Gulf Stream and south-north oceanic transport of heat warms the western coast of Europe, up to north of Norway, where it reduces the winter sea-ice cover. The fact that the western European coast is warmer than the western American coast is mostly explained by the offshore stationary waves and their interaction with heat storage and release by the Atlantic (Seager *et al.*, 2002).

The North Atlantic Oscillation (NAO) is an important manifestation of seasonal to inter-decadal climate variability in Europe. The NAO is a large scale meridional displacement of atmospheric mass between the North Atlantic regions of the Azorean high and the sub polar Icelandic Low. It is often defined as the difference between the mean cold season (December to March) surface pressure anomalies of the Azores and Iceland (Wanner *et al.*, 2001). ENSO also influences European winter weather regimes (Moron and Plaut, 2003).

Many recent studies have investigated the relation between NAO and European climate. NAO has been found to influence precipitation over the western half of Europe. A positive NAO index is associated with low winter precipitation in Southern and Central Europe (Marshall *et al.*, 2001; Turkes and Erlat, 2003) and above average precipitation in Northwest Europe. The reverse is true for periods with negative NAO index (Bolle, 2003; Trigo *et al.*, 2004). The link between NAO and summer precipitation is not well established because summer climate patterns seem to be governed by more local scale phenomena, although some weak correlations are found (Kettlewell *et al.*, 2003). The alpine region is also partly influenced by the NAO: a positive index is associated with a mild winter and below average snow cover (Beniston and Jungo, 2002; Scherrer *et al.*, 2004). The NAO index correlates not only with winter mean precipitation, but also with extreme rainfall in Europe (Haylock and Goodess, 2004). Sea surface temperatures (SST) appear to have a smaller direct influence on climate variability than atmospheric variables, but it might have an indirect influence by determining air flow over the Atlantic ocean (Junge and Stephenson, 2003).

The availability of climate data, such as the European Climate Assessment database Klein Tank *et al.*, 2002) enabled several recent studies of 20th century trends. A warming trend throughout Europe is well established. This trend is accompanied in winter by an increase in the warm spell days, but not by a negative trend in the number of cold spell days. Instead, the number of cold spell days has increased over Europe. Precipitation trends are more spatially variable. Mean precipitation is increasing in Northern Europe and decreasing in Southern Europe. An increase in mean precipitation per wet day is observed in most parts of the continent, even in areas getting drier (Frish et al, 2002; Klein Tank *et al.*, 2002). At the smaller scale, scientists identified an increase in multi-day, prolonged heavy rainfall events in Northern and western parts of the United Kingdom.

Cold outbreaks in Europe appear to occur regularly. In the second half of the 20th century, winter 1962-63 and January-February 1985 were probably the two most significant cold events. Although these events are related to a negative NAO index, the sea level pressure anomaly associated with NAO is generally shifted to the east of the nodal location of the NAO (Walsh *et al.*, 2001). Particularly notable events were the floods of Central Europe during summer 2002, and the heat wave of summer 2003, (Schär *et al.*, 2004; André *et al.*, 2004; Beniston, 2004). These are discussed in detail in specific sections of this chapter.

12.2.2 Non-climate factors and trends

Europe has a total population of 727 million, with the highest population density (60 persons per km^2) of any continent. On the average, 73% of the total European population lives in urban areas (UN, 2002), with 67% in Southern Europe and 83% in Northern Europe.

The 25 countries belonging to the European Union (EU) are developed countries with stable economies, high productivity levels and integrated markets. There is a larger diversity in economic conditions among the non-EU countries. The value of the GDP per capita in 2003 ranged from US$ 1 760 in Moldova to US$ 55 500 in Luxembourg (World Bank, 2005). The EU covers 60% of the total European population, but only 17% of the total European land area and 36% of its agricultural area. In 2003, the EU with its then 15 countries had 20% of global GDP and 40% of global exports of goods and services (IMF, 2004). Central and Eastern Europe plus European Russia had 16% of global GDP. Thus, Europe as a whole accounted for more than a third of global GDP.

Since 1990 countries in Central and Eastern Europe have undergone dramatic economic and political changes towards a market economy and democracy, and for some countries also political integration into the EU and NATO. This is likely to have contributed to annual GDP growth rates of more than 4% in all CEE countries and in Russia, as compared to 2% in the EU (IMF, 2004).

Europe is one of the world's largest and most productive suppliers of food and fibre (in 2004: 21% of global meat production and 20% of global cereal production). About 80% of this production occurred in the EU countries. The productivity of European agriculture is generally high, in particular in Western Europe, and average cereal yields in the EU countries are more than 60% higher than the world average. Trends in European agriculture are dominated by the EU Common Agricultural Policy (CAP). In 2003 it was decided to decouple agricultural subsidies and production. Instead, future payments to farmers will be linked to their compliance with environmental, food safety, animal and plant health and animal welfare standards, as well as the requirement to keep farmland in good agricultural and environmental condition. This is not expected to greatly affect agricultural production in the short run, although rice production will be reduced (OECD, 2004). However, agricultural reforms are expected to enhance the current process of structural adjustment leading to larger and fewer farms (Marsh, 2005). The revised CAP has a strengthened rural development policy with increased emphasis on environmental and employment issues.

The area of forests in Europe is increasing and annual fillings are considerably lower than required for sustainable wood production (EEA, 2002). European forests are estimated to be a sink of atmospheric CO_2 of about 380 Tg C yr^{-1} (Janssens *et al.*, 2003). However, CO_2 emissions from the agricultural and peat sectors reduce the net carbon uptake in Europe's terrestrial biosphere to between 135 to 205 Tg C yr^{-1}, equivalent to 7 to 12% of global anthropogenic CO_2 emissions in 1995.

The European countries in 1995 had CO_2 emissions from fuel combustion ranging from 3.8 to 11.6 t CO_2 per capita in Latvia and Belgium, respectively (Groenenberg *et al.*, 2001). There is no general difference in emissions between the original EU countries and countries in CEE (Groenenberg *et al*., 2001). Most European countries have ratified the Kyoto-protocol, and reduction targets for the first commitment period range from -27% in Portugal to 28% in Luxembourg (Babiker and Eckaus, 2002).

Continuous overfishing has put many fish stocks in European waters outside sustainable limits. This is the case for 62-92% of commercial fish stocks in the Northeastern Atlantic, 100% in the West Ireland Sea, 75% in the Baltic Sea, and 65-70% in the Mediterranean (EEA, 2002). This development has occurred despite policies to protect fish stocks (Gray and Hatchard, 2003). Aquaculture is increasing its share of the European fish market leading to possible adverse environmental impacts in coastal waters (Read and Fernandes, 2003).

The hydrological characteristics of Europe are very diverse, as well as its approaches to water use and management. Freshwater is withdrawn in 30 countries in Europe (EU plus additional countries) for use by agriculture (32%), for cooling water in power stations (31%), for use in the domestic sector (24%), and for manufacturing (13%) (Flörke and Alcamo, 2005). Freshwater abstraction has stabilised or is declining in Northern European countries and is growing more slowly in Southern Europe (Flörke and Alcamo, 2005). Although the quality of river water is improving in most European countries (Nixon *et al*., 2003), the impact of agriculture on Europe's water resources needs to be reduced if “good ecological” status of surface and ground water is to be achieved. There are many pressures on water resources including those arising from agriculture, industry, urban areas, households and tourism (Lallana *et al*., 2001). Recent floods and droughts have put additional stresses on water supplies and infrastructure (Estrela *et al*., 2001).

Tourism is one of Europe's fastest growing sectors, and Europe is the world’s leading tourist destination with almost 60% of world market share. In the EU, the sector contributes to 7% of GDP (12% if indirect effects are included) (EEA, 2001). Increasing urbanisation and tourism, as well as the intensification of agriculture have led to large pressures on the European land resources (EEA, 2004b). On the other hand, there is increasing political attention given to the conservation of land and sustainable use of natural resources. European countries participate in several international treaties and conventions to reduce pollution and protect the natural environment and habitats. Environmental protection in the EU has led to several directives such as the Emissions Ceilings Directive and the Water Framework Directive. The EU Species and Habitats Directive and the Wild Birds Directive have been combined into the Natura 2000 network, which protects nature over 18% of the EU territory. A similar trend in awareness of environmental issues is also seen in CEE (Zylicz, 1999).

12.3 Assumptions about future trends

12.3.1 Climate

12.3.1.1 Mean climate

Results presented here and in following sections are for the period 2070-2099 as compared to the climate normal period (1961-1990).

Mean sea level pressure

Regional climate simulations indicate a cell of increasing pressure centred somewhere around the British Isles from June to August (Raisanen *et al*., 2004). This indicates a Northeasternward extension of the summer mean Atlantic subtropical high. The climate simulations produce much larger differences for other seasons, depending especially on the global model used to drive regional climate simulations. The simulation of December-January-February mean pressure indicates an increase in average westerly flow in Northern Europe when the ECHAM4 global model (Roeckner *et al*., 1999) is used, but a slight decrease when the UK HadAM3H model (Gordon *et al*., 2000) is used.

Surface air temperature

In all seasons Europe undergoes warming in both the A2 and B2 scenarios. The warming is in the range of 2.5 to 5.5°C in the A2 scenario and 1 to 4°C in the B2 scenario. The warming is greatest over Eastern Europe in December-January-February and over Western and Southern Europe in June-July-August (Giorgi *et al*., 2004). This range results from the span of emission scenarios and uncertainties related to the climate system's response to changing concentrations of greenhouse gases (Parry, 2000). For Europe, a basic analysis for four regional climate model simulations was performed by Raisanen *et al.,* (2004) under the framework of EU project PRUDENCE. In Northern Europe all four simulations indicate a larger warming in winter than in summer. In Southern and Central Europe, the winter-summer contrast in warming is reversed from that in the North. A very large increase in summer temperatures occurs especially in the southwestern parts of the continent, where the warming locally exceeds 10°C in France (Raisanen *et al*., 2004, Kjellstrom, 2004, Good *et al*., 2004). The seasonal cycle of temperature change differs dramatically between Northern and Southern-Central Europe. As an example, the largest warming in Sweden occurs either in November or in February and the smallest in June-July. Conversely, in France, the temperature increase in winter is somewhat smaller than that in Sweden, but all four simulations show a pronounced peak in warming in late summer. Even in Southeastern Europe, the warming is largest in late summer, but its magnitude in this season is less extreme than in France.

Precipitation

All four scenario simulations (A2 and B2 scenarios and 2 global driving models) performed by Raisanen *et al*. (2004) agree on a general increase in winter precipitation in Northern and Central Europe. They also agree on a general and in some areas very large (up to 70% in scenario A2) decrease in summer precipitation in Central and Southern Europe, and on a smaller decrease in summer precipitation up to Central Scandinavia. Generally, the mean annual precipitation increases in Northern Europe and decreases further south. The change in precipitation varies substantially from season to season and across regions in response to changes in large scale circulation and water vapour loading. Giorgi *et al*. (2004) found that increased Atlantic cyclonic activity in December-January-February leads to enhanced precipitation (up to 15-30%) over much of Western, Central and Northern Europe. Precipitation from December to February is reduced over Southern Mediterranean regions in response to increased anticyclonic circulation. In June-July-August an enhanced anticyclonic circulation is found over the Northeastern Atlantic which induces a ridge over Western Europe and a trough over Eastern Europe. This blocking structure deflects storms northward, causing a substantial and widespread decrease of precipitation (up to 30-45%) over Western and Central Europe as well the Mediterranean basin. Both the winter and summer changes are statistically significant at the 95% confidence level over extended areas of the modelling domain. Relatively small precipitation changes are found in the intermediate seasons of spring and autumn (within +/-15%).

The seasonal cycle of precipitation changes is broadly in phase between Central Europe and Northern Europe, but with large absolute differences. For example, the mean precipitation in Sweden increases in all four simulations in most of the year, with the exception of July-August. In France, precipitation increases in winter but decreases substantially in the summer half-year. The seasonal extent and magnitude of this decrease varies between the different simulations, with the greatest reduction at least 25% in all months from March to September and about 60% in June-August. Another region with great variations between the different simulations is western Norway. There, circulation changes cause a large uncertainty in precipitation change over the western side of the Scandinavian mountains (Raisanen *et al*., 2004; Kjellstrom, 2004).

Mean wind speed

Windiness typically increases in Northern Europe by about 8% and decreases in the Mediterranean region. The increase in windiness in Northern Europe is largest in winter and early spring, when the increase in the average north-south pressure gradient is largest. In Northern Europe, two of the simulations using the ECHAM4 model (Roeckner *et al*., 1999) as driver show that the mean wind speed increases from October to May with the largest increases from January to May. In the summer no simulations show significant changes. In France and Central Europe in general, all four simulations indicate a slight increase in average wind speeds in winter and a slight decrease at least in spring and autumn. (Figure 12.2).

12.3.1.2 Extreme events

The yearly maximum temperature is expected to increase much more in Southern and Central than in Northern Europe. A large increase is also predicted for the yearly minimum temperature in most of Europe, which at many locations exceeds the average winter warming by a factor of two to three. This indicates a decrease in wintertime temperature variability. An increase in the lowest winter temperatures, although large, would only mean that the cold extremes of the present climate would dissipate. On the other hand, a large increase in the highest summer temperatures would expose Europeans to unprecedented high temperatures.

The maximum annual one-day precipitation increases even where mean annual precipitation declines. Palmer and Raisanen (2002) estimate that the probability of total boreal winter precipitation exceeding two standard deviations above normal will increase by a factor of five over parts of the UK over the next 100 years. For the Mediterranean region, Holt and Palutikof (PRUDENCE, 2004) report considerable drying under the A2 scenario between 1960-1990 and 2070-2100, involving reduced intensity of rainfall, earlier start of drought, and longer drought periods. The regions most affected are the Southern Iberian Peninsula, the Alps, the Eastern Adriatic seaboard, and Southern Greece. Changes under the B2 scenario are smaller, but still indicate a drier Mediterranean area. Generally, the most extreme changes have the highest uncertainty (up to about ±60%) but, on average, uncertainty at the 95% level is about ±20%.

Giorgi *et al*. (2004) found a predominant increase in the intensity of daily precipitation events and a decrease in the frequency of events, also in areas where the mean precipitation decreases. Kjellstrom (2004) has shown that in summer, the warming in large parts of Central, Southern and Eastern Europe may be more closely connected to higher temperatures on warm days, than to a general warming. Much of the warming in winter is connected to higher temperatures on cold days. Changes in precipitation are due to both changes in the number of wet days and changes in the amount of precipitation on these wet days. The intensity of precipitation extremes increases. Increased contributions from heavy precipitation events is a general feature even in areas where total precipitation is calculated to decrease, as in large parts of Southern Europe during summer. Schar *et al*. (2004) conclude that the European summer climate might experience a pronounced increase in year-to-year variability in response to greenhouse gas forcing. Such an increase in variability might be able to explain the unusual European summer of 2003 and would strongly affect the incidence of heat waves and droughts in the future. Good *et al*. (2004) show that the longest yearly dry spell will increase by as much as 50% under A2 scenario, especially over France and Central Europe. Although only the Eastern Mediterranean now has a regularly recurring dry period, later in the century also the rest of the Mediterranean and even much of Western Europe may have such a period.

12.3.2 Non-climate trends

The European population is expected to decline by about 8% over the period from 2000 to 2030 (UN, 2002). The relative overall stability of the population of Europe is due to population growth in Western Europe alone, mainly from immigration (Sardon, 2004). Central and Eastern Europe and Russia have a negative net birth rate, with the balance of migration being positive only in Russia. Fertility rates vary considerably across the continent, from 1.10 children per woman in Ukraine to 1.97 in Ireland. There is a general decline in old-age mortality in most European countries, although this trend has abated in many countries (Janssen *et al*., 2004). The low birth rate and increase in duration of life lead to an overall older population. The proportion of the population over 65 years of age in the EU is expected to increase from 16% in 2000 to 23% in 2030.

The SRES scenarios for socio-economic development have been adapted to European conditions (Jordan *et al*., 2000; Abildtrup *et al*., 2005; Holman *et al*., 2005), and their main characteristics are outlined in Table 12.1. Assumptions about future European land use and the environmental impact of human activities depend greatly on the development and adoption of new technologies. For the SRES scenarios it has been estimated that increases in crop productivity relative to 2000 could range between 25 and 163% depending on the time slice (2020 to 2080) and scenario (Ewert *et al*., 2005). These increases were smallest for the B2 and highest for the A1 scenario.

Table 12.1: *Adaptation of SRES scenarios to Europe (Jordan et al., 2000; Abildtrup et al., 2005; Rounsevell et al., 2005a, b).*

Scenario	Characteristics for Europe
A1. World market	Emphasis on pursuing economic growth and free trade European economic inequalities eradicated and rising income levels Stable political and social climate with good health care and education Rapid enlargement of the EU EU is a single market, functionally integrated with other markets
A2. Provincial enterprise	Society is dictated by short-term consumerist values Policy decisions are taken at national and sub-national levels Europe adopts protectionist economic and trade policies Declining equity between European countries EU competences remain as they are today and enlargement is restricted
B1. Global sustainability	Emphasis on international solutions to global environmental problems Enlargement of the EU and development towards a federal structure EU takes over responsibility to solve environmental problems International institutions will adopt social programmes
B2. Local sustainability	Focus on solving environmental problems locally (green technologies) In EU the principle of subsidiarity shifts governance to the local level The enlargement and the deepening of EU is abandoned Decisions are often taken at subnational levels Europe is more heterogeneous leading to larger inequities

Temporally and spatially explicit future scenarios of European land use have been developed for the four core SRES scenarios (Rounsevell *et al*., 2005b). These scenarios are based on supply/demand models of market forces, rural development and environmental policies based on qualitative descriptions in the scenarios and the characteristics of the European landscapes. The results show large declines in agricultural land uses resulting from the assumptions about future crop yield with respect to changes in demand for agricultural commodities (Rounsevell *et al*., 2005a). Expansion of urban area is similar between the scenarios, but the spatial patterns are very different reflecting alternative urban development processes (Reginster and Rounsevell *et al*., 2005a). Forest areas increase in all scenarios. The scenarios showed decreases in European cropland for 2080 that ranged from 28% to 47% (Rounsevell *et al*. 2005a). The reduction in European grassland for 2080 ranged from 6% to 58%. This decline in agricultural area will make land resources available for other uses such as biofuel production and nature reserves.

12.4 Expected future impacts and vulnerabilities

12.4.1 Water resources

Climate change will influence the water cycle differently in different parts of Europe. Under the most recently computed climate scenarios, annual runoff increases in northern (Werritty, 2002) and decreases in central and Southeastern Europe (Santos, 2002; Menzel and Bürger, 2002; Etchevers *et al.,* 2002; Chang *et al*., 2003; Estrela *et al*., 2005; Alcamo *et al*., 2005). Winter runoff tends to increase and summer runoff decrease in the Rhine (Middelkoop *et al.,* 2001), Volga (Oltchev *et al*., 2002) and Slovakian rivers (Szolgay *et al*, 2004). Lowest flows shift from winter to summer in east-central Europe (Lehner *et al.,* 2001) and decrease by up to 50% (Eckhardt and Ulbrich, 2003) in particular in the Alps after the melting of its glaciers (Schneeberger *et al*., 2003). Groundwater recharge may be reduced (Eitzinger *et al*., 2003), with a larger reduction in valleys (Krüger *et al.,* 2002) and lowlands (e.g. in the Hungarian Steppes) (Somlyódy, 2002*)*. Changes in the water cycle are likely to increase the risk of floods in almost all of Europe (EEA, 2005), whereas increasing drought stress will mainly occur in Southern and Southeastern Europe (Table 12.2).

Table 12.2: *Impact of climate change on water availability and floods for various time slices (selected IPCC-SRES and climate scenarios). Source: EEA (2005)*

Time slice	Water availability	Floods
2020s	Small changes in annual runoff (-5 to +5%) Increase in winter runoff and decrease in summer runoff	Increasing risk of snowmelt flood in central and Eastern Europe, of winter flood and flash floods in Northern Europe. Risk in snowmelt-caused flood shifts from spring to winter.
2050s	Increase in annual runoff by up to 10% in northern, decrease in annual runoff by up 20-30% and in summer flow by up to 50% in Southeastern Europe.	Increase of risk of flash floods and other types of floods.
2080s	In Northern Europe, increase in annual runoff by up 50 %. In Southeastern Europe decrease in annual runoff by up to 60%, in summer low flow by up 80%.	100-year flood discharges increases by more than 25% in Northeasternern Europe, more than 10% in Poland, Ireland, parts of Spain and Portugal

The risk of winter floods increases in maritime regions, while the risk of snowmelt-related floods increases in Central and Eastern Europe. The risk of flash floods rises throughout Europe (Lehner *et al*., 2005, EEA, 2005), but particularly in Southern and Southeastern Europe (Ludwig *et al.,* 2003). The magnitude of the 100-year flood discharge increases in Northeasternern Europe, in Ireland, and parts of Poland, Spain and Portugal. Flood discharge significantly increases in the upper and middle course of alpine rivers (Lehner *et al.,* 2005). Flood risk could be magnified by an increase in impermeable surfaces due to urbanisation (Ad De Roo *et al.,* 2003, EEA, 2005) and modified by changes in vegetation cover (Robinson *et al.,* 2003). The more frequent occurrence of high runoff may increase the risk to areas protected now by levees. The increasing volume of flow and peak discharge would make it more difficult for reservoirs to store high runoff and prevent floods.

Model calculations (Lehner *et al*., 2003; Arnell, 2004; Alcamo *et al*., 2005) indicate an increase in annual water availability in Northern and Northwestern Europe and a decrease in Southern and Southeastern Europe (Figure 12.1). There is little difference between SRES scenarios up to the 2050s for a given climate model. However, larger and sometimes contradictory results are produced by different climate models. Change in annual water availability is small up to the 2020s and greater by 2070s, in particular in the Mediterranean region. In Southern and Southeastern Europe water availability in the summer period may be reduced by 80% and more, which could lead to deterioration in water quality (Mimikou *et al*., 2000, Santos *et al*., 2002) (Figure 12.1). Trends in water demands strongly depend on economic growth and other changes in society. The irrigation water demand increases due to increasing water consumption by crops and increasing frequency and magnitude of droughts. The highest increase in irrigation water demand is projected in Southern and Southeastern Europe (Santos *et al*., 2002; Döll, 2002; Donevska and Dodeva, 2004; Mínguez *et al.,* 2005). Irrigation requirements become substantial in countries where it now hardly exists (Holden *et al*., 2003). The domestic and industrial water demands decrease in Western Europe due to the saturation of demands and increasing efficiency of water use, while in Eastern Europe increase due to economic growth (Alcamo *et al*., 2003; Alcamo *et al*., 2005). Water stress decreases in northern (Scandinavia, Benelux countries, Germany) and increases in southern and southeastern Europe (Spain, Portugal, Southern France and Italy, Greece, countries in Eastern Europe) (Alcamo *et al*., 2005). The percentage of river basin area in the severe water stress category may increase from 19% today to 34-36% by the 2070s (Lehner *et al*., 2001), leading to increasing competition for available water resources. Climate change will reduce the reliability of existing reservoirs by increasing evaporation and in some cases reducing inflow to reservoirs which may become vulnerable in Southern and Southeastern Europe. Some studies (e.g. the Vihorlat reservoir in Slovakia) show that feasible changes in the management of dams and reservoirs can minimize the impact of climate changes (Halmova, 2004).

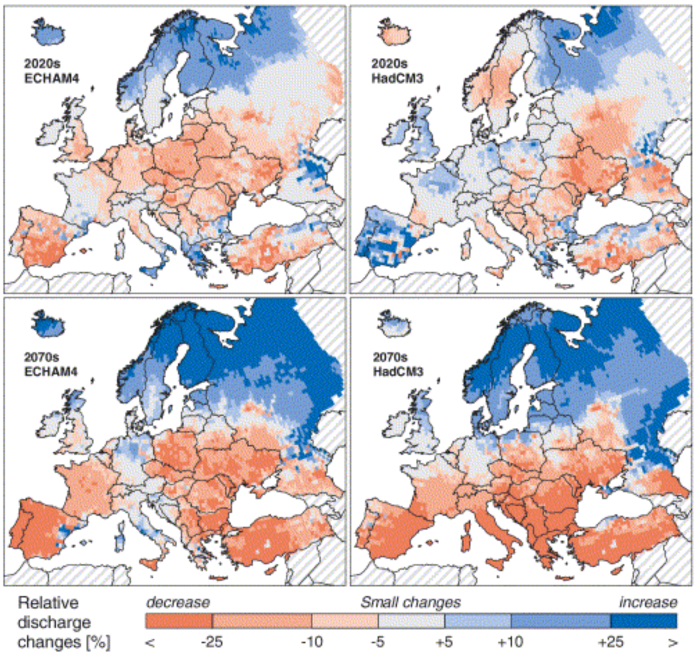

***Figure 12.1:** Change in river basin discharge under climate change. Depicted are relative changes of annual average river basin discharge between the climate normal period (1961-90) and two future time slices (2020s) and (2070s). Computations from WaterGAP 2.1 model (Alcamo, 2003a, Döll et al., 2003) with climate scenarios based on the IS92a scenario as computed by the ECHAM4 and HadCM3 global climate models, and with a reference water use scenario Lehner et al (2003).*

12.4.2 Coastal and marine systems

Climate variability associated with the North Atlantic Oscillation (NAO) determines many physical coastline processes in Europe (Woolf *et al*., 2003; Yan *et al*., 2004; Hurrell *et al*., 2003, 2004) including the seasonality in coastal climates, the speed of winter winds, the rate of storminess and coastal flooding in Northwest Europe (Lozano *et al*., 2004; Yan *et al*., 2004; Vijaykumar *et al*., in prep.; Weiss *et al*., in prep.) The NAO leads to fewer storms and calmer conditions southward and into the Mediterranean. Most AOGCM experiments show the continuation of a positive NAO beyond 2050 (Church *et al*., 2001; Cusbach, *et al*., 2001; Hulme *et al*., 2002; Hurrell *et al*., 2003). The NAO also has a strong influence on the rate and geographic distribution of sea level rise (Woolf *et al*., 2003), with a positive NAO raising sea levels over Northern Europe and lowering them over some parts of the Mediterranean. Coastal flooding and water levels in the Caspian Sea (> ±4 m since 1929) also appears to be linked to the NAO (Lal *et al*., 2001). In the Black Sea no correlation of SLR with the NAO is apparent.

Wind-driven waves and storms are seen as the primary drivers of short-term coastal processes on many European coasts (De Groot and Orford, 1999; Smith *et al*., 2000; Stone and Orford, 2004; Hesselbjerg *et al*., in prep.). No increase was seen in the intensities of wind-waves and storms on the European Atlantic coast during the 20th century (WASA, 1998; Alexandersson *et al*., 2000; Weisse *et al*., in prep; Smits *et al*., in prep.). Data do show, however, significant decadal cycles of increase and decrease, with strong regional and seasonal shifts in patterns of behaviour (Kaas and Andersen, 2000; Guedes Soares *et al*., 2002; Lozano *et al*., 2004; Woodworth *et al*., in press; HIPOCAS, in press). (Figure 12.2).

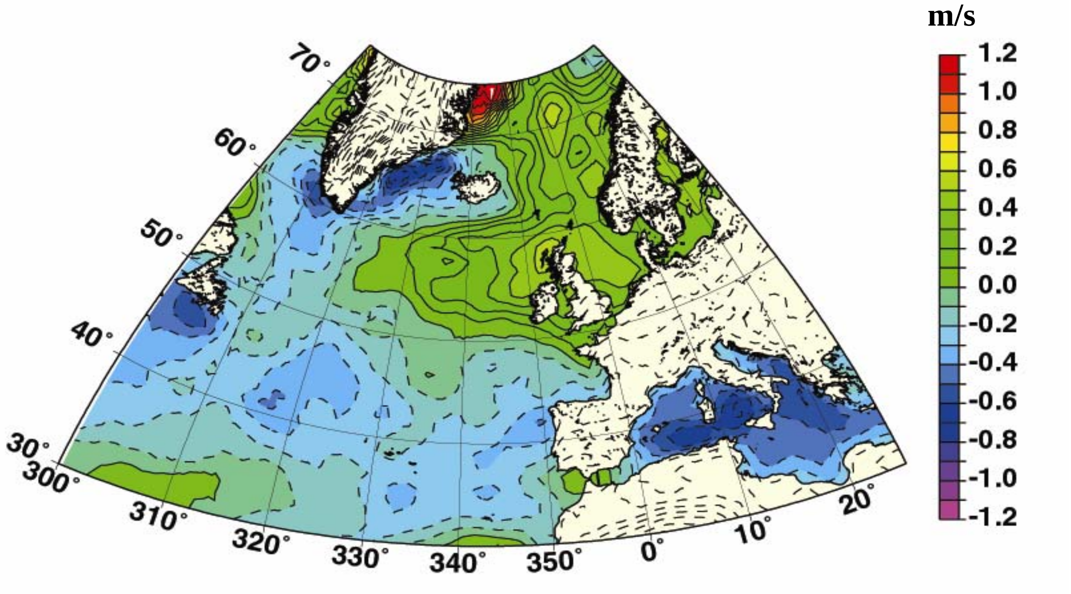

Figure 12.2: *Change in winter mean wind speeds on the European Atlantic coast under climate change. Depicted are changes in mean wind speeds in winter months (DJF) between reference period (1970-1999) and future time slice (2060-2089). Computed by ECHAM4 model for reference scenario of greenhouse gas emissions. Thick lines: increasing wind speed; Dashed lines: decreasing wind speed; Contours at 0.1 m/s interval) (Lozano et al., 2004).*

Projected changes in storminess for European waters using AOGCMs and regionally downscaled high-resolution models give different outcomes (Kaas and Andersen, 2000; Räisänen, *et al*., 2004; Hesselbjerg *et al*., in prep.). Most model experiments (based mainly on the IS92a scenario) show an increase in either the number or intensity of storms in the Northeastern Atlantic. These experiments also indicate an eastward, on-coast shift of peaks in storm centres (Knippertz *et al*., 2000; Leckebusch and Ulbrich, 2004; Lozano *et al*., 2004; McGrath *et al*., in press), and a decline in storminess and wind intensity along the Mediterranean (Busuioc, 2001; Tomozeiu *et al*., in press) (Figure 12.2).

Increased storminess is predicted in parts of the Adriatic, Aegean and Black Seas. Wave modelling suggests increased wave heights (H_{sig}) of > 0.4m in the Northeastern Atlantic by 2080 (Tsimplis *et al*., 2004b). Surge-tide models indicate a reduction in the frequency of large surge events (Lowe *et al*., 2001; Hulme *et al*., 2002; Lowe and Gregory, in prep.). The greatest effects are noted for estuaries, deltas and embayments, as in the Southern North Sea, Kattegat and Adriatic (Flather and Williams, 2000; Lionello, 2002).

The literature shows a wide range of estimates for the intensity of SLR in Europe in the 21st century (Smith *et al*., 2000; Carter *et al*., 2004; Woodworth *et al*., in press). AOGCM simulations of the IPCC-SRES scenarios estimate a global mean SLR of 0.3-0.5 m by 2100 (Church *et al*., 2001; IPCC, 2007). Regional evaluations of SLR in Europe show estimates up to 50% higher than global mean estimates. The impact of the NAO on winter sea levels adds an uncertainty of plus/minus 10 to 20 cm to these other estimates (Hulme *et al*., 2002; Tsimplis *et al*., 2004b). Furthermore, the possibility of a relatively abrupt melting of glaciers and permanent snow pack adds additional uncertainty (Gregory *et al*., 2004) (see Case Study in Section 12.6). Some projections indicate increased risk of coastal flooding in Scandinavia after 2050 (Gregory *et al*., 2001; Johansson *et al*., 2004; Warrick *et al*., 2004). Climate-related sea level rise could increase the risk of storm surges especially on coasts with low tidal range, coastal subsidence or tectonic activity, as in the Mediterranean and Black Sea regions

Sea level rise will cause an inland migration of Europe's beaches and low-lying, soft sedimentary coasts (Sánchez-Arcilla *et al*., 2000; Kundzewicz *et al*., 2001; Stone and Orford, 2004; Hall *et al*., in prep). Coastal retreat rates are currently about 0.5 to 1.0 m/yr for the parts of the Atlantic coast most affected by storms. These rates may increase under sea level rise (Lozano *et al*., 2004; Pilkey and Cooper, 2004). Climate-related reductions in sea ice cover in the Baltic and Arctic are also likely to lead to increased erosion in these regions (Kont *et al*., in press).

Studies of Europe's coastline have also shown that the vulnerability of particular stretches of coastline are very dependent on local factors (Duffy and Devoy, 1999; Swift *et al*., 2005). Low-lying coastlines with high population densities and small tidal ranges will be most vulnerable to SLR (Kundzewicz *et al*., 2001; Nicholls and Klein, in prep.). Coastal flooding related to SLR could affect large populations and impact tourism and recreation (Arnell *et al*., 2004) (Table 12.3). Under the A1F1 scenario approximately 2.5 million people each year might experience coastal flooding by 2080 (Nicholls, 2004). The increasing threat of coastal flooding will have important economic consequences on the population as more attention is given to coastal protection and management (De Groot and Orford, 2000; Tol, 2002). Sea level rise will also affect natural areas of Europe. For example, 20% of wetland area may disappear because of SLR by 2080 (Nicholls, 2004; Devoy, in prep.)

Table 12.3: *Potential impacts in coastal vulnerability for a 1 m sea level rise in selected European countries, assuming the socio-economic situation of the 1990s and no adaptation. Estimated adaptation costs to protect the human population are also shown (modified from Nicholls and De la Vega-Leinert, in prep., and Devoy, in prep.)*

Country	Coastal floodplain population	Coastal population flooded per year	Capital value loss	Land loss	Wetland loss	Adaptation costs	Coastal floodplain population	Coastal population flooded per year	Capital value loss	
	#(k)	% total	#(k)	% total	US$ (10^9)	% GNP	km^2	% total	km^2	US$ (10^9)
Ireland	<250	<5	<100	0.8	0.17	0.2	<230	<0.3	>400	42/a
Netherlands	10,000	67	3,600	24	186	69	2,165	6.7	642	12.3
Germany	3,120	4	257	0.3	410	30	n.a.	n.a.	2,400	30
Estonia	47	3	n.a.	n.a.	0.22	3	>580	>1.3	225	n.a.
Poland	235	0.6	196	0.5	22	24	1,700	0.5	n.a.	+0.4/a
Turkey	2450	3.7	560	0.8	12	6	n.a	n.a	n.a	20

12.4.3 Mountains and sub arctic regions

The duration of snow cover is expected to decrease by several weeks for each °C of temperature increase (Hantel *et al.*, 2000; Martin *et al.*, 2004; Wielke *et al.*, 2004). An upward shift of the glacier equilibrium line is expected from 60-70 to 140 m/°C (Vincent, 2002; Maish, 2000). Most alpine glaciers are likely to disappear during the 21st century, and areas below 2500 m will be ice-free by the end of the century (Haeberli and Burn, 2002; Paul *et al.*, 2004). A significant decrease in glacier volume is also expected in Northern Europe: e.g. the Stoglaciaren glacier in northern Sweden, may lose 30% of its present mass during the 21st century (Schneeberger *et al.*, 2001)). As glaciers disappear, spring and summer discharge will decrease (Hagg and Braun, 2004).

It is likely that the lower limits of permafrost will rise by several hundred meters. In the north of Europe, lowland permafrost will eventually disappear (Haeberli and Burns, 2002). This change will be modulated by changes in snow cover (in relation to winter precipitation patterns) (Harris et al, 2003; Stieglitz *et al.*, 2003). Changes in ice- and snow pack may also increase the likelihood of snow avalanches (Martin *et al.*, 2001). The likelihood of ice avalanches from steep hanging glaciers may change, depending on the complex interaction of surface geometry, precipitation, and temperature (Haeberli and Burns, 2002). Rock falls from rock walls destabilized by increased temperature will increase, threatening valleys (Gruber *et al.*, 2004).

Climate-related vegetation changes have already been documented in Europe, including an ongoing invasion of laurophylous evergreen species in valley bottoms (Walther, 2003), an upward shift of the tree line (Grace *et al.*, 2002, Kullman, 2002, Walther, 2003), a change in high mountain vegetation types (Peñuelas and Boada 2003; San Elorza *et al.*, 2003; Kullman 2001; Meshinev *et al.*, 200) and the new occurrence of alpine vegetation on high summits (Garbherr *et al.*, 2001; Klanderud and Birks, 2003; Walther 2003). It is virtually certain that the European mountain flora will undergo major transformation because of climate change (Theurillat and Guisan, 2001, Walther *et al.*, 2004). Indirect effects, mainly through change in snow cover distribution and growing season length (Körner, 2003), should have much more pronounced effects than direct effects on metabolism (Grace *et al.,* 2002, Niklaus and Körner, 2004). Overall trends are towards increased growth and earlier phenology (Grace *et al.,* 2002, Körner, 2003, Walther *et al.,* 2004, Sandvik *et al.,* 2005; Egli *et al.*, 2004). With the abandonment of traditional alpine land use, the tree line is predicted to shift upward by several hundred meters, thus restricting the true alpine zone to higher elevations (Guisan and Theurillat, 2001; Dirnböck *et al.*, 2003; Düllinger *et al.*, 2004). The composition and structure of alpine communities will change (Theurillat and Guisan 2001; Walther, 2003), and extreme scenarios show a 60% loss of species (Thuiller *et al.*, 2005). Many plant species with deeper root may be replaced by shallow-root species, and this could have consequences on the stability of steep mountain slopes at high elevations (Körner, 2003; Corominas, 2005).

12.4.4 Forest, grasslands, and shrublands

12.4.4.1 Forests

Future forest ecosystems in Europe will be strongly influenced by climate change, land-use change and forest management (Shaver *et al.,* 2000; Blennow and Sallnäs, 2002). An overview of likely climate impacts is given in Table 12.4. Forests, especially in the north, will continue their current expansion, although the rate of change is very uncertain. (Figure 12.6). Under the A1 and A2 SRES scenarios, forest area tends to increase in the north and decrease in the south. Under the B1 and B2 scenarios, it also increases in the south (Metzger *et al.,* 2004). A redistribution of tree species is also expected. Most native tree species in Europe will shift northwards especially at the boundary of the steppe and forests zones. Shifts inland from the coast may also occur (Bradshaw *et al.,* 2000). (Figure 12.6).Tree vulnerability until they adapt to new climate (Redfern and Hendry, 2002). The tree line in European mountains is likely to rise, and currently treeless areas are likely to become forested (in particular in Scandinavia and the Russian European north). There is evidence that this process has already begun in Scandinavia (Kullman 2002), Urals (Shiyatov *et al.,* 2005.), and Pyrenees (Camarero and Gutiérrez, 2004).

In Northern Europe, snow cover will decrease and the frost-free period of soils is likely to increase. The combination of reduced frost and increased precipitation during winters will lead to increased soil wetness, water logging, and floods (Nisbeth, 2002). Chilling requirements of some tree species could be endangered in some regions. Warming will cause reduced cold-hardiness during autumn and spring and faster onset of budburst. Elevated winter temperatures could increase needle loss and make growth slower during the following season (e.g. for *P. abies*), probably initiating top dying (Redfern and Hendry, 2002). Frost damage is expected to be reduced in winter, unchanged in spring, and more severe in autumn due to later hardening (Redfern and Hendry, 2002). Frost damage is often accelerated by combinations of different drivers, in particular drought (Barklund, 2002; Jönsson *et al.,* 2004). In Southern Europe, drier climate will reduce the area of forests and woodlands (Fernández-González *et al.*, 2005).

Changes in the length of photosynthetic activity in forests above 35ºN (Myneni *et al.,* 2001, Slayback *et al.,* 2003), as well as changes in phenology (Myneni *et al.,* 2002, Shvidenko *et al.,* 2004; Peñuelas *et al.,* 2002), have been documented during the last two decades of the 20th century. Climate change will alter phenology and substantially increase NPP and biomass of forests, particularly in the north (Shvidenko *et al.,* 2004), due to the longer growth period, elevated temperatures, and high nutrient availability caused by higher decomposition rates (Berg *et al.*, 2000; Jarvis and Linder 2000; Zheng *et al.*, 2002; Semevsky and Golubjev, 2002; Strömgren and Linder, 2002; Rustad *et al.*, 2001). Elevated CO_2 may also increase production of some species (Zheng *et al.*, 2002), although there are conflicting estimates (Medlyn *et al.*, 2001). Simulations show increases in productivity and expansion of high latitude forests (White *et al.,* 2000), halving the current tundra area by 2100. Increased NPP and water-use efficiency were simulated for conifer plantations in the south (Magnani *et al.,* 2004). NPP can either increase or decrease depending on the magnitude of temperature increase, although NPP usually declines at very high temperatures (Pretsch and Durshy, 2002).

Reduced water availability is likely to decrease the NPP and growth of coniferous and deciduous trees in Central Europe (Lasch *et al.,* 2002), and increase their mortality in the south (Martínez-Vilalta and Piñol, 2002).

European forests (in 30 countries) were estimated to be an increasing carbon sink during 1950-1999 (from 0.03 to 0.14 Pg C/a, for 132 and 140 million ha of forests, respectively; Nabuurs *et al.,* 2003). Forests in European Russia were estimated to be a sink of about 0.2 Pg C/a from 1961 to 1999 (Shvidenko and Nilsson, 2003). While NPP is expected to increase in major forest regions of Europe, expected changes of net ecosystem productivity are more complicated since warmer temperatures and humidity also increase respiration. Experiments indicate an increase of forest soil CO_2 fluxes to the atmosphere with increased temperature and atmospheric concentration of CO_2. (Niinisto *et al.,* 2004). Climate change may induce a reallocation of carbon to green parts (Magnani *et al.,* 2004), a process also observed in Russian forests (Lapenis *et al.,* 2004). In the taiga and boreal forests, warmer soils and increased decomposition of plant litter increase nutrient availability, which, in turn, enhances plant production (e.g. Hobbie *et al.,* 2002), but may also stimulate C losses (Mack *et al.,* 2004).

Fire occurrence in forests may increase, especially in the south, due to elevated temperature and reduced rainfall (Viegas 1998; Pausas, 2004). In Spain the fire season expands under a wide range of climate scenarios (Moreno, 2005). Fire danger may also increase in Central Europe, but the risk may be lower in Northern Scandinavia and Russia (Flannigan *et al.,* 1998). Increased fire frequency in the Mediterranean could lead to greater dominance of shrubs over trees (Vázquez and Moreno, 2001; Mouillot *et al.,* 2002). Similarly, in boreal forests and, in particular, at the forest-tundra ecotone, increased fire-frequency may lead to long-term (over several hundred years) replacement of forest by low productive grassy glades or wetlands (Sapozhnikov, 2003). An increased frequency of vegetation fires is also expected in the forest and steppe zones of Russia. Wind damage to trees may also substantially increase in many European regions. The warming and thawing of permafrost observed in Northern Europe (Mazhitova *et al.,* 2004) provides an additional threat to forests adapted to permafrost.

Climate change is likely to affect the survival and reproduction of insects, the natural enemies of pests, the nutrient content of the leaves of host trees, the vigour and defence capabilities of the hosts and phenological synchrony of the pest and host (Virtanen *et al.,* 1998; Evans *et al.,* 2002). Climate change may be responsible for the expansion northward and upward of some of the most important forest pests in Southern relict forests (Hódar *et al.,* 2003) and in northern temperate forests (Virtnaen and Neuvonen, 1999; Battisti, 2004). However, climate change will also affect the host plants and natural enemies of pests (Bale *et al.,* 2002; Niemela *et al.,* 2001). Hence the net impact of climate change on pests is difficult to estimate (Bale *et al.,* 2002; Harrington *et al.,* 2001).

Table 12.4: *Likely climate impacts on forests in different European countries over the next 20 to 100 years. "+" = increase, " – " = decrease*

Changes in	Countries				
	Sweden[1]	United Kingdom[2]	Spain[3]	Northern European Russia [4]	Ukraine (Forest Steppe) [5]
Tree species diversity	++	TBD	--	++	±
Wood production	+++		++ then ---	+	++
Damage caused by					
Windthrow	+		±	+	+
Snow breakage	-		±	-	±
Forest fires	+		+++	++	+
Spring frost	±		-	±	±
Autumn frost	-		-	-	-
Winter damage	±		-	±	-
Hardwood decline	±		?	±	±
Drought	+		+++	+	+
Water logging	+		±	+	-
Insect outbreaks	+		+	+	+
Vertebrates	+		±	±	±
Diseases	±		+	+	+
Ground vegetation	+		+	+	+

[1] Aggregated for three parts of the country from KSLA (2004). [3] Based on Moreno (2005). [4] Adapted from Shvidenko (2004). [5] From Ukrainian references listed at end of chapter.

12.4.4.2 Grasslands and shrublands

Permanent grasslands occupy about 37% of Europe's agricultural area. The type of grassland ranges from grass and shrub steppes around the Mediterranean to mires and tundra in Northern Europe. Different species will differ in their responses to CO_2 and climate change, resulting in alterations in their community structure (Buckland *et al.,* 2001; Lüscher *et al.,* 2004). However, the management and species-richness of grasslands may increase resilience to change (Duckworth et al., 2000). Legumes, which fix nitrogen from the atmosphere, will benefit more from a CO_2 increase than non-fixing species (Schenk *et al.,* 1995). This has been found experimentally to lead to larger nitrogen inputs to grass-clover swards (Zanetti *et al.,* 1996). Grasslands will differ in their response to climate change depending on grass species, soil type, soil management, and other factors. In general, intensively managed and nutrient-rich grasslands will respond positively to both an increase in CO_2 concentration and temperature, given adequate water and nutrient supply (Thornley and Cannell, 1997; Lüscher *et al.,* 2004). Nitrogen-poor and species-rich grasslands may respond differently to climate change and increasing CO_2. Short- and long-term responses could also be completely different (Cannnel and Thornley, 1998).

European shrublands deliver a variety of goods and services, several of which are linked to their biodiversity. Experimental studies have indicated that warming, and to some extent also drying, will reduce biodiversity (Wessel *et al.,* 2004). In grazed shrublands in Northern Europe, warming will increase productivity. In several Northern European heath lands warming may increase nutrient availability and lead to grass encroachment. In Southern Europe, warming and increased droughts are likely to reduce primary productivity and increase risks of wildfires and erosion in shrublands (Wessel *et al.,* 2004). Grasslands generally have a high soil carbon pool, which can be manipulated through land use changes (e.g. between arable and grassland) and from grassland management (Soussana *et al.,* 2004). Simulation studies suggest that European soils under climate change could be a long-term net sink of carbon (Thornley and Cannell, 1997). However, increasing frequency of heat waves and droughts in Central and Southern Europe may lead to increased carbon flux to the atmosphere, although experimental evidence is still weak (Jones and Donnelly, 2004; Wessel *et al.,* 2004).

Productive grasslands are closely linked to livestock production since grasslands are a major source of feed for ruminants (Parsons et al., 2001). In areas where dairy farming becomes less viable, grasslands may be replaced by cropland (Holman et al., 2005). A reduction in the viability of dairy and cattle farming may occur due to increased risk of failure to produce sufficient fodder for the cattle.

European grassland area (EU-15 plus Norway and Switzerland) may decrease under the IPCC-SRES scenarios from about 17% of land area in 2000 to about 8% in 2080 under the A1 and A2 scenarios, 11% under the B2 scenario, and 16% under the B1 scenario (Rounsevell *et al.,* 2005a) (Figure 12.6). Reductions of about 50% were computed for Italy and Portugal even under the lowest scenario. These scenarios predict an increase in surplus land in the A1 and A2 scenarios, part of which may be used to increase the area of forests, non-productive grasslands, and shrublands for landscape, recreational and biodiversity reasons. These scenarios were driven by a combination of changes in climate and socio-economic factors.

12.4.5. Wetlands and aquatic ecosystems

Warmer temperatures may result in earlier ice melt of lakes and rivers in Northern and Southeastern Europe, and in longer growing seasons at high elevations throughout Europe. A consequences of these changes could be a higher risk of algal blooms and increased growth of toxic cyanobacteria in lakes (Straile *et al.,* 2003; Briers *et al.,* 2004; Eisenreich, 2005, Moss *et al*., 2003). Other impacts could be the accelerated decomposition of soil and peat in Northern Europe (Weltzin *et al.,* 2003), and loss of permafrost areas in the Arctic (Arctic Council, 2004). These factors plus increased precipitation may result in higher nutrient loading to inland waters (Bouraoui *et al.,* 2004; Kaste *et al.,* 2004; Andersen *et al.,* submitted; Eisenreich, 2005) and increased loading of dissolved organic matter (Evans and Monteich, 2001; Worrall *et al.,* 2004; Arctic Council, 2004). Higher precipitation and reduced frost may enhance nutrient loss from cultivated fields (Andersen *et al.,* submitted; Eisenreich, 2005), augmenting eutrophication of lakes and wetlands (Jeppesen *et al.,* 2003), despite increased nutrient losses due to more frequent flooding (Kronvang *et al.,* 1999). Streams in catchments with impermeable soils may become more unstable, with increased run-off in winter and deposition of organic matter in summer which could reduce invertebrate diversity (Pedersen *et al.,* 2004). Inland waters in Southern Europe are likely to have a lower volume and increased salinisation (Williams, 2001; Zalidis *et al.,* 2002). Many ephemeral ecosystems may disappear, and permanent ones shrink (Alvarez Cobelas *et al.,* 2005). Although a drier climate may decrease the loading of nutrients to inland waters, the concentration of nutrients may increase because of the lower volume of inland waters (Zalidis *et al.,* 2002). Also an increased frequency of high rainfall events could increase nutrient discharge to some wetlands (Sánchez Carrillo and Alvarez Cobelas, 2001).

Warming will affect the physical properties of inland waters (Eisenreich, 2005, Livingstone *et al.,* 2005). The thermocline of summer-stratified lakes will sink, while the hypolimnion- temperature and duration of stratification will increase, leading to higher risk of oxygen depletion below the thermocline (Straile *et al.,* 2003; Catalán *et al.,* 2002; Blenckner, 2005;). Higher temperatures will also reduce dissolved oxygen saturation levels and increase the risk of oxygen depletion (Sand Jensen and Pedersen, in press).

Species richness of inland waters is highest in Central Europe and declines towards the south and north (Declerck *et al.,* 2005). Increased runoff and lower risk of droughts in the north will benefit the fauna of inland waters (Lake, 2000; Daufresne *et al*., 2003), and a drier climate in the south will have the opposite effect (Alvarez Cobelas *et al.,* 2005). Higher temperatures may lead to increased species richness in freshwater ecosystems in Northern Europe and decreases in parts of Southwest Europe (Gutiérrez Teira, 2003). Invasive species may increase in the north (McKee *et al.,* 2002). Woody plants and shrubs may become more important in bogs and fens (Weltzin *et al.,* 2003). Reduction of inundation periods in the South may favour amphibian species over genuinely aquatic ones (Alvarez Cobelas *et al.,* 2005). Cold-adapted species will be forced further north and upstream; some eventually disappearing from Europe (Daufresne *et al.,* 2003; Eisenreich, 2005).

12.4.6. Biodiversity

Climate change is affecting the physiology, phenology, and distribution of different European plant species (e.g. Parmesan *et al.,* 1999; Thomas and Lennon, 1999; Thomas *et al*., 2001; Warren *et al.,* 2001; Walther *et al.,* 2002; Parmesan and Yohe 2003; Root *et al.,* 2003; Brommer 2004; Austin and Rehfisch 2005; Hickling *et al.,* 2005; Root *et al.,* 2005). A European-wide assessment of future distribution areas of 1,350 plant species (10% of European flora) under various SRES scenarios and climate modelling results, indicated that by 2080 more than half of the analysed species could be classified as vulnerable, endangered, critically endangered, or extinct (Thuiller *et al.,* 2005). Under the most severe climate scenario (and assuming that species can adapt through dispersal) 22% of the analysed species would become critically endangered and 2% committed to extinction. Similar results were obtained by Bakkenes *et al.* (2002) who estimated the fate of 1,400 European plant species in 2050. According to these analyses, the range of plants may expand in Northern Europe and contract in mountainous areas of Southern Europe, and in the Mediterranean basin. Studies of specific European regions (Kienast *et al.,* 1998; Saetersdal *et al.,* 1998; Theurillat and Guisan, 2001, Duckworth *et al.,* 2000; Fernández *et al.,* 2005) are consistent with European-scale studies.

An assessment of European fauna indicated that the majority of amphibian (45% to 69%) and reptile (61% to 89%) species could expand their range under various SRES scenarios and climate modelling results if dispersal were unlimited (Araújo *et al.,* 2006). This is because warming in some of the cooler northern ranges of species is likely to create new opportunities for colonisation. However, if species were unable to disperse (the most likely scenario according to Araujo and Pearson, 2005) then the range of most species (>97%) would become smaller especially on the Iberian Peninsula, France and other parts of Southwest Europe. Meanwhile species in Britain, Southeastern Europe, and Southern Scandinavia were projected to benefit from a more suitable climate (Figure 12.3). This is because dry conditions in the southwest are projected to increase, where few amphibian species are able to persist (see also Teixeira and Arntzen, 2002).

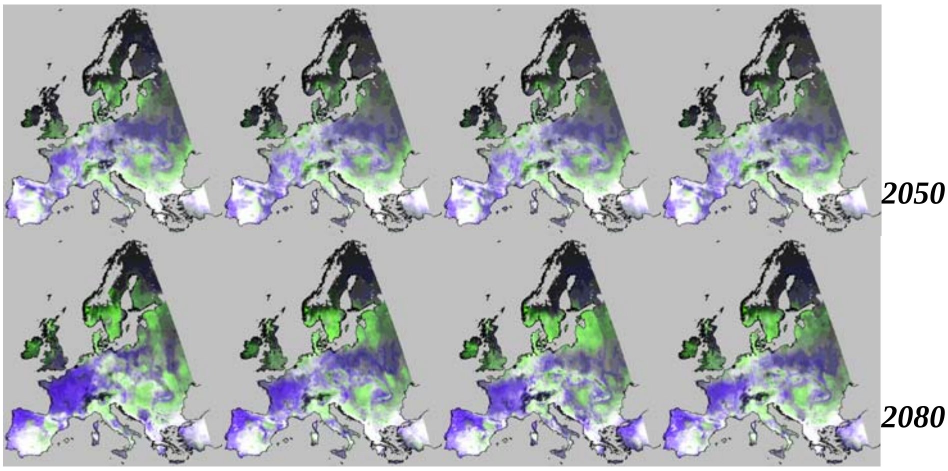

Figure 12.3: *Change in herptile species richness under climate change.*

Depicted is the change between baseline and future herptile species richness projected for 2-time periods (2050 and 2080) using artificial neural networks, four SRES scenarios (A1, A2, B1, B2) (shown left to right), and based on climate scenarios from the HadCm3 global climate model. Colours show regional differences in species richness in baseline and future projections. Increasing intensities of blue indicate increasing species richness in the baseline period (i.e. broad patterns of contraction) and increasing intensities of green represent increasing species richness in the future (i.e. broad patterns of range expansion). Black, white and grey cells indicate areas with stable species richness scores: black grid cells show low species richness in both periods; white cells show high species richness; grey cells show intermediate species richness (Araújo *et al.,* 2006)

12.4.7 Agriculture and fisheries

12.4.7.1 Crops

Climate change is expected to have a significant effect on crop production in Europe. Climate-related increases in crop yields are only expected in the Northern Europe, while the largest reductions are expected around the Mediterranean and in the Southwest Balkans. In Southern Europe, the decrease in yield is expected to be particularly large for spring-sown crops such as maize, sunflower and soybeans (ACCELERATES, 2004; Moriondo *et al.*, 2005). The impact of climate change on autumn-sown crops (e.g. winter and spring wheat) in Southern Europe is more geographically variable; yield is expected to strongly decrease in the most Southern areas and increase in the northern or cooler areas (e.g. northern parts of Portugal and Spain) (Olesen *et al.*, 2005; Moriondo *et al.*, 2005; Santos *et al.,* 2002). However, these results vary between SRES scenarios and climate models (Olesen *et al.*, 2005).

Some crops that currently grown mostly in Southern Europe (in particular, summer crops such as maize, sunflower and soybeans) will become more suitable further north or in higher altitude areas in the south (ACCELERATES, 2004). The projections for a range of SRES scenarios show a 30 to 50% increase in suitable area for maize production in Europe by the end of the 21st century. Potential maize-growing area extends as far north as Ireland, Scotland, Southern Sweden and Finland (Fig. 12.4, Olesen *et al.*, 2005). By 2050 energy crops show a northward expansion in potential cropping area, but a reduction in suitability in Southern Europe (Tuck *et al.*, 2005).

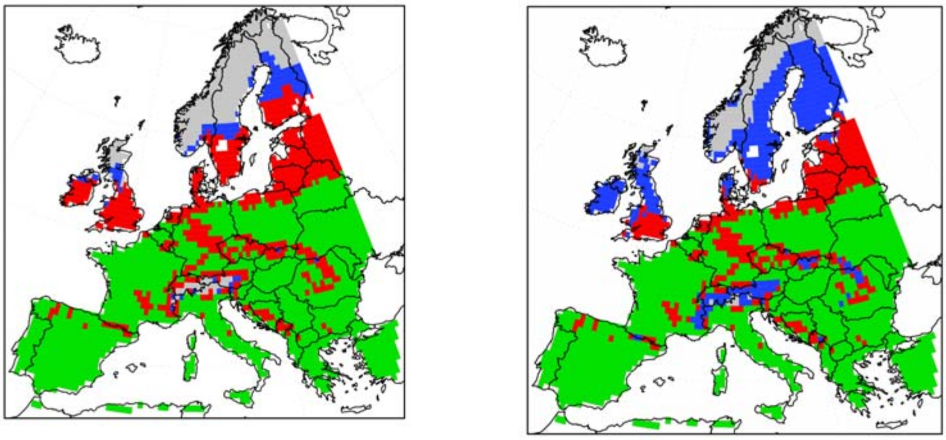

Fig. 12.4: *Suitability of maize cultivation under climate change. Modelled suitability for grain maize cultivation during a baseline (1961-1990) and future (2071-2100) period. Left: 7 scenarios computed with regional climate models driven by HadAM3H global climate model for the A2 emissions scenario. Right: 24 scenarios from 6 global climate models for the A1FI, A2, B1 and B2 emissions scenarios. Green areas show the suitable area for the baseline, red depicts the expansion common under all scenarios and blue the uncertainty range of the respective scenario group. Grey areas are unsuitable under all scenarios (Olesen et al., 2005).*

The effects of climate change and increased atmospheric CO_2 are expected to lead to overall small increases in European crop productivity. However, technological development (e.g. new crop varieties and better cropping practices) might far outweigh the effects of climate change (Ewert et al., 2005). Combined yield increases of wheat by 2050 could range from 37% under the B2 scenario to 101% under the A1 scenario (Rounsevell *et al.*, 2005a). Increasing crop yield and decreasing or stabilizing food and fibre demand could lead to a decrease in total agricultural land area in Europe (Rounsevell *et al.*, 2005a).

Extreme weather events, such as spells of high temperature and droughts, can severely disrupt crop production. An increase in temperature variability will increase yield variability (Jones *et al.* 2003) and may cause a reduction in average yield (Trnka *et al.* 2004). Thus the projected increases in temperature variability may have significant impacts on agricultural production in Central Europe (Meehl and Tebaldi, 2004; Schär *et al.,* 2004). An increase in the frequency of extreme climate events in the European Mediterranean region during specific crop development stages (e.g. heat stress during flowering period, rainy days during sowing dates), together with higher rainfall intensity and longer dry spells, may reduce the yield of durum wheat and sunflowers (Moriondo *et al.*, 2005).

Conditions are more favourable for the proliferation of insect pests in warmer climates (Cammel and Knight, 1992). Warmer winter temperatures may also allow pests to over winter in areas where they are now limited by cold, thus causing greater and earlier infestation during the following crop season. Similar effects can also be seen for fungal diseases, although there is a larger variation in the effect of weather on diseases (von Tiedemann, 1996, Chakraborty, 2000). It is thus likely that a warmer climate will lead to increased problems with pests and diseases, in particular in Northern Europe.

Climate change will modify other processes on agricultural land. Projections made at the European level for winter wheat showed that climate change beyond 2070 may lead to a decrease in nitrate leaching from agricultural land over large parts of Eastern Europe and some smaller areas in Spain, and an increase in the UK and in other parts of Europe (Olesen *et al.*, 2005) (Figure 12.5). Climate change, could also lead to increases in greenhouse gas emissions from agriculture. (Olesen *et al.*, 2004). The capacity of European agricultural soils to store C will decrease under higher temperatures. Changes are expected to be moderate in the north and larger in Central and Southern Europe (Metzger *et al.,* 2005).

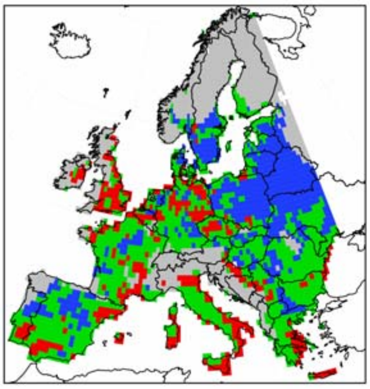

***Fig. 12.5:** Change in nitrate leaching from wheat cultivation under climate change. Estimated change in nitrate leaching from winter wheat cultivation computed with climate scenarios from 9 regional climate models driven by the HadAM3H global climate model for the A2 emissions scenario. Decreasing leaching (blue), increasing (red) and conflicting results (green). Grey areas are estimated to be unsuitable for winter wheat (Olesen et al., 2005)*

12.4.7.2 Livestock

The expected increases in temperature and droughts will affect livestock production throughout Europe. The impacts will be different for intensive, housed livestock production, semi-intensive systems based on farm feed production, and extensive grazing systems. The expected increased frequency of severe heat stress in Britain is expected to increase the risk of mortality of pigs and broiler chickens grown in intensive livestock systems. This risk could be offset by considerably reducing stocking densities or installing ventilation or cooling systems (Turnpenny *et al.*, 2001).

An increased frequency of droughts along the Atlantic coast (e.g. Ireland) may reduce the productivity of grasslands such that they are no longer sufficient for livestock. Alternative forage crops (e.g. maize, barley and soybean) may be required (Holden and Breton, 2002, 2003; Holden *et al.*, 2003). Increasing temperatures may also increase the risk of livestock diseases throughout Europe by (i) increasing the diffusion of insects (e.g. *Culicoides imicola*) that are the main vectors of several arboviruses (e.g. bluetongue, BT and African horse sickness, AHS); (ii) increasing the survival of viruses from one year to the next; (iii) improving conditions for new insect vectors that are now limited by colder temperatures (Wittmann and Baylis, 2000; Wittman *et al,*. 2001).

12.4.7.3 Fisheries

This section will be filled in the next draft by one of the selected contributing authors.

12.4.8. Energy

12.4.8.1 Energy demand

Energy production and use is the most important source of greenhouse gases in Europe (EEA, 2004a). European electricity usage has been rising steadily since the mid-1990s and this trend is expected to continue because of economic growth (EEA, 2004b). Electricity demand is closely linked to climatic conditions (Sailor, 2001, Howden and Crimp, 2001; Majithia, 2003; López Zafra *et al.,* 2005). There is a definable temperature at which electricity demand is at a minimum (e.g. 22°C for Athens) (Giannakopoulos and Psiloglou 2004). Under future warming, the seasonal cycle in energy demand will change, increasing the demand in summer, due to increased air conditioning (Valor et al., 2001, Giannakopoulos and Psiloglou, 2004, Majithia, 2003, Santos *et al*., 2002). This increase will be partly compensated by reduced demand for heating in winter (Giannakopoulos and Psiloglou, 2004; Levermore et al. 2004). In general, it is expected that warmer winter temperatures will cause a decrease in electricity demand, while warmer summer temperatures will cause an increase (Majithia 2003; López Zafra *et al.,* 2005).) Peaks in electricity demand during heat waves may equal or exceed peaks of winter demand (López Zafra et al., 2005). Thus, it will probably be necessary to install generating capacity over and above the additional capacity needed to satisfy future economic growth.

12.4.8.2 Energy supply and distribution

The key renewable energy sources in Europe currently are hydropower (19.8% of the electricity generated) and wind. Climate change may lead to a 25% or greater reduction in hydropower potential in parts of Southern and Southeastern Europe (Lehner *et al.* (2005). Recent climate modeling suggest no major change is expected in mean wind speeds across Europe (see Section 12.3.1.1) and, therefore, wind-generated power might not be appreciably affected. Biofuel production is determined by primary productivity which, in turn, is largely determined by the length of the growing season

(Olesen and Bindi, 2003). Under the SRES scenarios land area devoted to biofuels may increase by a factor of two to three in all parts of Europe up to the end of the 21st century (Metzger et al., 2005). Climate change could also have a negative impact on the efficiency of thermal power plants because water withdrawn for power plant cooling is expected to be somewhat warmer on the average, and the warmer cooling water would reduce the efficiency of power production. Furthermore, the availability of cooling water may be reduced at some locations of Europe because of climate-related decreases in river runoff (Arnell et al., 2005). The distribution of energy is also vulnerable to climate change (Thomas, 2002). For example, gas pipeline compressors become less efficient at higher temperatures, and electricity transmission is also sensitive to temperature (López Zafra *et al.*, 2005). Warmer temperatures can also cause transmission lines to sag (Colombo et al., 1999, Santos *et al.*, 2002).

12.4.9 Tourism and recreation

Several studies have examined tourist preferences with regards to climate (Palutikof and Agnew, 2001, Matzarakis, 2001, Lise and Tol, 2002). Tourists prefer a mean temperature of 21°C at their summer holiday destination (Lise and Tol (2002), and an optimal maximum daytime temperature of around 30.7°C (Maddison, 2001). Hence, increasing temperatures have the potential to discourage tourism (Matzarakis, 2001). Bohdanowicz and Martinec (2001) note that about 50% of overall energy consumption in hotels is due to air conditioning. A warmed climate may increase energy usage and reduce profitability of hotels. Higher temperatures are likely to shift summer vacation destinations from the south to the north, while summer heat waves in the Mediterranean may discourage tourism in summer and shift it to the spring and autumn months (Parry, 2000; Viner and Agnew, 1999).

Higher temperatures are also expected to disturb the important year-round but part-time residents of sunny parts of France, Italy and Spain. Mountainous parts of these regions could become more popular because of their relative coolness (Ceron and Dubois, 2004). Tourism on the European Atlantic coast could suffer because of increasing winter rainfall. Health risks related to hot temperatures and diseases might also increase. Water shortages during more frequent droughts could also disturb tourism. Perry (2001) reports that a tourist in Spain uses four times as much water as a Spanish city dweller, so current tourism is especially sensitive to changes in water availability. However, an extension of the tourist season into cooler months may alleviate the pressure on summer water supply. Also, desalination of water may become economically viable if profits from tourism continue to grow.

The ski industry in Europe is likely to be disrupted by significant reductions in natural snow cover especially at the beginning and end of the ski season (Elsasser and Burki, 2002). Adequate snow cover in relation to peak holiday periods is important in some cases and the availability of higher altitude snow slopes is critical. Snow depth in the Alps may decrease by 20-30% by 2020, and for every 1°C rise in temperature, there will be about 14 fewer skiing days (Schwarb and Kundewicz, 2004). From the perspective of snow pack the most sensitive altitude to future climate change is 1 000-1 500 metres (Schwarb and Kundewicz, 2004).

12.4.10 Property

Insurance systems differ widely between countries (e.g., in many countries flood damage is not insured) and this affects the vulnerability of their property to climate change. The value of property at risk also varies between countries. For example, the damage from a wind speed of 200 km/h is 0.2% of the value of insured property in Austria, to around 1.2% in Denmark (Munich Re, 2002). While insurers are able in principle to adapt quickly to new risks such as climate change, the uncertainty of future climate impacts has made it difficult for them to respond to this new threat.

It is expected that the risk of river flood damage will grow (ABI, 2000). However, the uncertainty of future climate as well as socio-economic factors leads to a wide range of estimates for the costs of future flood damage (Table 12.5). These figures assume that no measures are taken to adapt to climate-related flood risks. Of course society will be able to take precautionary measures (at a cost) to control future damage, but the inherent risk of damage will still exist. Results for 3 out of 4 scenarios for the UK (Table 12.4.10) imply an annual increase of 2 to 4% in insurance costs, which will have a large impact on the medium and long-term planning of infrastructure.

One of the first attempts to calculate the future cost of climate-related insurance was made in 1991 (CCIRG, 1991). An update of this calculation indicated that future climate-related insurance claims in the United Kingdom might be two to three times higher than current levels by 2050 assuming no change government policy on climate adaptation (Dlugolecki, 2004). One of the main uncertainties in this calculation is the future frequency and severity of extreme climate events because climate models do not yet provide a consistent estimation of future storm tracks and intensity. Regardless of this uncertainty, knowledge about extreme climate events is crucial for estimating future property damage. In the UK, the cost of a 1000-year extreme climate event is roughly two-and-a-half times larger than the cost of a 100-year event (Swiss Re 2002). In Germany, insurance claims increase as the cube of maximum wind speed (Klawa and Ulbrich, 2003), or a power relation of the fourth or fifth degree (Munich Re, 2002). Thus, if rare events become more common, future insurance costs will rise significantly.

***Table 12.5:** Annual expected river flood damage in the UK at present day and in 2080s (In 2004 £) under different SRES scenarios (Foresight Programme, 2004)*

Basis	Present day	A1	A2	B1	B2
Annual expected damage (10^9 £)	1.3	28.4	20.7	6.7	2.2

12.4.11 Human health

Although the future frequency and intensity of heat waves in Europe is uncertain, it is expected that they will become more common and severe. For example, by the 2080s, a heat wave similar to that of 2003 is expected every year in England (Department of Health, 2004). The number of deaths due to heat is also expected to increase although acclimatization is likely to reduce the number (Meehl and Tebaldi, 2004). It is likely that overall warming will reduce cold-related mortality, although reductions will vary greatly by location and will also depend on socio-economic variables (Keatinge *et al*, 2000; Martens and Huynen, 2001; Department of Health, 2002) (Zaninovic and Matzarakis, 2004).

Warming could extend the range of a number of disease-transmitting agents northward and to higher altitudes (Hunter, 2003; Kovats *et al*., 2001). Some models estimate the spread of *Lyme Borreliosis* under average climate changes, but a decrease in areas where the frequency of droughts or severe floods increase (Lindgren and Jaenson, 2004). In the UK TBE is likely to decrease, and the risk of tick-borne diseases is not expected to increase (Department of Health, 2002). However, robust assessments of future human infections are not possible due to the gaps in understanding the causal relationships between climate, ticks, and their transmission as well as on the heat-humidity thresholds for different vectors' habitats (Korenberg, 2004; Lvov *et al.,* 2004; Randolph, 2004). Under some climate scenarios malaria transmission may increase by 8 to 14% by the 2050s but this risk is too small to reestablish the disease (Kuhn *et al.,* 2003). Increases in malaria outside of Europe may increase the risk of malaria being imported to Europe (Mühlberger *et al.,* 2004; Wichmann *et al.,* 2004). In spite of an expected global increase of dengue fever, the probability of its transmission to Europe is very low (Hales et al., 2002).

Future warming in Europe is likely to cause an earlier onset and extension of the flowering and pollen seasons, and to an overall increase in the production of pollen (Beggs, 2004). As an exception, an increase in snowfall may cause later flowering in northern latitudes (Emberlin et al., 2002; Erdei et al., 2002; Jaeger, 2001). The greatest increase in pollen-induced allergies is expected in Central Europe and at elevations between 50 and 1000 m

Air pollution and its health risks are also related to climate change. Future climate conditions in Europe may lead to an increase in surface ozone levels with increasing mortality and morbidity (van der Leun and de Gruijl, 2002; WHO, 2004).

12.4.12 Spatial variability

European climate is marked by a decreasing temperature gradient from south to north and the decreasing influence of the Atlantic Ocean from west to east. Aridity also increases from the north-northwest to south-Southeast. Although this spatial variability of climate is expected to continue, the south is expected to become more arid relative to the north (Metzger *et al.,* 2004). For example vegetation typical of North Africa may appear on the Iberian Peninsula (Fernández-González *et al.,* 2005) (Figure 12.6). Climate change will lead to greater regional differences in runoff, with increases in some regions (e.g. on the Atlantic coast) and decreases in the south. Wood supply will increase in some parts of Europe (boreal, alpine-north), or increase at first then decline after the middle of the century. Risk of forest fires will increase several fold in the south, thus threatening the existence of forest (Moreno, 2005).

Carbon stocks in Northern and Central Europe may increase until the middle of the century, and decrease thereafter. In the Mediterranean region, carbon stocks are expected to decline with time. In the first part of the 21st century, net carbon uptake may be positive in all regions, whereas in the second half it may be negative in the north (particularly in the boreal zone) and positive in the Alps and other regions. Because of net changes in habitat (Figure 12.6), biodiversity may generally increase in the north and decrease in the south (Metzger *et al.,* 2004).

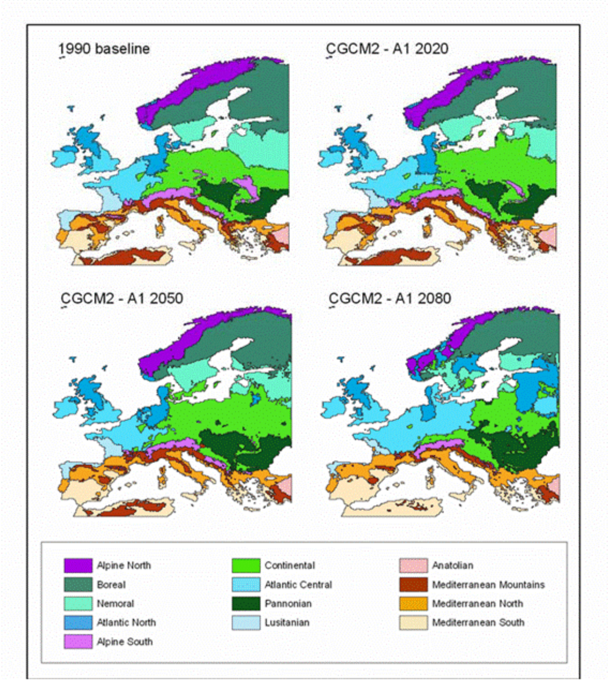

***Fig. 12.6:** Shifts in biogeographic zones under climate change. Depicted are the shifts in biogeographic zones for 3 time periods under the A1 scenario as computed by the CGCM2 global climate model (Metzger et al., 2005).*

As a result of combined socio-economic and climatic factors, arable land may expand in the north and decline in the south. Climate change is also likely to cause a shift in crop zones (Rounsevell *et al.,* 2005b). It is expected that regional differences in crop productivity will become smaller for crops that are particularly sensitive to temperature or length of growing season (e.g. particular fruits), and become larger for crops sensitive to water availability (e.g. sugar beet, potatoes). Although climate change may increase irrigation requirements in Northwest Europe (e.g. Denmark and Great Britain), Southern Europe will continue to have much higher irrigation requirements than the north. It may be expected that Northern Europe gains in tourism at the expense of Southern Europe because of the warmer summer temperatures in the north, the increasing frequency of heat waves in the south, and reduced snow pack in the alpine and Carpathian mountains. Overall, climate change may magnify the differences between north and south, and between west and east in Europe. In general climate impacts will be more adverse in the south and Southeast, and less adverse in Central Europe, and particularly less in Northern Europe. While adaptive capacity will increase everywhere with time, the magnitude of this capacity may continue to be greater in the west than in the east, and in the north as compared to the south (Metzger *et al.,* 2004).

12.5 Adaptation

12.5.1 Water resources

An important water management issue in Southern Europe is how to adapt to climate-related reductions in water availability and at the same time satisfy growing water demands Both supply- and demand-side adaptation strategies are being considered. Supply-side strategies include, for example, transfer and storage of water including the expansion of the capacity for wastewater reuse and desalinisation (Moreno, 2005). Some supply-oriented strategies seem to have large barriers to overcome. For example, new reservoir construction in Europe is hampered by the legal and environmental requirements of the EU Framework Directive on Water (Barreira, 2004). An expansion of desalinisation capacity is limited by high energy costs (Moreno, 2005), while the use of treated wastewater is limited by uncertainty regarding its potential risk to public health, and high costs of advanced wastewater treatment (Geres, 2004).

Some demand-side strategies seem more feasible than supply-side strategies (AEMA, 2002). Irrigation water requirements per hectare can be decreased by shifting to crops better suited to future climate, and by water-saving improvements in irrigation techniques (Somlyódy, 2002). On the other hand, improving the efficiency of irrigation can result in the build-up of salinity in soils (Moreno 2005). Water use in domestic and industrial sector may be reduced by in-plant recycling of process water and by reducing leaks in municipal water systems (Geres, 2004). Pricing policies are also a mechanism for controlling demand, especially when excessive consumption is penalised (Moreno, 2005).

In flood management there are non-structural and structural measures for flood protection. Non-structural measures such as reforestation can clearly reduce floods in small catchments (Moreno, 2005; Nael *et al.*; 2002, Niehoff *et al.,* 2002). Other effective non-structural measures are flood warning systems and emergency evacuation from flooded areas. Structural measures include flood-control reservoirs and levees, expanding flood plain area, (Helms, *et al*., 2002), and diverting floodwaters into temporary flood reservoirs (Pivot and Martin, 2002).

Adaptation strategies on the regional and watershed level can be incorporated into plans for integrated water management (IWRM). (Kabat, *et al.,* 2002), Cosgrove, *et al.*, 2004, Kashyap, 2004) while national strategies have to fit into existing governance structures (Hlavcová, *et al.,* 1999).

12.5.2 Coastal and marine systems

Strategies for adapting to sea level rise are well documented (Smith *et al*., 2000; IPCC, 2001; Vermaat *et al*., in prep.; Nicholls *et al*., 2005). Although a large part of Europe's coastline is relatively robust to sea level rise (De Groot and Orford, 1999; Stone and Orford, 2004), exceptions are subsiding, geologically 'soft', low-lying coasts with high populations, as in the Southern North Sea and coastal plains/deltas of the Mediterranean, Caspian and Black Seas. Adaptation strategies on low-lying coasts have to address the problem of sediment losses from marshes, beaches and dunes (Devoy *et al*., 2000; De Groot and Orford, 2000). The degree of coastal erosion to be expected by sea level rise is very uncertain (Cooper and Pilkey, 2004), though models do provide quantitative estimates (Walkden and Hall, in press; Dickson *et al*., in prep.).

The development of adaptation strategies for coastal systems has been encouraged by an increase in public and scientific awareness of the threat of climate change to coastlines. (Nichols and De la Vega-Leinert, in prep). Many countries in Northwest Europe have adopted the approach of developing detailed shoreline management plans that link adaptation measures with shoreline defence, accommodation and retreat strategies (European Commission, 1999; Cooper *et al*., 2002; DEFRA, 2004a). Parts of the Mediterranean and Eastern European regions have been slower to follow this pattern and management approaches are more fragmented (Tol *et al*., in prep.).

A key element of adaptation strategies for coastlines is the development of new laws and institutions for managing coastal land (Devoy *et al*., 2000; De Groot and Orford, 2000). For example, no EU Directive exists for coastal management, although EU member governments must publish coastal policy statements by 2006. The lack of a Directive reflects the complexity of socio-economic issues involved in coastal land use and the difficulty of defining acceptable management strategies for the different residents, users, and interest groups involved with the coastal region (Nichols and Klein, in prep.).

12.5.3 Mountains and sub arctic regions

Mountainous and sub arctic regions have a limited number of adaptation options. It may be possible to change building techniques once permafrost dissipates or disappears at a particular location. Elsewhere a variety of demand-side and supply-side strategies for adapting to changes in water availability have already been mentioned, and these apply as well to changes in the hydrology of mountainous and sub arctic regions caused by earlier snowmelt, glacier ablation and shrinking. There are no obvious climate adaptation options for either tundra or alpine vegetation. Perhaps the best that can be done is to lessen other stresses on this vegetation (e.g. by lessening the impact of tourism on this vegetation), so that it has a better chance of coping with climate change.

12.5.4. Forests, grasslands and shrublands

Among the many approaches for adaptation of coniferous forests to climate change are the planting of deciduous trees as appropriate, and the introduction of multi-species planting into currently mono-species plantations (Vakuljuk and Samoplavsky, 1998, Fernando and Cortina, 2004). Planting of forests could also be provided with genetically improved seedlings adapted to the new climate, if the risks of genetically modified species is considered acceptable (KSLA, 2004). More intensive stand management is also a general adaptive measure. Extending the rotation period of commercially important tree species may increase carbon sequestration, and therefore can be viewed as another adaptation measure (Kaipainen, *et al.,* 2004). Prescribed burning is also a possible adaptation option (Carter and Foster, 2004). An important prerequisite of adaptation and mitigation measures is the development of advanced systems of forest inventory and forest health monitoring.

Productive grasslands are closely linked with livestock production because grasslands provide feed for livestock (Parsons et al., 2001). Climate risks to fodder production can be reduced by applying irrigation and by changing intensities and frequencies of cutting and grazing (Riedo *et al.,* 2000).

12.5.5 Wetlands, aquatic system

To compensate for climate-related increases in nutrient loading to aquatic ecosystems from cultivated fields in Northern Europe, better management practices are needed, including optimized fertilizer use and less intensive farming. Another approach to compensate for increased nutrient loading is to re-establish wetland areas and river buffer zones as sinks for nutrients. A higher level of treatment of domestic and industrial sewage can reduce nutrient loadings to surface waters and also compensate for climate-related increases in these loadings.

To compensate for increased climate-related risks of salinisation, species loss, eutrophication and lowering of the water table in Southern Europe, a lessening of the overall human burden on water resources is needed. This could include less intensive agriculture in sensitive areas, improved recycling of water within catchments, and increased efficiency of water allocation among different users.

Storage and selective release of water through reservoirs and sluices can also help compensate for climate-related changes in runoff.

12.5.6 Biodiversity

Adaptation strategies for conserving biodiversity can be classified as '*in situ*' or '*ex situ*'. The first involves the selection, design and management of conservation areas (protected areas, nature reserves, NATURA 2000 sites), while the second involves conservation of germplasm in botanical gardens, museums and zoos. Very few studies have addressed the problem of '*in situ*' conservation under climate change in Europe, and to our knowledge '*ex situ*' conservation for mitigating climate change impacts on biodiversity have not yet been explicitly addressed in the context of European conservation science and policy.

The dynamic changes caused by global warming pose a difficult challenge to existing conservation policy which hinges upon a static view of current conditions. A modelling analysis of the relative robustness of plant species in selected European reserves indicated that 5% of the species would be faced with unfavourable climate, and 6 to 11% may disappear within 50 years (Araújo, 2004). In another study, it was estimated that protected areas in Europe need to be expanded by 19% to meet the goal that each of 1200 European plant species would be represented in a habitat of at least 100 km^2. Under climate change the area must be expanded by 43% (Hannah *et al.* 2006). The authors compared various policy approaches to conservation: 1) a proactive approach in which targeted areas would be expanded immediately, and 2) a reactive approach whereby action would be taken after impacts had occurred. The cost of the reactive strategy was estimated to be 39% higher than the proactive approach. These and other results suggest that '*ex situ*' conservation strategies (e.g. maintaining germplasm in botanical gardens) may become very important for ensuring the persistence of biodiversity over the long term.

12.5.7 Agriculture and fisheries

12.5.7.1 Agriculture

Short-term adaptations to climate-related threats to crop production in Southern Europe include agronomic and cultural measures such as changes in crop species (e.g. replacing winter with spring wheat (Minguez *et al,* 2005)), changes in cultivars and sowing dates (e.g. sowing the same cultivar earlier, or choosing cultivars with longer crop cycle (Olesen *et al*., 2005). Earlier sowing of irrigated summer crops could prevent yield reductions or enhanced water demand (Olesen *et al*., 2005).

A likely long-term adaptation measure is to change the allocation of agricultural land according to its changing suitability under climate change. Rounsevell *et al.* (2005a,b) estimate a decline of up to 50% in cropland and grassland areas under the A1-F1, and A2 IPCC scenarios. For the A1 and A2 scenarios scenarios both the quantity and the spatial distribution of crops will change, whilst, for the B1 and B2 scenarios the pressures toward declining agricultural areas should be counterbalanced by policy mechanisms that seek to limit crop productivity.

The interpretation of the four IPCC-SRES scenarios suggests that different types of adaptation of farming systems may be appropriate for particular scenarios (ACCELERATES final report, 2004). A revision of the Common Agricultural Policy (CAP) in the European Union may be capable of stimulating autonomous adaptation to climate change. In particular, since the impacts of climate change will vary between the regions, the CAP cold be re-designed to deal with these regional differences. For example, in Southern Europe the major concern may be cropland abandonment and increasing water demand for irrigation, whereas in Northern Europe intensified production and the negative environmental effects of farming may be major concerns (Olesen and Bindi, 2002).

12.5.7.2 Fisheries

This section will be filled in the next draft by one of the requested contributing authors

12.5.8 Energy and transport

A wide variety of adaptation measures are available in the energy sector ranging from modifications of human behaviour to re-design of the energy supply system (Santos *et al.,* 2002; Johansson and Goldemberg, 2002; MICE, 2004). Increasing the overall robustness of the European electricity system is likely to also increase its capacity to cope with climate change. The sensitivity of the energy supply and distribution network to increasing temperature could be reduced by laying supply lines underground and other infrastructure changes (Majitha, 2003). Another kind of adaptation is improving the efficiency of energy use and production, for example, by adopting energy-saving building codes, by adopting low-electricity standards for new appliances, by changing energy prices, and by training and public education. Moreover, a move towards the use of more local micro-grids would also reduce sensitivity of energy distribution to disruption from extreme climate events (Arnell et al., 2005).

An effective adaptation measure over the medium to long term will be shifting from fossil fuels to renewable low-carbon fuels. While there are many efforts in Europe to promote the use of renewable energy (e.g. 20% of Danish electricity is provided by wind energy), the shift away from fossil fuels will be slowed by the inertia of the existing energy production system, and the overall increase in energy demand related to economic growth in Europe. (MICE, 2004). In the course of adapting to increasing energy demand it is likely that European energy companies will also inadvertently adapt to climate change and climate extremes, which are likely to have a smaller impact on energy production than increasing energy demand. A very important remaining question is the cost of this adaptation.

12.5.9 Tourism and recreation

It appears that the tourist industry must adapt to changing climate conditions. Some of these changes will entail the shifting of conditions for tourism as in the case of warmer, drier summers in Northern Europe leading to greater domestic travel and a reverse tourist flow from the South.

Possible adaptation measures include (WTO, 2003, MICE, 2004).

- Compensating for reduced snowfall by artificial snowmaking which is already common for coping with year-to-year variability in snow pack. This adaptation may or may not be economic.
- Adaptation of seaside tourism to sea level rise by constructing tourism infrastructure further back from the coast.
- Cooperating with local governments to deal with new climate-related risks to health, availability of water, and infrastructure.
- Promoting new forms of tourism such as cultural tourism having greater emphasis on man-made rather than natural attractions.

- Promoting a change in the pattern of tourism, for example, compensating for a reduction in tourists in the Mediterranean area during the hotter summer months by encouraging visits during the cooler months.

2.5.10 Property

The insurance industry has several tactics to cope with increasing climate-related risk to property including pricing of insurance premiums, risk transfer, and improved loss remediation (Dlugolecki, 2001). Insurers are introducing geographical information systems to provide themselves with the information needed to adjust insurance tariffs to climate-related risks (Munich Re, 2004; Dlugolecki, 2001). Insurers are also alerting other stakeholders to the increasing risk from climate change and are actively involved in discussions of measures for climate change mitigation and adaptation (Dlugolecki and Keykhah, 2002).

Although the threat of major climate-related property damage to Europe as a whole does not seem to be very large, extreme climate events do result in significant local or regional damage. Not all Europeans are covered by the same degree of disaster relief, and some firms do not appear to be sufficiently insured against low frequency, high impact events such as severe floods (Swiss Re, 2000). In the business sector, some large firms "self-insure" in that they reserve internal funds to cope with disasters, but often these funds inadequate to cover extreme climate events (Dlugolecki, 2001).

An obvious adaptation measure against property damage is to change construction techniques to make buildings and infrastructure more robust to extreme climate events. However, retrofitting existing building stock can be difficult, and the long lifetime of this stock implies that it will not be replaced by more resilient structures for many years. Other barriers to the adoption of measures to prevent climate-related property damage are given in Table 12.6.

Table 12.6*: Overview of barriers to adopting protective measures against property damage*

Type of barrier	**Explanation**
Retrofitting buildings	Retrofitting existing building stock disrupts current residents and is expensive.
Uncoordinated financial relief	The wide variety of available financial mechanisms for disaster recovery makes the administration and coordination of disaster response difficult to manage.
Poor construction practices	Poor construction practices and poor enforcement of building regulations sometimes make it difficult to enhance the robustness of buildings and infrastructure.
Link between property and infrastructure	All property requires considerable infrastructural support and it is difficult to factor in the vulnerability of all associated infrastructure when estimating future risk of property damage.
Uncertainty of future climate	The uncertainty of the type, frequency, and intensity of future extreme climate events makes it difficult to adopt appropriate plans to avert property damage.

12.5.11 Human health

The population of Europe has adjusted successfully to mean summer temperatures ranging from 13.5°C to 24.1°C and can be expected to adjust to global warming predicted for the next half century with little sustained increase in heat related mortality (Keatinge, *et al*, 2000). To ameliorate the situation society needs to prepare for an increased frequency of heat waves and other risks. The extent of adaptation measures is a political decision (WHO, 2004). Possible measures include educational programmes to change society's behaviour, and urban planning measures to reduce urban heat islands and heat load on buildings in summer. More research has to be done on how climate change will affect the urban thermal environment, including downscaling of climate scenarios to a city level and the development of special urban scenarios. Because climate and culture differ within Europe, adaptation measures to lessen health risks should be adapted to the local setting (Kidsrk, 2002 ; Ballester *et al.,* 2003; Koppe *et al.,* 2004).

One strategy to reduce health risks of heat-waves is to develop health warning systems and intervention plans. Fifteen European cities have claimed to have such systems (Koppe, *et al.,* 2004), but only Rome and Lisbon have comprehensive ones. Similar warning systems are under development in Barcelona, Budapest, London and Paris (WHO, 2003a). Methodology for heat warning systems is under development by WMO (2005), and PHEME (2005).

Strategies to lessen the risk of injury from flooding has shifted from disaster response to risk management (improved warning) and this may have contributed to the recent decrease in fatal casualties per flood events in Europe (WHO, 2003; EEA, 2005). The Dresden flood of 2002 (see below) has raised public health issues that need to be urgently addressed: (1) the public health community needs to be prepared to address potential public hygiene issues; (2) hospital equipment must be assembled in a waterproof manner; and (3) for effective general crisis management, a decision hierarchy between hospitals and administrative authorities should be established before an extreme event (WHO, 2004).

12.6 Case Studies

12.6.1 Heat wave of 2003

A severe heat wave over large parts of Europe in 2003 extended from June to mid-August, raising summer temperatures by 3 to 5 °C from Northern Spain to the Czech Republic and from Germany to Italy (Schär *et al.*, 2004). Maximum temperatures of 35 to 40 °C were repeatedly recorded in July and August in most Southern and Central European countries. High temperatures were caused by an anti-cyclone firmly anchored over the western European land mass holding back the rain-bearing depressions that usually enter the continent from the Atlantic ocean. This situation was exceptional due to its long duration and to the very high minimum temperatures compared to previous heat waves (André *et al.,* 2004; Rebetz, 2004; Beniston and Diaz, 2004).

The small amount of precipitation during July and August failed to compensate for evapotranspiration of 300-400 mm over large parts of Central and Southern Europe. The extreme weather conditions reduced agricultural production and increased production costs (Olesen and Bindi, 2004). Damage to the agricultural sector has been estimated at more than 11 billion Euro. Many major rivers (e.g. the Po, Rhine and Loire) were at record low levels, resulting in disruption of irrigation and power plant cooling. Elevated temperatures led to permafrost thawing and increased number of rock falls in the Alps (Beniston and Diaz, 2004).

The heat wave increased mortality in many countries, in particular among elderly people (WHO, 2003; Valleron and Boumedil, 2004). Excess mortalities were estimated to be more than 15000 in France (Valleron and Boumedil, 2004), 3100 in Italy (Conti *et al.,* 2005), 1300 in Portugal (WHO, 2003), and 960 in Switzerland (Grize *et al.,* 2003). Other countries, including Germany, Spain and United Kingdom, were also severely affected (WHO, 2003). The rate of mortality differed significantly between cities within individual countries, perhaps because of differences in local climatic conditions and/or preparedness of the health sector to deal with health risks to elderly people (Vandentorren *et al.,* 2004; Conti *et al.,* 2005; Grize *et al.,* 2005).

The heat wave of 2003 has been found to be extremely unlikely statistically under current climate, even when observed long-term warming is taken into account (Schär *et al.,* 2004). However, it is consistent with a combined increase in mean temperature and temperature variability (Schär *et al.,* 2004; Meehl and Tebaldi, 2004; Pal *et al.,* 2004). As such the 2003 heat wave resembles simulations by regional climate models of summer temperatures in the latter part of the 21st century under the A2 scenario (Beniston, 2004; Beniston and Diaz, 2004).

12.6.2. Thermohaline circulation shutdown and other abrupt climate changes in Europe

The possibility of the North Atlantic thermohaline circulation (NATHC) shutting down as a result of regional warming has been discussed widely (e.g. Broecker, 1997, 1999). Data from ice and ocean sedimentary cores indicate many occurrences of rapid climate changes over the last 250 thousand years, many involving disruption of the NATHC (Dansgaard, 1993; Clark *et al*., 2002; Martrat *et al*., 2004).

Although studies of the impact of a possible shutdown of the NATHC date back several years (e.g. Alcamo *et al.,* 1994), these studies have been recently updated with the most recent climate and impact models (IPCC, 2001; Stocker, 2002; Vellinga and Wood, 2002; Schaeffer *et al*., 2002; Wood *et al*., 2003; Wu *et al*., 2005; Schlesinger *et al*., in press). The possible impacts on Europe of a NATHC-shutdown, as well as other abrupt changes in climate, are summarized in Table 12.7. A shutdown of the NATHC under the IPCC IS92a and A2 scenarios indicate that temperatures on Europe's western margin would be most affected, as would operation of the NAO, with widespread impacts throughout Europe on precipitation, coastal flooding, agriculture and natural ecosystems (Vellinga and Wood, 2002; Wood *et al*., 2003). An experiment with the HadCM3 model showed that following established climate warming to 2049, the initiation of an NATHC shutdown led subsequently to an interruption in warming over the North Atlantic-European region and surface cooling of Northern coastal Europe by 0.5-3.5^{o}C.

Table 12.7: *Summary of major environmental and related socio-economic implications of possible abrupt climate changes in Europe (Source: Arnell, N. et al., 2005)*

Collapse of thermohaline circulation in the North Atlantic
▪ Major reductions in crop production with consequent impacts on food prices, access to food and rural economies ▪ Increases in cold-related deaths and ill-health ▪ Movement of populations to Southern Europe and shift in the centre of economic gravity ▪ Major changes in temperature and Mediterranean ecosystems and the services they provide (e.g., food, biodiversity, forest products, recreation) ▪ Disruption to winter travel opportunities and increased icing of Northern ports and seas ▪ Requirement to refurbish infrastructure, especially in western Europe, towards Scandinavian standards ▪ Reductions in runoff and water availability in Southern Europe and major increase in snowmelt flooding in Western Europe.

Accelerated climate change
▪ Major reductions in crop production with consequent impacts on food prices, access to food and rural economies ▪ Increase in summer heat-related mortality and ill-health and increased risk of transmission of disease ▪ Major reductions in water availability in Southern and western Europe, coupled with large increases in demand for water, particularly for irrigation ▪ Major changes in boreal and Mediterranean ecosystems and the services they provide ▪ Requirement to refurbish infrastructure, especially in western and Northern Europe ▪ Reduction in ice cover in Northern ports and seas.
Rapid sea-level rise, primarily from sources of rapid ice sheet disintegration/ permafrost melt
▪ Inundation of parts of coastal cities (including London, Hamburg, Venice, Amsterdam and Rotterdam), coastal wetlands and deltas ▪ Inundation of coastal facilities, including ports and power stations ▪ Very substantial increase in coastal flooding damages and requirement for major investment in coastal flood defences ▪ Major threat to variability of the financial services industry, particularly insurance ▪ Relocation of economic activity away from coastal cities.

Some investigators believe that a NATHC-type abrupt event superimposed upon the more likely impacts of climate change would have significant environmental and socio-economic repercussions that should be considered in developing policy for climate change impacts (Tol, 2002; DEFRA, 2004b; Arnell *et al*., 2005; Schlesinger *et al*., 2005). But policy actions to mitigate this risk are difficult to identify (Manning *et al*., 2004; Parry, 2004).

Other investigators have identified smaller consequences of disruption of the NATHC. Results from an integrated assessment model suggests a NATHC-shutdown could lead to slow warming rather than rapid cooling on the western/Northern margins of Europe and lower impacts than estimated elsewhere (Link and Tol, 2004). Indeed, even the likelihood of a collapse of the NATHC is vigorously debated (Alley *et al*., 2003; Arnell *et al*., 2005). The current salinity/ freshwater balance from ice melt in the Northern North Atlantic does not indicate a likely shutdown in the 21st century (Curry and Mauritzen, 2005). Most experts surveyed considered the likelihood of NATC-type events even after 2100 to be less than 1% (Arnell *et al*., 2005).

12.7. Implications for sustainable development

To obtain the goods they consume Europeans exert great pressure on both their own ecosystems and on those beyond their borders. Western Europe appropriates 2.86 t C/cap-a of net primary production for its consumption which is 72.2% of its terrestrial net primary production, and much larger than the global average of 20% (Imhoff *et al*., 2004).

In 2001, the ecological footprint (EF) for Western and Central and Eastern Europe was 5.1 ha/cap and 3.8 ha/cap, respectively, much larger than the global average of 2.2 ha/cap (WWF 2004). The EF is a measure in global hectare-equivalents of surface needed to support the resources consumed by a given population (Wackernagel *et al.,* 2002). The future trend of EF in Europe depends on the scenario considered. EF increases up to 2050 by a factor of two to three under the A1b and A2 scenarios of IPCC, and by more than 50% under the B1 and B2 scenarios (van Vuuren and Bouwman, 2005). Under these scenarios the growth in per capita consumption is more important than population growth as a driving force. The EF for Western and Central and Eastern Europe converge under these scenarios (van Vuuren and Bouwman, 2005). Under the same IPCC scenarios, climate change was found to have a negative impact on most services provided by European ecosystems, be it water supply, farmland, biodiversity, climate regulation potential, or forestry products (Metzger *et al.,* 2004). Negative impacts will predominate in Southern Europe.

Although it is expected that Europe's capacity to cope with climate change is increasing and will continue to increase, important differences will remain among regions due to their different socioeconomic levels (Yohe and Tol, 2002). Since climate impacts will not necessarily occur where adaptive capacity is high, climate change can be expected to exert additional pressure on European ecosystems (Klein *et al.,* 2005).

In the realm of sustainable development, Europe is seen as an example of well-developed environmental management, social institutions, and governance structures. Developing better governance structures is high on the European agenda (CEC, 2001). European countries have shown that there might be avenues for reconciling economic productivity, social cohesion and environmental efficiency (NEAA, 2004). Whether this will be possible or not remains not only a scientific challenge but also a particularly daunting political challenge (Robinson, 2004).

In a recent public opinion poll in the European Union, climate change ranked third among environmental problems, with a lower ranking in the new EU member countries (TNS Opinion & Social 2005). Climate change may further increase awareness of the limits and dangers of our current economic and social system, supporting the willingness of some Europeans to limit the growth of consumption or even to reduce it (TNS Opinion & Social, 2005).

12.8 Key uncertainties and research priorities

Computed climate change varies between climate models and emission scenarios, and these differences become more important with the length of simulation. For example, the computed increase in annual temperature in Northern Europe ranges from 1 to 3 °C up to 2025, 1 to 7 °C up to 2050 and 2 to 14 °C up to 2075. Precipitation change has an even wider range, and sometimes the sign of the change is different between models for the same scenario and year. For example, in Southern Europe roughly one-half of published climate scenarios predict a decrease and the other half an increase in winter precipitation by 2025, while the projected change range from -10 to 10%. The uncertainty of climate models in predicting extreme climate events is high, and this limits their usefulness for predicting short-term events such as flash floods (Bronstert, 2003). Climate scenarios have a low spatial resolution, and their downscaling for local scale analyses is another source of uncertainty (e.g. for runoff calculations, Etchevers *et al.*, 2002). The amount and rates of sea level rise for different regions within Europe are likely to differ from the global best estimates by values of at least 50%.

Uncertainties in assessing future climate impacts also stem from the uncertainties of climate impact models. One of the main sources of these uncertainties is "structural uncertainty" due to the inability of models to capture all influential factors affecting climate impacts. For example, current hydrological models treat soils and vegetation very simply, and this contributes to their uncertainty when used to assess the impact of climate change on hydrology (Moreno, 2005). In the flood management there is no clear evidence to which extent the climate variability and the other effects (e.g. land use change) explain the change in variability of flood occurrence frequency (Somlyódy 2002). Biogeographic models show wide variability in projection of areas of ecosystem shifts (Thuiller 2004; Thuiller *et al.* 2004; Araújo *et al.* 2005b; Pearson *et al.* 2005). Models used to assess health impacts of climate change usually neglect human factors in the spread of disease (Kuhn *et al.*, 2004; Reiter *et al.,* 2004; Sutherst, 2004).

Climate impact models cannot be tested in a traditional sense because they predict impacts that have not yet taken place. Hence, other approaches must be taken to reduce their uncertainty. For bioclimate models Araújo *et al.* (2005a) suggests 1) improving the quality of their biological and climate input variables; 2) improving the performance of algorithms and realism of their assumptions; and 3) use probabilistic forecasting techniques to produce ensembles of forecasts.

Model testing is also often constrained by lack of data. For example, in the public health sector there is a paucity of long-term representative data on disease and vector distributions in areas where climate variability has been observed and where a response is most likely to have occurred. Not only are data lacking in the public health sector, but basic understanding of climate-society relationships also needs to be improved in order to develop adequate adaptation strategies. To reduce health risk of climate change it is necessary to clarify the population at risk, the lag time of the effects of climate change, the role of respiratory infections, and the significance of different meteorological variables (Ballester *et al.,* 2003). To better assess the possible impacts of heat waves it is necessary to clarify the interactions between harmful air pollutants and extreme weather events (WHO, 2004. Also better understanding is needed about the differences between the comparatively small changes in infectious and non-infectious disease driven by short-term climate variability and the long-term effects of climate change (EEA, 2004a; Izmerov *et al.,* 2004).

There is also a high level of uncertainty about the effectiveness of different approaches for adapting to climate change. A key question in the water sector is whether current methods of water management and flood protection, based on the assumption of stationary climate, are suitable for adapting to an uncertain non-stationary climate (Kabat *et al.,* 2002). Another example is the question of whether integrated coastal management can deal with coastal changes expected from sea level rise and other impacts of climate change. In the public health sector an important question is, how effective will various physiological, behavioural or technological mechanisms be in adapting to adverse changes in temperature and other climatic variables? (Haines and Pats, 2004; Crawford *et al.,* 2003).

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