IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 12 - Europe

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Executive Summary

- **Extensive research since the TAR has advanced our understanding of the potential impacts and adaptation in Europe to climate change.** Results reported here are based on a range of emission scenarios which assume no specific climate policies to mitigate greenhouse gas emissions.

- **The climate of Europe will continue changing during the 21st century, but unevenly across regions and among seasons (very high confidence).** A warming trend is observed throughout Europe [12.2.1], while precipitation is increasing in the north and decreasing in south [12.2.1]). Climate scenarios indicate warming mostly in winter in N. Europe, and mostly in summer in S. and Central Europe [12.3.1.1]. Winter precipitation increases in N., Central and W. Europe, but decreases in the Mediterranean. Summer precipitation decreases very substantially along the Mediterranean and in W. and Central Europe. [12.3.1.1]. These changes will lead to the key vulnerabilities depicted in Fig. 12.1

- **Water stress will increase, as well as the number of people living in river basins under high water stress (high confidence).** Differences in water availability between countries may become sharper (annual average runoff increases in north/northwest, decreases in south/southeast) [12.4.1]. Water availability during summer in S. Europe may be reduced by 80% or more, leading to water shortages and deterioration of water quality [12.4.1]. Irrigation requirements increase in S. and southeastern Europe. Industrial and domestic water withdrawals are likely to stabilize in W. Europe but increase in E. Europe due to economic growth [12.4.1]. The reliability of water reservoirs and hydroelectricity is likely to decline in S. and southeastern Europe [12.4.1, 12.4.8].

- **Overall European food and fiber production is not expected to be altered by climate change. However, greater differences will arise between countries (high confidence).** Warming and higher CO_2 levels are expected to slightly increase N. European crop productivity [12.4.7.1], with warmer and drier conditions leading to reductions around the Mediterranean and Balkans [12.4.7.1]. The extent of forests is expected to expand in the north and retreat in the south [12.4.4.1]. Climate change will increase net primary productivity and total biomass in the north while reduced water availability is likely to decrease NPP and forest growth in Central Europe, and accelerate tree mortality in the south [12.4.4.1].

- **Climate-related natural hazards will increase throughout Europe, although different types of hazard will predominate in different regions (very high confidence). A**n increasing risk of floods is expected in Europe under climate change: winter floods in maritime regions, snowmelt-related floods in Central and E. Europe, flash floods throughout Europe [12.4.1]. The number and intensity of storms in the northeastern Atlantic may increase, but storminess and wind intensity may decline along the Mediterranean [12.4.2]. Insurance costs related to flood risks may increase in some countries by 2 to 4% annually [12.4.10]. Coastal flooding related to sea level rise threatens up to 2.5 million people each year in low lying areas [12.4.2]. In mountainous areas, changing snow and temperature conditions increase the likelihood of snow avalanches and rock falls [12.4.2]. Reduced snow cover and frost-free periods increase water logging and floods in northern forests [12.4.4.1]. Increased temperate and reduced precipitation will lead to a longer fire-season, and increased fire occurrence in Mediterranean forests and grasslands [12.4.4.1]. Year-to-year climate variability and the frequency of heat waves will increase. Later in the century the Mediterranean and much of E. Europe will have a regularly recurring dry period [12.3.1.2].

- **The persistence and nature of some major European (eco)systems is seriously endangered (very high confidence).** Sea-level rise will cause an inland migration of beaches and loss of up to

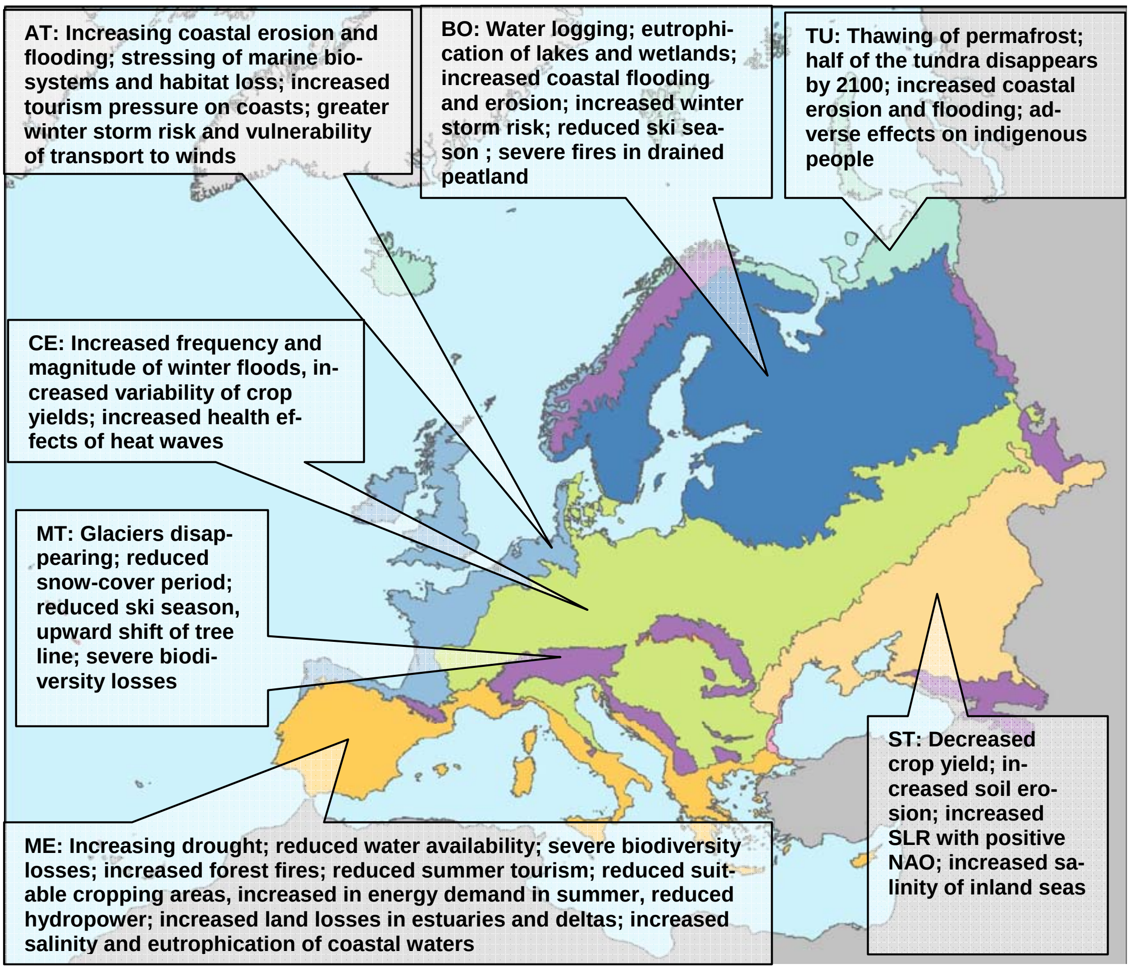
20% of coastal wetlands [12.4.2.]. Increasing temperature will cause changes in the growing season and production of marine water bodies [12.4.7.2]. Small glaciers will disappear, while larger glaciers will suffer large volume reductions during the 21st century [12.4.3]. Many permafrost areas in the Arctic will disappear [12.4.5.] and the northward expansion of forests may halve current tundra areas [12.4.4]. The tree-lines of mountains will move up. [12.4.4.]. Increasing fire frequency could result in greater dominance of shrubs over trees in the Mediterranean [12.4.4]. Warming may increase the risk of algal blooms and growth of toxic cyanobacteria in lakes [12.4.5.]. Many ephemeral aquatic ecosystems could disappear, and permanent ones shrink in the Mediterranean zone [12.4.5].

- **European biodiversity will be severely threatened (high confidence).** Alpine communities face up to 60% loss of species under extreme scenarios [12.4.3]. Higher temperatures may lead to increased species richness in freshwater ecosystems in N. Europe and decrease in the southwest [12.4.5]. Aquatic, cold-adapted species will be forced further north and upstream, some eventually disappearing from Europe [12.4.5]. Up to 50% of the European flora could become vulnerable, endangered, critically endangered or extinct by the end of this century [12.4.6]. Up to 97% of amphibians and reptiles will have a reduced range [12.4.6]. Increases in sea temperature will cause changes in the distribution and abundance of exploited and non-exploited fish species [12.4.7.2].

- **Climate change will pose challenges to many European economic sectors and is likely to alter the distribution of economic activity (high confidence).** Much of tourism along the Mediterranean area is likely to shift from summer to spring and autumn, thereby distributing the tourism season more equally throughout the year [12.4.9]. Higher temperatures will shift tourism northward and to mountainous areas. The ski season is very likely to be reduced due to limited snow cover [12.4.9]. The seasonal cycle in electricity demand will change, increasing in summer and decreasing in winter. Peak electricity demand may shift in some locations from winter to summer [12.4.8.1].

- **Climate change is likely to magnify regional differences within Europe in natural resources and assets (low confidence).** Climate change is likely to increase the differences in natural resources (water, agriculture, forestry, fisheries, hydropower generation) [12.4.1, 12.4.2, 12.4.7, 12.4.8], or reduce those of existing assets (biodiversity, outdoor comfort for recreation) [12.4.6, 12.4.9] between north and south, and west and east. In general, effects will be more adverse in the south and southeast and less adverse, or even positive, in Central Europe and the north [12.7]. Adaptive capacity is currently higher in W. than E. Europe, and in the central and northern parts of W. Europe as compared to its southern areas [12.7].

- **Current thinking about adaptation to extreme climate events has moved away from reactive disaster relief and towards more proactive risk management. To enable ecosystems to adapt, human stresses on these ecosystems must be reduced (high confidence).** Although a quick *reaction* to disaster is crucial, increasing emphasis is being put on *proactive* measures to avert climate-related disasters (Examples: heat wave warning systems adopted in 15 European cities since recent heat waves; new construction of river flood warning systems and “flood-ways”.) [12.6.2]. In many cases, the best or only viable strategy for helping ecosystems to cope with the stresses of climate change will be to reduce all other human-related stresses on ecosystems as much as possible [12.5]



AT: Increasing coastal erosion and flooding; stressing of marine biosystems and habitat loss; increased tourism pressure on coasts; greater winter storm risk and vulnerability of transport to winds

BO: Water logging; eutrophication of lakes and wetlands; increased coastal flooding and erosion; increased winter storm risk; reduced ski season ; severe fires in drained peatland

TU: Thawing of permafrost; half of the tundra disappears by 2100; increased coastal erosion and flooding; adverse effects on indigenous people

CE: Increased frequency and magnitude of winter floods, increased variability of crop yields; increased health effects of heat waves

MT: Glaciers disappearing; reduced snow-cover period; reduced ski season, upward shift of tree line; severe biodiversity losses

ST: Decreased crop yield; increased soil erosion; increased SLR with positive NAO; increased salinity of inland seas

ME: Increasing drought; reduced water availability; severe biodiversity losses; increased forest fires; reduced summer tourism; reduced suitable cropping areas, increased in energy demand in summer, reduced hydropower; increased land losses in estuaries and deltas; increased salinity and eutrophication of coastal waters

Fig. 12.1: *Key vulnerabilities of European systems and sectors to climate change during the 21st century for the main biogeographic regions of Europe (EEA 2004): TU (Tundra, light blue); BO (Boreal, dark blue); AT (Atlantic, medium blue); CE (Central, green [includes the Pannonian Region]); MT (Mountains, magenta); ME (Mediterranean, orange); ST (Steppe, cream).*

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 most regions in winter rather than summer. The 1990s were the warmest in the instrumental record. Precipitation trends in the 20th century showed an increase in N. Europe (10-40%) and decrease in S. Europe (up to 20% in some parts of S. Europe). The latest data reported in this assessment have confirmed these trends.

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. 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 the seasonality of precipitation will change and the frequency of intense precipitation events will increase, especially in winter. The TAR noted a very likely increase in the intensity and frequency of summer heat waves throughout Europe and one such major heat wave occurred since TAR.

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 which among other impacts, will put particular pressure on coastal areas

More information is now available on the geographic variability of Europe's sensitivity.

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. Climate change will have greater or lesser impacts on different social groups (age classes, income groups, occupations).

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

- Sea level rise will affect important coastline industries.
- Increasing CO_2 concentrations may increase agricultural yields, although this may be counteracted by decreasing water availability in S. and southeastern Europe.
- Recreation preferences are likely to change (more outdoor activity in north, less in south).
- The insurance industry should expect increased climate-related claims.
- Warmer temperatures and higher CO_2 levels may increase potential timber harvest in N. Europe, while warmer temperatures increase forest fire risk in S. Europe.

12.2 Current sensitivity/vulnerability

12.2.1 Climate factors and trends

The warming trend throughout Europe for 1901-2000 is well established (+0.76°C) (Jones and Moberg, 2003). However, the recent period shows a trend considerably higher than the mean trend (+0.425°C/decade for the period 1977-2001, Jones and Moberg, 2003). For the 1977-2000 period, trends are higher in Central, northeastern Europe and in mountainous regions, while the lowest temperature trends are found in the Mediterranean region (Böhm *et al.*, 2001; Klein Tank, 2004). Temperatures are increasing more in winter than summer (EEA, 2004; Jones and Moberg, 2003). An increase of temperature variability is observed during the period 1977-2000 due to increase in warm extremes, rather than a decrease of cold extremes (Klein Tank *et al.*, 2002, 2003).

Precipitation trends are more spatially variable. Mean precipitation is increasing in most of Atlantic- and N. Europe and decreasing along the Mediterranean (Klein Tank *et al.*, 2002). An increase in mean precipitation per wet day is observed in most parts of the continent, even in areas getting drier (Frich *et al.*, 2002; Klein Tank *et al.*, 2002). Some recent aspects of Europe have shown particular sensitivity to recent trends in temperature and precipitation. (Table 12.1). (See Chapter 1 for additional data).

Table 12.1: *Attribution of recent changes in ecosystems and economic sectors to recent temperature and precipitation trends.*

Region	**Observed change**	**Reference**
Coastal and marine systems		
Northeast Atlantic, North Sea	Northward movement of range of plankton and fish	Brander and Blom, 2003; Edward and Richardson, 2004; Perry *et al.*, 2005
Terrestrial ecosystems		
Europe	Upward shift of the tree line	Kullman, 2002; Camarero and Gutiérrez, 2004; Walther, 2004; Shiyatov *et al.,* 2005
Europe	Increasing productivity and carbon sink during 1950-1999 (in 30 countries)	Nabuurs *et al.,* 2003, Shvidenko and Nilsson, 2003.
Alps	Invasion of *laurophylous* evergreen species in forests ; upward shift of pine mistletoe	Walther, 2004; Dobbertin *et al.,* 2005
Fennoscandian mountains	Disappearance of palsa mires in Lapland ; Increased species richness and frequency at altitudinal margin of plant life	Luoto *et al*. 2004; Klanderud and Birks, 2003
High mountains	Change in high mountain vegetation types and new occurrence of alpine vegetation on high summits	Grabherr *et al.*, 2001; Kullman, 2001; Klanderud and Birks, 2003; Peñuelas and Boada 2003; Petriccione, 2003; San Elorza and Dana, 2003; Walther, 2004
Agriculture		
Britain, southern Scandinavia	Increase of area of silage (more favourable conditions due to warmer summer temperatures)	Olesen and Bindi, 2003
France	Increased in growing season wine-grape and changes in wine quality	Duchene and Schneider, 2005; Jones and Davis, 2000
Germany	Advance in the beginning of growing season for fruit trees	Chmielewski, *et al.*, 2004
Cryosphere		
Russia	Decrease in thickness and areal extent of permafrost and damages to infrastructure	Mazhitova *et al.,* 2004; Frauenfeld *et al.*, 2004
Alps	Decrease in seasonal snow cover (at lower elevation)	Laternser and Schneebeli, 2003; Martin and Etchevers, 2005;
Europe	Decrease in glacier volume and area (except some glaciers in Norway)	Hoelzle *et al.*, 2003

12.2.2 Non-climate factors and trends

Europe had a total population of 727 million in 2000, with the highest population density (60 persons per km^2) of any continent. Of the total European population 73% lives in urban areas (UN, 2002), with 67% in S. Europe and 83% in N. Europe. The 25 countries belonging to the European Union (EU25) have stable economies, high productivity and integrated markets. Economic conditions among the non-EU countries are more varied. European income (as annual GDP per capita based on MER) ranges from US$ 1760 in Moldova to US$ 55500 in Luxembourg (World Bank, 2005). The EU25 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 (EU15) had 20% of global GDP and 40% of global exports of goods and services (IMF, 2004). Central and E. Europe (CEE) 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 CEE have undergone dramatic economic and political changes towards a market economy and democracy, and for some countries also integration in 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 EU25. The productivity of European agriculture is generally high, in particular in W.Europe; average cereal yields in the EU are more than 60% higher than the world average. During the last decade the EU Common Agricultural Policy has been reformed to reduce overproduction, reduce environmental impacts and improve rural development. This is not expected to greatly affect agricultural production in the short run (OECD, 2004). However, agricultural reforms are expected to enhance the current process of structural adjustment leading to larger and fewer farms (Marsh, 2005).

The area of forests in Europe is increasing and annual fellings are considerably lower (EEA, 2002). Forest policies have been modified during the past decade to promote multiple forest services at the expense of timber production (Kankaapää and Carter, 2004). European forests are a sink of atmospheric CO_2 of about 380 Tg C yr^{-1} (mid 1990's) (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 European anthropogenic emissions in 1995 (Janssens *et al.*, 2003).

Despite policies to protect fish, overfishing has put many fish stocks in European waters outside sustainable limits (62-92% of commercial fish stocks in northeastern Atlantic, 100% in West Ireland Sea, 75% in the Baltic Sea, and 65-70% in the Mediterranean; EEA, 2002; 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 EU25 in 2002 had average greenhouse gas emissions of 11 t CO_2 per capita (ranging from 5 to 24 t CO_2 per capita in Latvia and Luxembourg; EEA, 2004a). Most European countries have ratified the Kyoto-protocol, and the EU15 countries have a common reduction target for the first commitment period of 8% (Babiker and Eckaus, 2002). From 1990 to 2002 EU15 greenhouse gas emissions decreased in most sectors, but emissions in the transport sector grew 22%. (EEA, 2004a).

The hydrological characteristics of Europe are very diverse, as well as its approaches to water use and management. Of the total withdrawals of 30 European countries (EU plus additional countries) 32% is for agriculture, 31% for cooling water in power stations, 24% for the domestic sector, and 13% for manufacturing (Flörke and Alcamo, 2005). Freshwater abstraction is stable or declining in N. Europe and growing slowly in S. Europe (Flörke and Alcamo, 2005). There are many pressures on water quality and availability 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).

Increasing urbanization and tourism, as well as intensification of agriculture have put large pressures on land resources (EEA, 2004b). On the other hand, there is increasing political attention given to sustainability of land use and natural resources. Despite general reductions in the extent of air pollution in Europe over the last decades, significant problems still remain with acidification, terrestrial N deposition, ozone, particulate matter and heavy metals (WGE, 2004). 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 integrated in the Natura 2000 network which protects nature over 18% of EU territory. Awareness of environmental issues is also growing in CEE (Zylicz, 1999; TNS Opinion & Social, 2005).

12.2.3 Current adaptation and adaptive capacity

It is apparent that climate variability and change already affects features and functions of Europe's production systems (e.g. agriculture, forestry, fisheries), key economic sectors (e.g. tourism, energy) and its natural environment. Some of these effects are beneficial, but most are expected to be negative (EEA, 2004). European institutions have recognized the need to prepare for an intensification of these impacts even if greenhouse gas emissions are substantially reduced (e.g. EU Environmental Council meeting, December, 2004).

The sensitivity of Europe to climate change has a distinct north-south gradient, with many studies indicating that S. Europe will be more severely affected than N. Europe (EEA, 2004). The already hot and semi-arid climate of S. Europe is expected to become yet warmer and drier, and this will threaten its waterways, agricultural production and timber harvests (e.g. EEA, 2004). But northern countries are also sensitive to climate change. The Netherlands, for example, is among the countries most susceptible to large fluctuations in river discharge and climate-related sea level rise (expected to be up to 1.1m by 2100; KNMI, 2003) because 60% of its population and 65% of its GNP is produced on the 55% of its territory below sea level

As in other regions, natural ecosystems in Europe are more vulnerable to climate change than managed systems such as agriculture and fisheries (Hitz and Smith, 2004). Natural ecosystems usually take decades to be established and therefore adapt more slowly to climatic changes than managed systems. The expected rate of climate change in Europe is likely to exceed the rate of adaptation of various non-cultivated plant species (Hitz and Smith, 2004). Sensitivity to climate variability and change also varies across different ecosystems. The most sensitive natural ecosystems in Europe are located in the Arctic, in mountain regions, in coastal zones (especially the Baltic wetlands), and in various parts of the Mediterranean (WBGU, 2003). Here, substantial losses of habitats (50% or more) are projected for global temperature rises of 2-3 ^{o}C and ecosystems are already affected by an increasing trend in temperature and regional decreases in precipitation.

The possible consequences of climate change in Europe have stimulated efforts by the European Union (EU), national governments, businesses, and NGOs to develop adaptation strategies. The EU is supporting adaptation research at the pan-European level while Denmark, Great Britain, Finland, Hungary, Portugal and Spain are setting up national programs for adapting to climate change. Norway and the Netherlands have begun to integrate plans for climate change adaptation into flood defense, coastal protection, and other policy areas. Many of the national adaptation strategies build on a long tradition of dealing with climate extremes in areas of expertise such as flood defense, coastal protection, and human health.

12.3 Future trends

12.3.1 Climate projections

12.3.1.1 Mean climate

Results presented here and in following sections are for the period 2070-2099 and are mostly based on the IPCC-SRES scenarios (described in section 12.3.2) using the climate normal period (1961-1990) as a baseline.

Surface air temperature. Europe undergoes a warming in all seasons in both the A2 and B2 scenarios (A2: 2.5 to 5.5^{o}C, B2: 1 to 4^{o}C). The warming is greatest over E. Europe in Dec.-Jan.-Feb. and over

W. and S. Europe in June-July-Aug. (Giorgi *et al*., 2004) (range of change due to emission scenarios and different climate modeling results). Results using two regional climate models under the Prudence project showed a larger warming in winter than in summer in N. Europe and the reverse in S. and Central Europe. A very large increase in summer temperatures occurs in the southwestern parts of Europe (exceeds 6°C in parts of France and the Iberian Peninsula) (Räisänen *et al*., 2004, Kjellström, 2004, Good *et al*., 2006, Kjellström *et al*., 2006, Christensen and Christensen, 2006).
Precipitation. Generally for all scenarios, the mean annual precipitation increases in N. Europe and decreases further south. But 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. For all scenarios under the Prudence Project, Räisänen *et al*. (2004) identified an increase in winter precipitation in N. and Central Europe. Likewise, Giorgi *et al*. (2004) found that increased Atlantic cyclonic activity in Dec.-Jan.-Feb. leads to enhanced precipitation (up to 15-30%) over much of W., N., and Central Europe. Precipitation during this period decreases over Mediterranean Europe in response to increased anticyclonic circulation.

Räisänen *et al*. (2004) found that summer precipitation decreases substantially (in some areas up to 70% in scenario A2) in S. and Central Europe, and to a smaller degree in N. Europe up to Central Scandinavia. Giorgi *et al*. (2004) identified enhanced anticyclonic circulation in June-July-Aug. over the northeastern Atlantic which induces a ridge over W. Europe and a trough over E. Europe. This blocking structure deflects storms northward, causing a substantial and widespread decrease of precipitation (up to 30-45%) over the Mediterranean basin as well as W. and Central Europe.

Both the winter and summer change were found to be statistically significant (95% confidence level) over large areas of the regional modeling domain. Relatively small precipitation changes were found for spring and autumn seasons. The simulated seasonal cycle of precipitation changes is broadly in phase between Central Europe and N. Europe, with significant exceptions such as large areas of France and western Norway. (Räisänen *et al*., 2004; Kjellström, 2004).

Mean sea level pressure and wind speed. Regional climate simulations indicate a cell of increasing pressure centered near the British Isles from June to August (Räisänen *et al*., 2004). This indicates a northeastward extension of the summer mean Atlantic subtropical high. The climate simulations produce much larger differences for other seasons, depending on the global model used to drive regional climate simulations. The simulation of Dec.-Jan.-Feb. mean pressure indicates an increase in average westerly flow in N. 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.

Change in windiness is highly sensitive to the differences in large-scale circulation that can result between different global models. From regional simulations based on ECHAM4, mean annual windiness increases over N. Europe by about 8% and decreases in Mediterranean Europe (Räisänen et al. 2004, Pryor *et al.,* 2005). The increase for N. Europe is largest in winter and early spring, when the increase in the average north-south pressure gradient is largest. From regional simulations based on HadAM3H, change in windiness is small throughout Europe, and where it does occur it is mostly within the bounds of internal variability. For France and Central Europe, all four of the simulations documented by Räisänen et al. (2004) indicate a slight increase in mean wind speeds in winter and some decrease in spring and autumn. None of the reported simulations show significant change during summer for N. Europe.

12.3.1.2 Extreme events

The yearly maximum temperature is expected to increase much more in S. and Central Europe than in N. Europe (Räisänen *et al*., 2004; Kjellström *et al*. 2006). Kjellström (2004) shows that in summer the warming in large parts of Central, S. and E. Europe may be more closely connected to higher temperatures on warm days than to a general warming. A large increase is also expected for yearly minimum temperature in most of Europe, which at many locations exceeds the average winter warming by a factor of two to three. Much of the warming in winter is connected to higher temperatures on cold days, which indicates a decrease in winter temperature variability. An increase in the lowest winter temperatures, although large, would primarily mean that current cold extremes would decrease. On the other hand, a large increase in the highest summer temperatures would expose Europeans to unprecedented high temperatures.

Christensen and Christensen (2003), Giorgi *et al.* (2004) and Kjellström (2004) all found a substantial increase in the intensity of daily precipitation events. This holds even for areas with a decrease in mean precipitation, such as Central Europe and the Mediterranean region during summer. It is associated with both changes in the number of wet days (decreasing for S. Europe) and changes in the amount of precipitation on wet days. Palmer and Räisänen (2002) estimate that the probability of total winter precipitation exceeding two standard deviations above normal would increase by a factor of five over parts of the United Kingdom while Ekström et al (2005) have found a 10% increase in short duration (1-2day) precipitation events across the UK.

The combined effects of warmer temperatures and reduced mean summer precipitation would enhance the occurrence of heat waves and droughts. Schär *et al.* (2004) concluded that the future European summer climate would experience a pronounced increase in year-to-year variability and thus a higher incidence of heat waves and droughts. Beniston *et al.* (2006) estimated that countries in Central Europe would experience the same number of hot days as currently occur in S. Europe and that Mediterranean droughts would start earlier in the year and last longer. The regions most affected could be the southern Iberian Peninsula, the Alps, the eastern Adriatic seaboard, and southern Greece. Although only the eastern Mediterranean currently has a regularly recurring dry period, the rest of the Mediterranean and even much of E. Europe may also experience such periods by the late 21st century. According to Good *et al.* (2006), the longest yearly dry spell would increase by as much as 50%, especially over France and Central Europe.

Projected changes in extreme winds have also been analyzed, but results are not robust for all of Europe. Rockel and Woth (2006) and Leckebusch and Ulbrich (2004) found an increase in extreme wind speeds for W. and Central Europe, although the changes were not statistically significant in all months of the year. Results for both Fennoscandia and Mediterranean areas are inconclusive. According to Räisänen *et al.* (2004), scenarios for future winds are quite sensitive to the different global boundary conditions used. Beniston et al. (2006) found extreme wind speeds to increase for the area between 45ºN and 55ºN, except over and south of the Alps. Beniston et al. (2006) and Woth et al. (2005) conclude that this would generate more North Sea storms leading to increases in storm surges along the North Sea coast, especially in the Netherlands, Germany and Denmark.

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 W.Europe alone, mainly from immigration (Sardon, 2004). CEE 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 (Janssen *et al.*, 2004), although there has been a recent reduction in life expectancy in Former Soviet Union. 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 EU15 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 (Parry, 2000; Abildtrup *et al.*, 2005; Holman *et al.*, 2005). 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 A1FI scenario. Temporally and spatially explicit future scenarios of European land use have been developed for the four core SRES scenarios (Rounsevell *et al.*, 2006; Schröter *et al.*, 2005). 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, whereas forest areas increase in all scenarios (Schröter *et al.*, 2005). 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. Over the shorter term (up to 2030) changes in agricultural land use may be small (van Meijl *et al.*, 2006).

12.4. Expected future impacts and vulnerabilities

The wide range of climate change impacts expected in Europe is summarized in Table 12.7 (end of chapter).

12.4.1. Water resources

It is likely that climate change will have a range of impacts on water resources in different parts of Europe (Fig. 12.2). Projections based on various scenarios and GCM’s show that annual runoff increases in Atlantic- and N. Europe (Werritty, 2001; Andréasson *et al.*, , 2004), and decreases in Central, Mediterranean and E. Europe (Menzel and Bürger, 2002; Etchevers *et al.*, 2002; Chang *et al.*, 2002; Iglesias *et al.*, 2005). Most of the hydrologic impact studies reported here are based on global rather than regional climate models.

Studies show an increase in winter flows and decrease in summer flows in the Alps (Schröter *et al.*, 2005; Zierl and Bugmann, 2005), the Rhine (Middelkoop *et al.*, 2001), Slovakian rivers (Szolgay *et al.*, 2004), the Volga and Central and E. Europe (Oltchev *et al.*, 2002). Lowest annual flows shift from winter to summer in Central and E. Europe (Lehner *et al.*, 2001). The volume of summer low flow may decrease by up to 50% in Central Europe (Eckhardt and Ulbrich, 2003), and by up to 80% around the Mediterranean (Santos *et al.*, 2002).

Changes in the water cycle are likely to increase the risk of floods and droughts. Projections under IPCC IS92a scenario (similar to SRES A1) and two GCM’s (Lehner *et al.,* 2005) indicate that the risk of floods increases in almost all of Europe, while the risk of drought increases mainly in Mediterranean-, and E. Europe (Table 12.2). Increase in extreme, short-time precipitation would lead to increasing risk of flash floods in all of Europe, particularly in Mediterranean-, and E. Europe (Ludwig *et al.,* 2003).

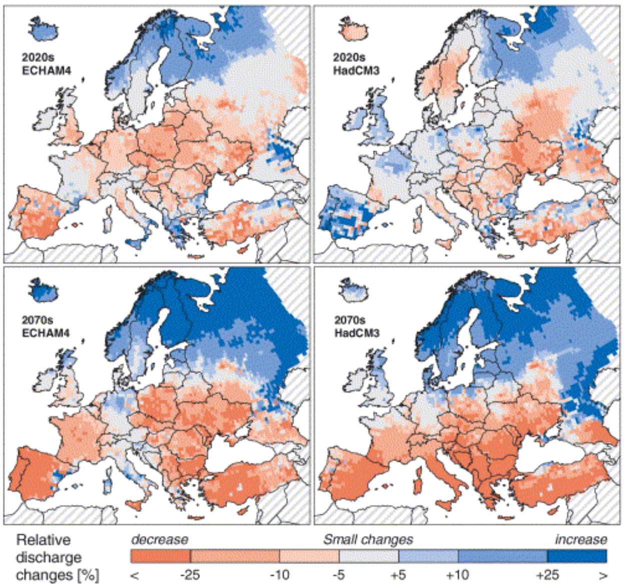


***Fig. 12.2:** Change annual in river basin discharge between the base-line period (1961-90) and two future time slices (2020s) and (2070s) as computed by the ECHAM4 and HadCM3 global climate models and the Baseline-A water use scenario (Lehner et al., 2003).*

***Table 12.2:** Impact of climate change on water availability and flood occurrence in Europe for various time slices and under various scenarios based on the ECHAM4 and HadCM3 models*

Time slice	Water availability	Floods
2020s	Small changes in annual runoff (-5 to +5%) Increase in winter runoff and decrease in summer runoff [1, 2]	Increasing risk of snowmelt flood in Central and E. Europe, of winter flood in northern Europe, of flash flood in all of Europe. Risk in snowmelt-caused flood shifts from spring to winter [2]
2050s	Increase in annual runoff by up to 10% in N. Europe, decrease in annual runoff by up 20-30% and in summer flow by up to 50% in southeastern Europe [1]	Increasing risk in flood 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% [2, 3]	Floods occur earlier in Alpine rivers (Rhone, Po, Rhine, Danube). 100-year flood discharges rises more 25% in Sweden, Finland, Russia, more 10% in Poland, Ireland, Island, in parts of Spain and Portugal, decrease in large part of Central and Southern Europe [2]

[1] Arnell, 2004, [2] Lehner *et al.*, 2005, [3] Santos *et al.*, 2002

Increasing flood risk from climate change could be magnified by increasing impermeable surface due to urbanization (de Roo *et al.*, 2003) and modified by changes in vegetation cover (Robinson *et al.*, 2003) in small catchments. The effects of land use on floods in large catchments are still being debated (Bronstert *et al.*, 2005). The more frequent occurrence of high runoff increases the risk to areas protected now by dikes. The increasing volume of flow and peak discharge would make it more difficult for reservoirs to store high runoff and prevent floods.

The river basin area affected by severe water stress increases under some scenarios due to both climate change and increasing water withdrawals and will lead to increasing competition for available water resources (Alcamo *et al.*, 2003; Schröter *et al.*, 2005). Under the IS92a scenario, the percentage of river basin area in the severe water stress category (withdrawal/availability higher than 0.4) increases from 19% today to 34-36% by the 2070s (Lehner *et al.,* 2001). Water stress may increase in Great Britain, Italy, Greece, the Balkan region and large areas in Central and E. Europe, and decrease in north and some parts of Central Europe (Germany, Alps). The regions most prone to an increase in water stress are the Mediterranean (Portugal, Spain) and some parts of Central and E. Europe, where the 100-year deficit volumes may increase by 25% (Lehner *et al.,* 2005), and the highest increase in irrigation water demand is projected (Döll, 2002; Santos *et al.,* 2002; Donevska and Dodeva, 2004). Irrigation requirements are likely to become substantial in countries where it now hardly exists (Holden *et al.*, 2003). The irrigation demands may be influenced by changes in the amount and distribution of agricultural land as affected in the future by the EU Common Agricultural Policy (CAP). Groundwater recharge may be also be reduced (Eitzinger *et al.*, 2003), with a larger reduction in valleys (Krüger *et al.*, 2002) and lowlands (e.g. in Hungarian steps) (Somlyódy, 2002).

12.4.2 Coastal and marine systems

Climate variability associated with the NAO determines many physical coastal processes in Europe (Hurrell *et al.*, 2003, 2004) including variation in seasonality of coastal climates, speed of winter winds, and patterns of storminess and coastal flooding in northwest Europe (Lozano *et al.*, 2004; Stone and Orford, 2004; Yan *et al.*, 2004). The NAO also has a strong influence on the rate and geographic distribution of sea level rise (SLR) (Woolf *et al.*, 2003), and some relation to coastal flooding and water levels in the Caspian Sea (Lal *et al.*, 2001). Most IPCC-SRES climate scenarios show a continuation of NAO into the 21st century with significant impacts on coastal areas (Cusbach, *et al.*, 2001; Hurrell *et al.*, 2003).

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). Climate modeling using the IS92a and A2 and B2 SRES scenarios (Meier *et al.*, 2004a; Räisänen, *et al.*, 2004; Christensen,

2005), show some increase in wind speeds and intensity of storms in the northeastern Atlantic during at least the early part of the 21st century (2010-2030), and an on-coast shift of peaks in storm centres (Knippertz *et al.*, 2000; Leckebusch and Ulbrich, 2004; Lozano *et al.*, 2004). These experiments indicate a decline in storminess and wind intensity eastwards into the Mediterranean (Busuioc, 2001; Tomozeiu *et al.*, in press), but with localized increased storminess in parts of the Adriatic, Aegean and Black Seas (Guedes Soares *et al.*, 2002).

Ensemble modelling of storm surges and tidal levels under some IPCC-SRES scenarios compute rising values in shelf seas, but with a reduction in the frequency of large surge events (Hulme *et al.*, 2002; Meier *et al.*, 2004a; Lowe and Gregory, 2005). Wave simulations show higher wave heights of >0.4m in the northeastern Atlantic by the 2080s (Tsimplis *et al.*, 2004a). Higher wave and storm surge elevations will be particularly significant because they will cause erosion and flooding in estuaries, deltas and embayments (Flather and Williams, 2000; Lionello *et al.*, 2002; Tsimplis *et al.*, 2004b; Woth *et al.*, 2005; Meier *et al.*, in press).

Simulations of the IPCC-SRES scenarios give values for global mean SLR of 0.09-0.88 m by 2100 at rates 2.2-4.4 times higher than present (EEA, 2004a, b; IPCC, 2007). SLR in Europe SLR may be up to 50% higher than these global estimates (Woodworth *et al.*, in press). The impact of the NAO on winter sea levels adds an uncertainty of another ± 0.1 to 0.2 m to these estimates (Hulme *et al.*, 2002; Tsimplis *et al.*, 2004a). Furthermore, the possible abrupt melting of Greenland ice and other ice stores provides additional uncertainty (Gregory *et al.*, 2004; Wigley, 2005).

Sea level rise can have a wide variety of impacts on Europe's coastal areas (Table 12.3). For the Baltic and Arctic coasts SLR projections under some SRES scenarios indicate an increased risk of flooding and coastal erosion after 2050 (Johansson *et al.*, 2004; Meier *et al.*, 2004a, b; Kont *et al.*, in press). In areas of coastal subsidence or high tectonic activity, as in the low tidal range Mediterranean and Black Sea regions, climate-related SLR could significantly increase potential damage from storm surges and tsunamis (Gregory *et al.*, 2001). Sea level rise will also cause an inland migration of Europe's beaches and low-lying, soft sedimentary coasts (Sánchez-Arcilla *et al.*, 2000; Stone and Orford, 2004; Hall *et al.*, in press). Coastal retreat rates are currently 0.5 to 1.0 m/yr for parts of the Atlantic coast most affected by storms and under SLR these rates are expected to increase (Lozano *et al.*, 2004; Cooper and Pilkey, 2004).

The vulnerability of shelf – coastal waters and some stretches of coastline are very dependent on local factors (Duffy and Devoy, 1999; Smith *et al.*, 2000; EEA, 2004a, b; 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). Coastal flooding related to SLR could affect large populations (Arnell *et al.*, 2004). Under the A1FI SRES scenario up to 2.5 million people each year might experience coastal flooding by 2080 (Nicholls, 2004). Approximately 20% of existing coastal wetlands may disappear by 2080 under SRES scenarios for SLR (Nicholls, 2004; Devoy, in press). Impacts of SLR and related climate warming upon coastal - marine ecosystems are also likely to intensify problems of eutrophication and stress on biological systems (EEA, 2004; Robinson *et al.*, 2005; SEPA, 2005; SEEG, 2006).

Table 12.3: *Potential impacts on coastal areas of 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, 2006 and Devoy, 2006).*

Country	Coastal flood-plain population		Coastal population flooded per year		Capital value loss		Land loss		Wetland loss	Adaptation costs	
	#(k)	% total	#(k)	% total	US$ (10^9)	% GNP	km^2	% total	km^2	US$ (10^9)	%GNP
Ireland	<250	<5	<100	0.8	0.17	0.2	<230	<0.3	>400	<0.42/yr	0.6/yr
Netherlands	10,000	67	3,600	24	186	69	2,165	6.7	642	12.3	5.5
Germany	3,120	4	257	0.3	410	30	n.a.	n.a.	2,400	30	2.2
Estonia	47	3	n.a.	n.a.	0.22	3	>580	>1.3	225	n.a.	n.a.
Poland	235	0.6	196	0.5	22	24	1,700	0.5	n.a.	4.8+0.4/yr	14.5+1.2/yr

12.4.3 Mountains and subarctic regions

Mountain regions are among the most vulnerable regions of Europe (Schröter *et al.*, 2005). The duration of snow cover is expected to decrease by several weeks for each °C of temperature increase (Hantel *et al.*, 2000; Wielke *et al.*, 2004; Martin and Etchevers, 2005). An upward shift of the glacier equilibrium line is expected from 60 to 140 m/°C (Maisch, 2000; Vincent, 2002; Oerlemans, 2003). Glaciers will experience a substantial retreat during the 21st century (Haeberli and Burn, 2002). Small glaciers will disappear, while larger glaciers will suffer a volume reduction between 30% and 70% by 2050 (Schneeberger *et al.*, 2003; Paul *et al.*, 2004). During the retreat of glaciers, spring and summer discharge will decrease (Hagg and Braun, 2004). It is likely that the lower elevation of permafrost will rise by several hundred meters. Rising temperatures and melting permafrost will destabilize mountain walls and increase the frequency of rock falls, threatening mountain valleys (Gruber *et al.*, 2004). In the north of Europe, lowland permafrost will eventually disappear (Haeberli and Burns, 2002). Changes in snowpack and glacial extent may also alter the likelihood of snow and ice avalanches, depending on the complex interaction of surface geometry, precipitation, and temperature (Martin *et al.*, 2001; Haeberli and Burns, 2002).

It is virtually certain that European mountain flora will undergo major changes due to climate change (Theurillat and Guisan, 2001; Walther, 2004). Change in snow cover distribution and growing season length should have much more pronounced effects than effects on metabolism (Grace *et al.*, 2002; Körner, 2003). Overall trends are towards increased growing season, earlier phenology and shifts of species distributions towards higher elevations (Kullman 2002; Körner, 2003; Egli *et al.*, 2004; Sandvik *et al.,* 2004; Walther, 2004). Similar shifts in elevation are also documented for animal species (Hughes 2000). The treeline is predicted to shift upward by several hundred meters (Badeck *et al.*, 2001). There is evidence that this process has already began in Scandinavia (Kullman, 2002), the Ural Mountains (Shiyatov *et al.*, 2005), West Carpathians (Mindas *et al.*, 2000) and the Mediterranean (Peñuelas and Boada, 2003; Camarero and Gutiérrez, 2004). These changes, together with the effect of abandonment of traditional alpine pastures, will restrict the alpine zone to higher elevations (Guisan and Theurillat, 2001; Grace *et al.,* 2002, Dirnböck *et al.*, 2003; Dullinger *et al.*, 2004), severely threatening nival flora (Gottfried *et al.,* 2002). The composition and structure of alpine and nival communities will change (Guisan and Theurillat 2000; Walther, 2004). Local plant species losses of up to 62% are projected for Mediterranean and Lusitanian mountains by the 2080s under the A1 scenario (Thuiller *et al.*, 2005). Similar extreme impacts are expected for habitat and animal diversity as well, making mountain ecosystems among the most threatened in Europe.

12.4.4 Forest, shrublands and grasslands

12.4.4.1. Forests

Forest ecosystems in Europe will be strongly influenced by climate change and other global changes (Shaver *et al.,* 2000; Blennow and Sallnäs, 2002; Askeev *et al.*, 2005; Maracchi *et al.*, 2005). Forests area is expected to expand in the north (Kljuev, 2001; MNRRF, 2003) halving the current tundra area by 2100 (White *et al.,* 2000) while contracting in the south (Metzger *et al.*, 2004). The range of important forest insect pests may expand northward (Virtnaen and Neuvonen, 1999; Battisti 2004). Native conifers are likely to be replaced by deciduous trees in W. and Central Europe (Maracchi *et al.,* 2005). Tree vulnerability will increase as populations/plantations are managed to grow outside their natural range (Ray *et al.*, 2002; Redfern and Hendry 2002; Fernando and Cortina, 2004). Wind damage to trees is likely to substantially increase in many European regions (Barthod, 2003; Cucchi *et al.*, 2005).

In N. Europe, snow cover will decrease, and soil frost-free periods and winter rainfall increase, leading to increased soil water logging and winter floods. Warming will endanger chilling requirements, reduce cold-hardiness during autumn and spring, and increase needle losses (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 (Linkosalo *et al.*, 2000; Barklund 2002; Redfern and Hendry 2002; Jönsson *et al.*, 2004). In this region climate change will alter phenology (Badeck *et al.*, 2004) and substantially increase net primary productivity (NPP) and biomass of forests (Shvidenko, 2004); Jarvis and Linder 2000; Rustad *et al.,* 2001; Strömgren and Linder 2002; Zheng *et al.,* 2002).

In the boreal forest, soil CO_2 fluxes to the atmosphere increase with increased temperature and atmospheric CO_2 concentration (Niinisto *et al.,* 2004), although many uncertainties remain (Fang and

Moncrieff, 2001; Ågren and Bosatta, 2002; Hyvönen *et al.*, 2005). Climate change may induce a reallocation of carbon to foliage (Magnani *et al.,* 2004); Lapenis *et al.* 2005) and stimulate C losses (Mack *et al.,* 2004). Higher temperatures may have a positive effect on wood properties (Wilhelmsson *et al.,* 2002).

NPP and growth of conifers in Central and S. Europe are likely to decrease in the south due to decreased water availability (Lasch *et al.,* 2002; Martínez-Vilalta and Piñol, 2002) and higher temperatures (Pretzch and Dursky, 2002). Water stress in the south may be partially compensated by increased water-use efficiency due to biomass relocation to fine roots (Magnani *et al.,* 2004) and elevated CO_2 (Kellomäki, 2000; Wittig *et al.*, 2005), and increased LAI (Kull *et al.*, 2005), although this is being debated (Medlyn *et al.,* 2001; Ciais *et al.* 2004).

In the south, climate change will increase the length of the fire season and frequency of fire occurrence (Santos *et al.* 2002, Pausas 2004; Moreno, 2005, Pereira *et al.*, 2006). This may lead to increased dominance of shrubs over trees (Pausas 1999; Mouillot *et al.,* 2002). Fire danger will also increase in Central Europe, but less so in N. Scandinavia and northern European Russia (Flannigan *et al.,* 1998). In the forest-tundra ecotone, increased frequency of fire and other anthropogenic impacts may lead to a long-term (over several hundred years) replacement of forest by low productive grassy glades or wetlands (Sapozhnikov, 2003).

12.4.4.2 Shrublands

The area of European shrubland has increased over the last decades, particularly in the south (Debussche *et al.,* 1999; Moreira *et al.,* 2001; Mouillot *et al.,* 2003; Alados *et al.*, 2004). Climate change is likely to affect its key ecosystem functions such as C storage, nutrient cycling, and species composition (Wessel *et al.,* 2004). The response to warming and drought will depend on the current conditions, with cold-moist sites being more responsive to temperature changes, and warm-dry sites being more responsive to changes in rainfall (Peñuelas *et al.*, 2004). In N. Europe, warming will increase microbial activity (Sowerby *et al.*, 2005), growth and productivity (Peñuelas *et al.,* 2004) and this could enable higher grazing densities (Wessel *et al.*, 2004). Also possible is encroachment with grasses (Werkman and Callaghan, 2002) and elevated nitrogen leaching (Emmet *et al.*, 2004; Gorissen *et al.*, 2004; Schmidt *et al.*, 2004). In S. Europe, warming and, particularly, increased drought are likely to lead to reduced plant growth and primary productivity (Ogaya *et al.,* 2003; Llorens *et al.,* 2004), reduced nutrient turnover and nutrient availability (Sardans and Peñuelas 2004, 2005), altered plant recruitment (Quintana *et al.,* 2004; Lloret *et al.,* 2004a), changed phenology (Llorens and Peñuelas, 2005), and changed species interactions (Maestre and Cortina, 2004; Lloret *et al.*, 2005). Frequency of fires is likely to increase (Vázquez and Moreno, 2001; Mouillot *et al.,* 2005; Nunes *et al.,* 2005; Salvador *et al.,* 2005). Erosion is also likely to increase (De Luis *et al.,* 2003) because of increased frequency of fires (Delitti *et al.,* 2005) and heavy rainfall events (De Luis *et al.*, 2001; Giorgi *et al.* 2004).

12.4.4.3 Grasslands

Permanent pastures occupied 37% of the agricultural area in Europe in 2000 (FAOSTAT, 2005). Climate change is likely to alter the community structure of grasslands (Buckland *et al.*, 2001; Lüscher *et al.*, 2004), in ways specific to their location and type. Management and species-richness of grasslands may increase their resilience to change (Duckworth *et al.*, 2000). Fertile, early succession grasslands have been found to be more responsive to climate change than more mature and/or less fertile grasslands (Grime *et al.*, 2000). In general, intensively managed and nutrient-rich grasslands will respond positively to both increased CO_2 concentration and temperature, given that water and nutrient supply is sufficient (Lüscher *et al.,* 2004). Nitrogen-poor and species-rich grasslands may respond to climate change with small changes in productivity in the short-term (Winkler and Herbst, 2004). As a general rule, productivity of European grassland is expected to increase (Byrne and Jones, 2002; Kammann *et al.*, 2005).

12.4.5. Wetlands and aquatic ecosystems

Warmer temperatures may result in earlier ice melt of lakes and rivers when present, and in longer growing seasons at high elevations throughout Europe. A consequence of these changes could be a higher risk of algal blooms and increased growth of toxic cyanobacteria in lakes (Moss *et al.*, 2003; Straile *et al.,* 2003; Briers *et al.,* 2004; Eisenreich, 2005). Other expected impacts include accelerated decomposition of soil and peat in N. Europe (Weltzin *et al.,* 2003), and loss of permafrost areas in the Arctic (ACIA, 2004). Higher precipitation and reduced frost may enhance nutrient loss from cultivated fields (Eisenreich, 2005). These factors may result in higher loadings to inland waters of nutrients (Bouraoui *et al.,* 2004; Kaste *et al.,* 2004; Eisenreich, 2005) and dissolved organic matter (Evans and Monteith, 2001; ACIA, 2004; Worrall *et al.,* 2004). Higher nutrient loadings may intensify the eutrophication of lakes and wetlands (Jeppesen *et al.,* 2003).

Streams in catchments with impermeable soils may have increased run-off in winter and deposition of organic matter in summer, which could reduce invertebrate diversity (Pedersen *et al.,* 2004). Inland waters in S. Europe are likely to have lower volume and increased salinization (Williams, 2001; Zalidis *et al.,* 2002). Many ephemeral ecosystems may disappear, and permanent ones shrink (Alvarez Cobelas *et al.,* 2005). Although an overall drier climate may decrease the external 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 bottom water - temperature and duration of stratification will increase, leading to higher risk of oxygen depletion below the thermocline (Catalán *et al.,* 2002; Straile *et al.,* 2003; Blenckner, 2005). Higher temperatures will also reduce dissolved oxygen saturation levels and increase the risk of oxygen depletion (Sand-Jensen and Pedersen, 2005).

12.4.6 Biodiversity

Climate change is affecting the physiology, distribution and phenology of different European plant species. (Parmesan *et al.,* 1999; Thomas and Lennon 1999; Thomas *et al.,* 2001; Warren *et al.* 2001; van Herk *et al.,* 2002; 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; Hickling *et al.* 2006.) A European-wide assessment of future distribution areas of 1,350 plant species (10% of European flora) under various SRES scenarios indicated that more than half of the species considered could be vulnerable, endangered, critically endangered, or extinct by 2080 if they are unable to disperse (Thuiller *et al.,* 2005.) Under the most severe climate scenario (A1) and assuming that species could adapt through dispersal, 22% of the considered species would become critically endangered, and 2% committed to extinction. Similar results were obtained by Bakkenes *et al.* (2002) for 1,400 European plant species. According to these analyses, the range of plants may expand northward and contract in southern European mountains and in the Mediterranean basin. Studies of specific European regions (Kienast *et al.,* 1998; Saetersdal *et al.,* 1998; Duckworth *et al.,* 2000; Theurillat and Guisan, 2001) are consistent with European-wide 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 if dispersal were unlimited (Araújo *et al.,* 2006) (Fig. 12.3). This is because warming in some of the cooler northern ranges of species is likely to create new opportunities for colonization. However, if species were unable to disperse, then the range of most species (>97%) would become smaller, especially in the Iberian Peninsula, France and other parts of southwestern Europe. This is because few amphibian species would be able to survive the expected drier conditions (see also Teixeira and Arntzen, 2002). Meanwhile species in UK, southeastern Europe and southern Scandinavia were projected to benefit from a more suitable climate. In a European-wide study, the "climate space" of 47 species, including plants, insects, birds and mammals was found to generally shift from the southwest to the northeast (Berry *et al.,* 2006); Harrison *et al.,* 2006). Increased habitat fragmentation are also likely because of both climate and land-use change (Del Barrio *et al.,* 2006). Endemic plants and vertebrates in the Mediterranean Basin, a biodiversity hotspot, seem particularly vulnerable to climate change (Malcolm *et al.*, 2006).

Species richness in inland waters is highest in Central Europe and declines towards the south and north because of periodic droughts and salinization (Declerck *et al.,* 2005). Increased runoff and lower risk of droughts in the north will benefit the fauna of these 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 N. 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 encroach upon bogs and fens (Weltzin *et al.,* 2003). Reduction of inundation periods in the south may favor amphibian over aquatic species (Alvarez Cobelas *et al.,* 2005). Cold-adapted species will be forced further north and upstream; some may eventually disappear from Europe (Daufresne *et al.,* 2003; Eisenreich, 2005).

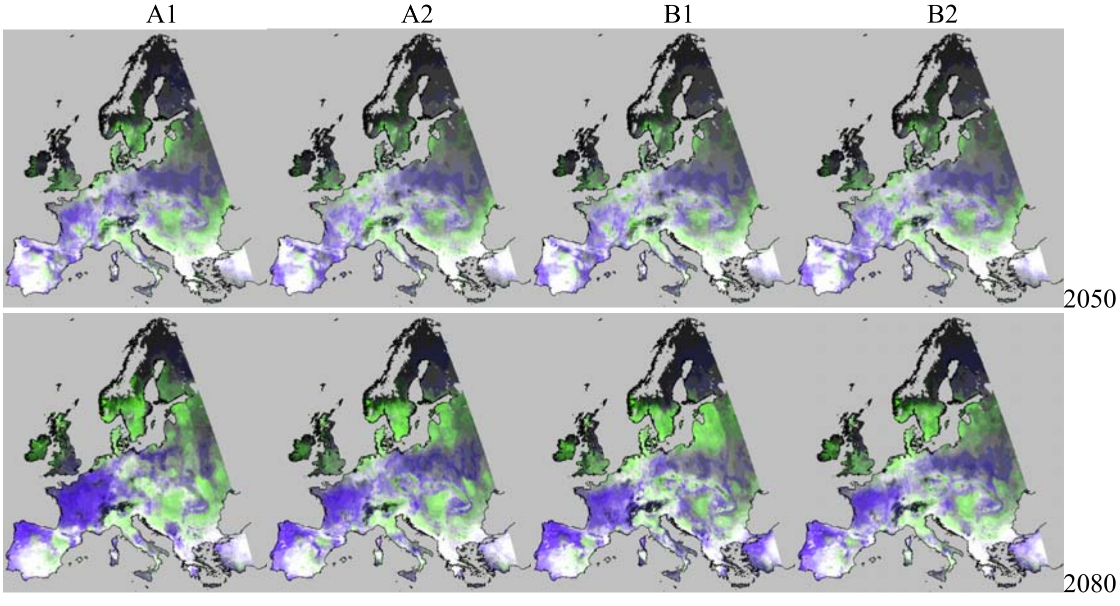


Fig. 12.3: *Change in combined amphibian and reptile species richness under climate change. Depicted is the change between baseline and future species richness projected for 2-time periods (2050 and 2080) using artificial neural networks, four SRES scenarios (A1, A2, B1, B2) (shown left to right), and based on climate scenarios from the HadCm3 global climate model. 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 and livestock

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.*, 2005). 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.*, 2005). Climate-related increases in crop yields are only expected in N. Europe, while the largest reductions are expected in the Mediterranean and in the southwest Balkans and in the south of European Russia (Olesen and Bindi, 2002; Maracchi *et al.*, 2005). In S. Europe, particularly large decreases in yield are expected for spring-sown crops (e.g. maize, sunflower and soybeans) (Audsley *et al.*, 2006). The impacts on autumn-sown crops (e.g. winter and spring wheat) are more geographically variable; yield is expected to strongly decrease in most southern areas, and increase in northern or cooler areas (e.g. northern parts of Portugal and Spain) (Santos *et al.,* 2002; Olesen *et al.*, 2006). However, these results vary between SRES scenarios and climate models (Olesen *et al.*, 2006).

Some crops that currently grow mostly in S. Europe (e.g. maize, sunflower and soybeans) will become more suitable further north or at higher altitude areas in the south (Audsley *et al.*, 2006). Projections for a range of SRES scenarios show a 30 to 50% increase in suitable area for grain maize production in Europe by the end of the 21st century, including Ireland, Scotland, southern Sweden and Finland (Hildén *et al.*, 2005; Olesen *et al.*, 2006). By 2050 energy crops (26 crops) show a northward expansion in potential cropping area, but a reduction in S. Europe (Schröter *et al.*, 2005). The predicted increase in extreme weather events (e.g. spells of high temperature and droughts) (Meehl and Tebaldi, 2004; Schär *et al.,* 2004) is expected to increase yield variability (Jones *et al.,* 2003) and to reduce average yield (Trnka *et al.,* 2004). In particular, in the European Mediterranean region increases in the frequency of extreme climate events 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, is likely to reduce the yield of summer crops (e.g. sunflower). Climate change will modify other processes on agricultural land. Projections made for winter wheat showed that climate change beyond 2070 may lead to a decrease in nitrate leaching from agricultural land over large parts of E. Europe and some smaller areas in Spain, and an increase in the UK and in other parts of Europe (Olesen *et al.*, 2006).

An increase in the frequency of severe heat stress in Britain is expected to enhance the risk of mortality of pigs and broiler chickens grown in intensive livestock systems (Turnpenny *et al.*, 2001). 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 (Holden and Breton, 2002; 2003; Holden *et al.*, 2003). Increasing temperatures may also increase the risk of livestock diseases by (i) supporting the dispersal of insects (e.g. *Culicoides imicola*) that are main vectors of several arboviruses (e.g. bluetongue, BT and African horse sickness, AHS); (ii) enhancing 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; Wichmann *et al.,* 2004).

12.4.7.2 Marine fisheries and aquaculture

An assessment of the vulnerability of the northeast Atlantic marine eco-region concluded that climate change is very likely to produce significant impacts on selected marine fish and shellfish (Baker, 2005). Temperature increase has a major effect on fisheries production in the North Atlantic, causing changes in species distribution, increased recruitment and production in northern waters and a marked decrease at the southern edge of current ranges (Clark *et al.*, 2003; Dutil and Brander, 2003; Hiscock *et al.*, 2004; Perry *et al.*, 2005). High fishing pressure is likely to acerbate the threat to the fishery (e.g. on Northern cod) (Brander, 2005). Temperature changes affect phytoplankton communities, leading to potential trophic mismatches and, together with fishing pressure, is expected to influence most regional fisheries operating at trophic levels close to changes in zooplankton production (Heath, 2005). Long-term climate variability is an important determinant of fisheries production at the regional scale (see Klyashtorin, 2001; Sharp, 2003), with multiple negative and positive effects on ecosystems and livelihoods (Hamilton *et al.*, 2000; Eide and Heen, 2002; Roessig *et al.*, 2004). Our ability to assess biodiversity impacts, ecosystem effects and socio-economic costs of climate change in coastal and marine ecosystems is still limited (Gitay *et al.*, 2002; Pinnegar *et al.*, 2002; Robinson and Frid, 2003; Boelens, *et al.*, 2005). The overall interactions and cumulative impacts on the marine biota of sea level rise (coastal squeeze with losses of nursery and spawning habitats), increased storminess, changes to the NAO, acidification of coastal waters and other stressors such as pollutants, are likely but little known.

Marine and freshwater fish and shellfish aquaculture represented 33% of the total EU fishery production value and 17% of its volume in 2002 (EC, 2004). Warmer sea temperatures, increased growing seasons, growth rates, feed conversion, and primary productivity will benefit shellfish production. Opportunities for new species will arise from expanded geographic distribution and range, but increased temperatures will increase stress and susceptibility to pathogens. Ecosystem changes with new, exotic or invasive species such as gelatinous zooplankton and medusa, toxic algal blooms, increased fouling and decreased dissolved oxygen events, will increase operation costs. Increased storm-induced damage to equipment and facilities will increase capital costs. Aquaculture has its own environmental impacts that are likely to compound climate-induced ecosystem stress (Boelens *et al.*, 2005).

12.4.8. Energy and transport

12.4.8.1 Energy

Under future climate change demand for heating decreases and demand for cooling increases (Santos *et al.*, 2002; Livermore, 2005; López Zafra *et al.*, 2005). In the United Kingdom and Russia a 2^{o}C warming by 2050 will decrease space heating needs in the winter, thus decreasing fossil fuel demand by 5-10%, and electricity demand by 1-3%. Wintertime heating demand in Hungary and Romania will decrease by 6-8% (Vajda *et al.*, 2004) and by 10% in Finland (Venalainen *et al.*, 2004) by the period 2021-2050. By 2100, this decrease rises from 20-30% in Finland (Kirkinen *et al.*, 2005) to around 40% in the case of Swiss residential buildings (Frank, 2005, Christenson *et al.*, 2006). Around the Mediterranean, 2-3 fewer weeks in a year will require heating but an additional 2-3 (along the coast) to 5 weeks (inland areas) will need cooling by 2050 (Giannakopoulos *et al.*, 2005). Cartalis *et al.* (2001) estimated up to 10% decrease in energy heating requirements and up to 28% increase in cooling requirements in 2030 for the southeast Mediterranean region. Summer space cooling needs for air conditioning will particularly affect electricity demand (Valor *et al.*, 2001; Giannakopoulos and Psiloglou, 2006) with up to 50% increases in Italy and Spain by the 2080s (Livermore, 2005). Peaks in electricity demand during summer heat waves are very likely to equal or exceed peaks in demand during cold winter periods in Spain (López Zafra *et al.*, 2005).

The key renewable energy sources in Europe currently are hydropower (19.8% of the electricity generated) and wind. Under one scenario, by the 2070s, hydropower potential for the whole of Europe is expected to decline by 6% (Lehner *et al.*, 2005b) (20-50% decrease around the Mediterranean, 15-

30% increase in N. and E. Europe and a stable hydropower pattern for W. and C. Europe.) There will be a small increase in the annual wind energy resource over Atlantic- and N. Europe with more substantial increases in energy density during the winter season by 2071-2100 (Pryor *et al.*, 2005). Biofuel production is largely determined by the supply of moisture and the length of the growing season (Olesen and Bindi, 2003). By the 2100s, land area devoted to biofuels may increase by a factor of two to three in all parts of Europe (Metzger *et al.*, 2004). More solar energy will be available in the Mediterranean region (Santos *et al.*, 2002). Climate change could have a negative impact on the efficiency of thermal power production plants because water withdrawn for power plant cooling is expected to be somewhat warmer on the average (Hanson *et al.*, 2006). Furthermore, the availability of cooling water may be reduced at some locations of Europe because of climate-related decreases (Arnell *et al.*, 2005) or seasonal shifts (Zierl and Bugmann, 2005) in river runoff. The distribution of energy is also vulnerable to climate change (Thomas, 2002). There is a small increase in line resistance with increasing mean temperatures (Santos *et al.*, 2002) coupled with negative effects on line sag and gas pipeline compressors’ efficiency due to higher maximum temperatures (Colombo *et al.*, 1999; López Zafra *et al.*, 2005). All these combined effects add to the overall uncertainty of climate change impacts on power grids.

12.4.8.2 Transport

Higher temperatures can affect passenger comfort in-vehicle and influence mode choice (London Climate Change Partnership, 2002. They can also cause heat damage to rails and road surfaces (London Climate Change Partnership, 2005). Reduced occurrence of frost and snow can reduce maintenance and treatment costs. The likely increase in extreme weather events may result in increased flooding risk, particularly in underground rail systems and roads with inadequate drainage (London Climate Change Partnership, 2002; Suarez *et al.* 2005; London Climate Change Partnership, 2005). High winds may affect the safety of air, sea and land transport and heavy rainfall can also increase road risks (Keay and Simmonds, 2006) although in some areas this may be offset by fewer snowy days. Reduced runoff in S. Europe can inhibit river navigation (Middelkoop and Kwadijk, 2001).

12.4.9 Tourism, recreation and cultural heritage

Climatic factors, such as temperature, sunshine hours and rainfall determine a large share of the tourist flows within Europe, especially to the Mediterranean region. Higher summer temperatures will lead to a gradual decrease in summer tourism in the Mediterranean but an increase in spring and perhaps autumn, particularly in Greece, Spain (Amelung and Viner, 2006; Maddison, 2001). Mountainous parts of France, Italy and Spain could become more popular because of their relative coolness (Ceron and Dubois, 2000). Summer conditions will improve in N. and W. Europe (Hanson *et al.*, 2006).

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). Hantel *et al.* (2000) found at the most sensitive elevation in the Austrian Alps a 1^{o}C rise leads to 4 fewer weeks of snow cover in winter and 6 fewer weeks in spring. From the perspective of snow pack the most sensitive altitude to future climate change is 1 000-1 500 metres (Schwarb and Kundewicz, 2004). Beniston *at al.* (2003) calculated that a 2^{o}C warming with no precipitation change would reduce the seasonal snow cover at a Swiss Alpine site by 50 days per year, and with a 50% increase in precipitation by 30 days.

Climate change is likely to produce direct and indirect effects on Europe’s cultural heritage of old buildings (Cassar *et al.,* 2001; Cassar, 2005). Changes in rainfall intensity, extreme climatic events, ground water, freeze-thaw and wet-frost cycles could have a detrimental effect on the structure of buildings. Some damage processes will be enhanced and accelerated by climate change while others will be reduced (Cassar, 2005; Brimblecombe, 2005).

12.4.10 Property insurance

Insurance systems differ widely between countries (e.g. in many countries flood damage is not insured) and this affects the vulnerability of property to climate change. The value of property at risk also varies between countries: The damage from a wind speed of 200 km/h varies from 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.
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 12.4). Moreover, future insurance costs will rise significantly if current rare events become more common. This is because the costs of infrequent catastrophic events are much higher than more frequent events (e.g. in the UK, the cost of a 1000-year extreme climate event is roughly 2.5 times larger than the cost of a 100-year event, and in Germany, insurance claims increase as the cube of maximum wind speed (Swiss Re 2002; Klawa and Ulbrich, 2003)).

Table 12.4: *Annual expected river flood damage in the UK at present day and in 2080s (In 2004 £) under different SRES scenarios (Foresight Programme, 2004)*

	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

Countries in Europe currently experience mortality due to heat and cold (Braga *et al.,* 2001; Beniston, 2002; Ballester *et al.,* 2003; Keatinge and Donaldson, 2004). The most severe impacts are during heat waves [see Cross-cutting case study on the 2003 heatwave and Ch. 8] which are likely to become more common and severe in the future (Meehl and Tebaldi, 2004). Consequently, the number of deaths due to heat is expected to increase, with the number being dependent on counteractive measures (Casimiro and Calheiros, 2002). Reductions in cold-related mortality due to climate warming are likely (Keatinge *et al.*, 2000; Martens and Huynen, 2001; Dept of Health, 2002; Zaninovic and Matzarakis, 2004).

Global warming could change habitats for a number of disease-transmitting agents and could extend their ranges to the north and higher altitudes (Kovats *et al.*, 2001; Hunter, 2003). Tick distribution with the potential for tick-related diseases (e.g. TBE. Lyme disease) has been observed to have moved northward in Sweden (Lindgren and Gustafson, 2001; Lindgren and Jaenson, 2004), and upward in the Italian Alps and Czech Republic (Daniel and Kriz, 2002; Daniel *et al.*, 2003; Beran *et al.,* 2004). The distribution ranges of the sandfly vectors and associated pathogens may expand northwards (Bröker and Gniel, 2003; Molyneux, 2003; Korenberg, 2004; Kuhn *et al.*, 2004; Lindgren and Naucke, 2004; Randolph, 2002, 2004).

Climate change may reduce runoff in southern and other parts of Europe and thereby pose risks to public water supply (Miettinen *et al.*, 2001; Hunter, 2003; Elpiner, 2004; Knight *et al.*, 2004). Other factors remaining constant, warmer temperatures could increase the ground-level concentration of ozone which would endanger public health (Johnson *et al.*, 2005; Pirard, 2005; WHO, 2004). The timing of pollen seasons might be affected by warming, and this may amplify asthma, hay-fever and allergies (Verlato *et al.*, 2002; Beggs, 2004; Weiland *et al.*, 2004).

12.5 Adaptation: practices, options and constrains

12.5.1. Water resources

Climate change will pose two major water management challenges in Europe: increasing water stress in southeastern Europe, and increasing risk of floods throughout most of the continent. Adaptation options to cope with these challenges are well documented (IPCC 2001). The main structural measures to protect against floods are likely to remain reservoirs in highland areas and dikes in lowland areas (Hooijer *et al.,* 2004). However, other options however are becoming more popular such as expanded floodplain areas (Helms *et al.*, 2002), emergency flood reservoirs (Somlyódy, 2002), and flood warning systems.

To adapt to increasing water stress the most common strategies remain supply-side measures such as impounding rivers to form in-stream reservoirs (Santos *et al.*, 2002; Iglesias *et al.*, 2005). However new reservoir construction is being increasingly constrained in Europe by environmental regulations (Barreira, 2004) and high investment costs (Schröter *et al.,* 2005). Other supply-side approaches such as wastewater reuse and desalination are being more widely considered but their popularity is dampened by health concerns in using wastewater (Geres, 2004), and high energy costs of desalination (Iglesias *et al.*, 2005). Some demand-side strategies are also feasible (AEMA, 2002) such as household, industrial and agricultural water conservation, reducing leaky municipal and irrigation water systems (Geres, 2004; Donevska and Dodeva, 2004), and water pricing (Iglesias *et al.*, 2005). As is the case for the supply-side approaches, most demand-side approaches are not specific to Europe. An example of a unique European approach to adapting to water stress is the current discussion about changing land use patterns in Europe so that they are more suitable for the expected new climate regime. (Rounsevell *et al.*, 2006). Another example is that regional and watershed level strategies to adapt to climate change are being incorporated into plans for integrated water management (Kabat, *et al.,* 2002; Cosgrove, *et al.*, 2004; Kashyap, 2004) while national strategies are being designed to fit into existing governance structures (Hlavcová, *et al.,* 1999; Donevska and Dodeva, 2004)

12.5.2 Coastal and marine systems

Strategies for adapting to SLR are well documented (Smith *et al.*, 2000; IPCC, 2001; Vermaat *et al.*, in press; Nicholls *et al.*, 2007). Although a large part of Europe's coastline is relatively robust to SLR (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 that may result from SLR is very uncertain (Cooper and Pilkey, 2004), though modelling is beginning to provide some quantitative estimates (Walkden and Hall, in press; Dickson *et al.,* in press; Nicholls *et al.*, 2007).

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 (Nicholls and Klein, in press). Many countries in northwest Europe have adopted the approach of developing detailed shoreline management plans that link adaptation measures with shoreline defense, accommodation and retreat strategies (European Commission, 1999; Cooper *et al*., 2002; Hansom *et al*., 2004; DEFRA, 2004b). Parts of the Mediterranean and E. European regions have been slower to follow this pattern and management approaches are more fragmented (Tol *et al*., in press).

A key element of adaptation strategies for coastlines is the development of new laws and institutions for managing coastal land (Devoy *et al*., 2000, in press; 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 (Vermaat *et al*., in press).

12.5.3 Mountains and sub arctic regions

Mountainous and subarctic regions have only a limited number of adaptation options. In northern European climates it will become necessary to factor in the dissipation and eventual disappearance of permafrost in infrastructure planning (Nelson, 2003) and building techniques (Mazhitova *et al.,* 2004). There are few obvious adaptation options for either tundra or alpine vegetation. It may be possible to preserve many alpine species in managed gardens at high elevation since many mountain plants are likely to survive higher temperatures if they are not faced with competition from other plants (Guisan and Theurillat, 2005. Yet, this option is very uncertain because the biotic factors determining the distribution of mountain plant species are not well known. As another minimal adaptation option, other stresses on high elevation ecosystems could be reduced to a minimum (e.g. by lessening the impact of tourism; EEA, 2004). Specific management strategies have yet to be defined for mountain forests (Price, 2005).

12.5.4. Forests, grasslands and shrublands

Since forests are intensely managed in Europe there is a wide range of available management options that can be employed for adapting forests to climate change. General strategies for adapting forests to climate change include changing the species composition of forest stands,, and planting forests with genetically improved seedlings adapted to a new climate (if the risk of genetically modified species is considered acceptable) (KSLA, 2004). Extending the rotation period of commercially important tree species may increase sequestration and/or storage of carbon, and can be viewed as an adaptation measure (Kaipainen, *et al.,* 2004). Adaptive forest management could substantially decrease the risk of forest destruction by wind and other extreme weather events (Linder, 2000; Olofsson and Blennow 2005; Thurig *et al*., 2005). Strategies for coniferous forests include the planting of deciduous trees better adapted to the new climate as appropriate, and the introduction of multi-species planting into currently mono-species coniferous plantations (Vakuljuk and Samoplavsky, 1998, Fernando and Cortina, 2004).

Adaptation strategies need to be specific to different parts of Europe. The range of alternatives is constrained, among other factors, by the type of forest. Forests that are already moisture-limited (Mediterranean forests) or temperature-limited (boreal forests) will have grater difficulty in adapting to climate change than other forests (e.g. in Central Europe) (Gracia *et al.,* 2005). Fire protection will be important in Mediterranean and boreal forests and includes replacement of highly flammable species, regulation of age class distributions, and widespread management of accumulated fuel, eventually through prescribed burning (Baeza *et al.*, 2003; Fernandes and Botelho, 2004). Public education, development of advanced systems of forest inventories, and forest health monitoring are important prerequisites of adaptation and mitigation.

Productive grasslands are closely linked to livestock production. Dairy and cattle farming may become less viable because of climate risks to fodder production and therefore grasslands could be converted to cropland or other use (Holman *et al.,* 2005). Grassland could be adapted to climate change by changing the intensity of cutting and grazing, or by irrigating current dryland pastures (Riedo *et al.,* 2000). Another option is to take advantage of continuing abandonment of cropland in Europe (Rounsevell *et al*., 2005) to establish new grassland areas.

12.5.5 Wetlands, aquatic system

Better management practices are needed to compensate for possible climate-related increases in nutrient loading to aquatic ecosystems from cultivated fields in N. Europe. These practices include "optimized" fertilizer use and (re-)establishment of wetland areas and river buffer zones as sinks for nutrients. New wetlands could also dampen the effects of increased frequency of flooding. A higher level of treatment of domestic and industrial sewage and reduction in farmland areas can further reduce nutrient loadings to surface waters and also compensate for climate-related increases in these loadings.

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

12.5.6 Biodiversity

Conservation strategies relevant to climate change can take at least two forms: '*in situ*' involving the selection, design and management of conservation areas (protected areas, nature reserves, NATURA 2000 sites, wider countryside), or '*ex situ*' involving conservation of germplasm in botanical gardens, museums and zoos. In Europe very few studies have addressed the problem of '*in situ*' conservation, while '*ex situ*' conservation for mitigating climate change impacts have not yet been explicitly addressed in the context of European conservation science and policy. Indeed, climate change poses significant problems for conservation planning because this planning normally does not take into account future environmental conditions. Araújo *et al*. (2004) have pointed out the importance of taking into account climate change in nature conservation. In a modeling study of climate change impacts on vegetation in Europe, they estimated that climate could become unsuitable for 6 to 11% of plant species within existing reserves and for 5% of plant species inside and outside of reserves in Europe (over a 50 year simulation period). In the light of these and other findings, conservation experts have concluded that an expansion of reserve areas will be necessary to conserve species in Europe. For example, Hannah *et al,* (2006) calculated that European protected areas need to be increased by 19% to meet the EU goal of providing conditions by which 1200 European plant species can continue thriving in at least 100 km^2 of habitat. To meet this goal under climate change they estimated that current reserve area must be increased by 43%. They also point out that it would be very cost effective to expand protected areas proactively now rather than in the future after climate change impacts occur.

Another important adaptation tool could be dispersal corridors for target species. Current planning for new nature reserves could factor in the need for such corridors (Williams *et al.,* 2005). Despite the importance of modifying reserve areas, the only feasible adaptation strategy for some plant species may be preserving their germplasm in botanical gardens until an approach is found for restoring them in the wild.

12.5.7 Agriculture and fisheries

12.5.7.1 Agriculture

Short-term adaptations of agriculture in S. Europe may include changes in crop species (e.g. replacing winter with spring wheat) (Mínguez *et al.,* 2006), cultivars, or sowing dates (Olesen *et al*., 2006). Introducing new crops and varieties are also an alternative for N. Europe (Hilden *et al*., 2005). A feasible long-term adaptation measure is to change the allocation of agricultural land according to its changing suitability under climate change. For example, Rounsevell *et al*., 2006 took into account climate change and estimated under the IPCC-SRES scenarios a decrease of up to 50% in 2050 in cropland and grassland in Europe. Large-scale abandonment of cropland in Europe may provide an opportunity for increasing the cultivation of bioenergy crops (Schröter *et al*., 2005). Berry *et al*. (2006) found that different types of agricultural adaptation (intensification, extensification and abandonment) may be appropriate under different IPCC-SRES scenarios and at different locations. It is indisputable that the reform of European Union agricultural policies will be an important vehicle for encouraging European agriculture to adapt to climate change (Olesen and Bindi, 2002).

12.5.7.2 Fisheries and Aquaculture

On the small scale there is evidence that the fish and shellfish farming industries are adapting their technology and operations to changing climatic conditions, for example, by expanding offshore and selecting optimal culture sites for shellfish cages (Pérez *et al*., 2003). However, adaptation is more difficult for smaller coastal-based fishery businesses which do not have the option to sail long distances to new fisheries as compared to larger businesses with long distance fleets.

On the larger scale, adaptation options have not yet been considered in important policy institutions such as the European Common Fisheries Policy (CFP) although its production quotas and technical measures provide an ideal platform for such adaptation actions. Another major adaptation option is to factor in the long term potential impacts of climate change in the planning for new Marine Protected Areas (Soto, 2001).

Adaptation strategies should eventually be integrated into comprehensive plans for managing coastal areas of Europe. But these plans are lacking especially around the Mediterranean, and urgently need to be developed (Coccossis, 2003).

12.5.8 Energy and transport

A wide variety of adaptation measures are available in the energy sector ranging from modifications of human behavior to re-design of the energy supply system (Santos *et al.,* 2002). The sensitivity of European energy systems to climate change could be reduced by enhancing the interconnection capacity of the European electricity grids, and by using more decentralized electric generation systems and local micro grids (Hanson *et al.,* 2006; Arnell *et al.,* 2005). Another type of adaptation would be to reduce exposure of energy users and producers to unfavorable climate by reducing overall energy use. This can be accomplished through various energy conservation measures such as energy-saving building codes and low-electricity standards for new appliances, by increasing energy prices, and by training and public education.

Adaptation of the transport sector to climate change should include an increase in the robustness of transport infrastructure (road network, bridges, tunnels) to climate change impacts such as increased frequency of avalanches and rockfall in mountain regions. As a general approach, climate change impacts should be considered in integrated in general plans to improve the resilience and reliability of the European transportation system (National Assessment Synthesis Team 2001, AEAT 2003, Highways Agency 2005).

12.5.9 Tourism and recreation

A variety of adaptation measures are available to the tourism industry (WTO, 2003, Hanson *et al.,* 2006). Some of these changes will entail the shifting of conditions for tourism as in the case of warmer, drier summers in N. Europe leading to greater domestic travel and a reverse tourist flow from the south.

Possible adaptation measures include (WTO, 2003).

- Compensating for reduced snowfall by artificial snowmaking which is already common for coping with year-to-year variability in snow pack. However this measure has ecological impacts that make it undesirable from the point of view of environmental protection. As the winter ski industry declines, the tourist industry will need to promote alternative activities such as hiking.
- Adaptation of seaside tourism to sea level rise by adopting appropriate protective measurres (e.g. coastal sea barriers).
- Promoting new forms of tourism such as cultural tourism having greater emphasis on an-made rather than natural attractions.
- Cooperating with local governments to deal with new climate-related risks to health, availability of water, and infrastructure.

12.5.10 Property Insurance

The insurance industry has several approaches for adapting to growing climate-related risk to property. These include raising costs of insurance premiums, restricting or removing coverage, “reinsurance”, and improved loss remediation (Dlugolecki, 2001). Insurers are beginning to use GIS to provide themselves with the information needed to adjust insurance tariffs to climate-related risks (Munich Re, 2004; Dlugolecki, 2001) although the uncertainty of future climate change is an obvious problem in making these adjustments. Insurers are also involved in discussions of measures for climate change mitigation and adaptation, including more stringent control of flood plain development and remedial measures for damages derived from weather action and extreme events (Dlugolecki and Keykhah, 2002; ABI, 2000).

An obvious adaptation measure against property damage is to improve construction techniques such that buildings and infrastructure are more robust to extreme climate events. However, even if building techniques are immediately improved they will not have a large impact because the current building stock has a long remaining lifetime. Hence these buildings would not be replaced for many years by more resilient structures unless they are retrofitted. While retrofitting of property can be an effective adaptation measure it also has its drawbacks. – Costs are often high, residents are disrupted, and poor enforcement of building regulations and construction practices could lead to unsatisfactory results.

12.5.11 Human health

One of the most important areas requiring climate adaptation in the field of health is the expected increased frequency of heat waves. Possible adaptation measures include developing public heat wave warning systems and preparing emergency rescue plans (Garssen *et al.,* 2005; Nogueira *et al.,* 2005; Pirard, 2005). Many cities in W. Europe have already developed heat wave response measures especially as a result of the serious summer 2003 heat wave (WHO, 2003; Koppe *et al.,* 2004; Ministerio, 2004; Nogueira *et al.*, 2005; Pirard, 2005) [See also Box in Chapter 8 on Lessons Learned]. Furthermore it is possible to adapt housing design, shift work patterns, and expand air conditioning to cope with expected extreme summer temperatures (Keatinge, *et al*, 2000). Another measure for coping with heat waves is to mitigate urban “heat islands” through urban planning. (Ballester *et al.,* 2003; Koppe *et al.,* 2004).

Adaptation is also needed to cope with increased risk of flooding. Options include: public flood warning systems, evacuations from lowlands, waterproof assembling of hospital equipment, and establishment of a decision hierarchy between hospitals and administrative authorities (EEA, 2004; Hajat *et al*., 2003; Ohl and Tapsell, 2000; WHO, 2004).

Extreme rainfall and runoff events and low water levels resulting from droughts may also increase microbial loads in watercourses and drinking water reservoirs (Kistemann *et al*., 2002; Schijven and de Roda Husman, 2005) Therefore, climate change impacts should be included in risk management plans for public water supply systems (Ekdahl, 2004; Izmerov *et al*., 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 (Fig. 12.4). Maximum temperatures of 35 to 40 °C were repeatedly recorded in July and August in most S. and Central European countries (André *et al.,* 2004; Beniston and Diaz, 2004). This heat wave was determined to be extremely unlikely under current climate (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) (Fig. 12.4). 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; Stott *et al.,* 2004). The heat wave was accompanied by annual precipitation deficits up to 300 mm, and this drought was a major contributor to the estimated reduction of 30% over Europe in gross primary production of terrestrial ecosystems (Ciais *et al.*, 2005). This reduced agricultural production and increased production costs, giving an estimated damage of more than 11 billion euros (Olesen and Bindi, 2003). The hot and dry conditions led to many very large wildfires, in particular in Portugal (420,000 ha) (EC, 2005). Many major rivers (e.g. Po, Rhine and Loire) were at record low levels, resulting in disruption of irrigation and power plant cooling (Beniston and Diaz, 2004).

An estimated 50,000 excess deaths occurred in summer 2003 across Europe (Kosatsky, 2005), in particular among elderly people (WHO, 2003; Kovats and Jendritzky, 2005; Menne and Ebi, 2005). The highest mortalities occurred in France, resulting in a health system crisis in France (Le Tertre *et al.,* 2006; Vandentorren *et al.,* 2004; Poumadère *et al.,* 2005). The rate of mortality differed significantly between cities within individual countries, perhaps because of differences in local climatic conditions, different temperature threshold to produce an increase in mortality, and/or preparedness of the health sector (Vandentorren *et al.,* 2004; Conti *et al.,* 2005; Díaz *et al.,* 2005; Grize *et al.,* 2005). The heat wave in 2003 has led to the development of heat health watch warning systems in several S. European countries, including France (Pascal *et al.*, 2006), Spain (Simón *et al*., 2005), Italy (Michelozzi *et al*., 2005), the United Kingdom and Hungary (Kosatsky and Menne, 2005).

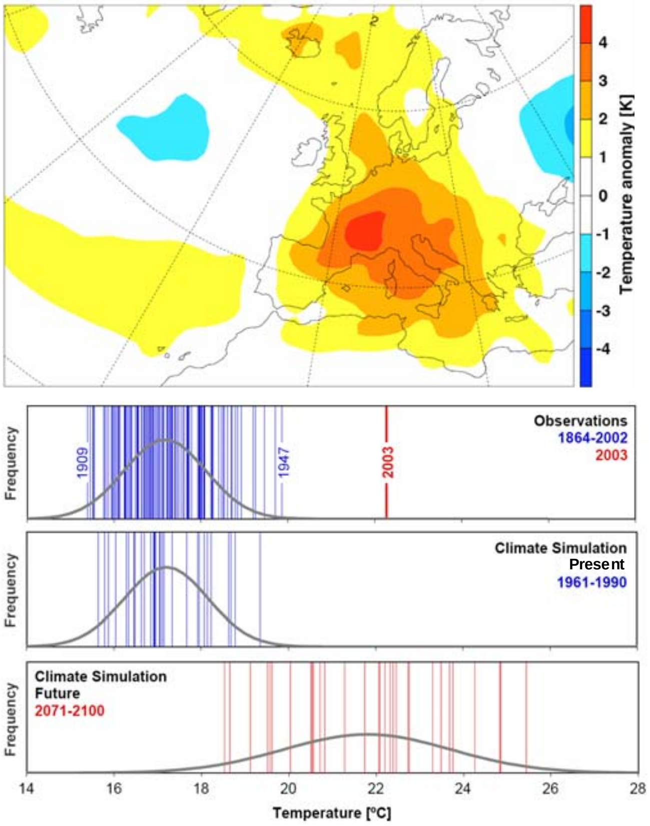


Fig. 12.4: *Characteristics of the summer 2003 heat wave (adapted from Schär et al., 2004). a) JJA temperature anomaly with respect to 1961–90. a-d) JJA temperatures for Switzerland observed during 1864-2003 (b), simulated using a RCM for the period 1961-1990 (c) and simulated for 2071-2100 under the A2 scenario.*

12.6.2. Thermohaline circulation changes in the North Atlantic: possible impacts for Europe

Earlier studies of the possible impacts of rapid change in Meridional Overturning Circulation (MOC) in the North Atlantic (Alcamo *et al.,* 1994; Broecker, 1997, 1999) are now being updated (Vellinga *et al*., 2002; Schaeffer *et al*., 2002; Gregory *et al*., 2005; Stouffer *et al*., in press; Schlesinger *et al*., in press). Simulations of an abrupt shutdown of this circulation under the IPCC IS92a and A2 scenarios (Vellinga and Wood, 2002; Wood *et al*., 2006) indicate that temperatures on Europe's western margin would be most affected, as would operation of the NAO. However these modeling results are contentious and may represent extreme cases of impact (Alley *et al*., 2003; Meehl *et al*., 2004; Rahmstorf and Zickfeld, 2005). Of the scientists surveyed, nearly all believed the chance of an abrupt change in the MOC before 2100 is less than 1%, while a few thought it was very likely (Arnell *et al*., 2005). Although there are no indications of an imminent change in thermohaline circulation (Dickson *et al.,* 2003; Curry and Mauritzen, 2005), it is recognised that should such a change would have significant impacts for Europe (Table 12.5). Hence, these impacts should be considered in climate policy (DEFRA, 2004a; Arnell *et al*., 2005; Keller, 2004; Schlesinger *et al*., 2005; Patwardhan, *et al*., 2007)

Table 12.5: *Main impacts of a rapid change in Meridional Overturning Circulation (Source: Arnell et al., 2005)*

- Reductions in runoff and water availability in S. Europe; major increase in snowmelt flooding in W. Europe.
- Major reductions in crop production with consequent impacts on food prices
- Major changes in temperature and Mediterranean ecosystems.
- Disruption to winter travel opportunities and increased icing of northern ports and seas
- Increases in cold-related deaths and ill-health,
- Movement of populations to S. Europe and shift in the centre of economic gravity
- Requirement to refurbish infrastructure towards Scandinavian standards

12.7 Implications for sustainable development

Human Appropriation of Net Primary Production in W. Europe amounts to 2.86 t carbon/cap/a, which is 72.2% of its terrestrial net primary production, far exceeding the global average of 20% (Imhoff *et al.*, 2004). In 2001, the "ecological footprint" of Central and E. Europe was 3.8 ha/cap, and of W. Europe 5.1 ha/cap (WWF 2004). (This is an estimate of the territory required to provide resources consumed by a given population; Wackernagel *et al.,* 2002). These values also far exceed the global average of 2.2 ha/cap (WWF 2004). By 2050 the "global ecological footprint" of Europe could increase between 70% (B2 scenario) and 300% (A1b scenario) thus putting additional pressure on ecosystems. It is also likely that the ecological footprint of Europe will remain much higher than the global average (van Vuuren and Bouwman, 2005). However, it could turn out that Europe is forced to reduce its footprint because some of the countries now using their land to provide food and other commodities for Europe may need this land for their own domestic requirements (van Vuuren and Bouwman, 2005).

Climate change in Europe is very likely to reduce ecosystem services such as soil fertility, water availability, climate regulation potential or biodiversity, among other (Schröter *et al.*, 2005). Therefore, existing pressures on the already burdened natural environment of Europe may increase (EEA 2003). Furthermore, impacts may be unevenly distributed between the north (some positive, some negative) and south (nearly all negative). On the other hand, the capacity of Europe's social systems to cope with climate change is high and is expected to continue rising (Metzger *et al.*, 2004). Adaptive capacity will vary between countries because of their different socioeconomic levels (Yohe and Tol, 2002).

Climate change may further increase awareness of the limits and dangers of our current economic and social system. Sustainability is a global (world-wide) concept and Europe has shown that it might be possible to reconcile 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). Certainly developing better governance structures will play an important role in meeting this challenge (CEC, 2001).

12.8 Key uncertainties and research priorities

This section and Table 12.6 discuss important uncertainties in estimating future impacts of climate change in Europe (see Table 12.7). A major uncertainty is the future behaviors of the NAO and North Atlantic thermohaline circulation, in particular how they could be affected by rapid ice-melt. It is urgent to improve our estimation of these future processes. Also important but not specific to Europe are the uncertainties associated with the low resolution of GCMs (e.g. Etchevers *et al.*, 2002; Bronstert, 2003), and with downscaling techniques of RCMs (Mearns *et al.*, 2003). Uncertainties in climate impact assessment also stem from the uncertainties of land-use change and socio-economic development (Rounsevell 2005; 2006). Although most impact studies now use the IPCC-SRES scenarios, some scientists are of the opinion that that these scenarios do not accurately reflect current thinking and economic theory. This is a particularly important point for Europe since the future adaptive capacity of its many countries in economic transition will depend on the pace of their future economic growth.

Uncertainties in assessing future impacts also arise from limitations of climate impact models including (i) structural uncertainty due to the inability of models to capture all influential factors, (e.g. the 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]), (ii) lack of long-term representative data for testing the models (e.g., future health effects based on current vector-monitoring systems [Kovats *et al.,* 2001]). Hence, more attention should be given to structural improvements of models and intensifying efforts of long-term monitoring of the environment. Another way to address the uncertainty of deterministic models is to use probabilistic modeling which can produce an ensemble of scenarios (e.g. Araújo *et al.*, 2005a; EU project ENSEMBLES).

Until now, most impact studies have been conducted for separate sectors even if, in some cases, several sectors have been included in the same study (e.g. Schröter *et al.*, 2005). Few studies have addressed impacts on various sectors and systems including their possible interactions by integrated modelling approaches (Berry *et al.*, 2006). Even in these cases, there are various levels (supranational-national-regional-subregional) that need to be jointly considered, since, if adaptation measures are to be implemented, knowledge down to the lowest decision level will be required. The varied geography, climate, and human values of Europe pose a great challenge for an evaluation of the ultimate impacts of climate change.

Studies of adaptation to climate change are only in their early stage and need to be urgently carried out. These studies need to match adaptation measures to specific climate change impacts (e.g. targeted to alleviating impacts to particular types of agriculture, or on tourism at specific locations). They need to take into account regional differences in adaptive capacity (e.g. wide regional differences exist in Europe in the style and application of coastal management). Adaptation studies need to factor in that in some cases both positive and negative impacts may occur as a result of climate change (e.g. the productivity of some crops may increase, while others decrease at the same location; e.g., Alexandrov *et al.,* 2002).

Key research priorities for different sectors are included in Table 12.6

Table 12.6: *Selected uncertainties and research needs in particular European sectors.*

	Uncertainties and research needs
Water resources	Impact of climate change on groundwater recharge, shallow lakes. Approaches for including climate change in the water management policy and institutions. Consideration of non-stationary climate in the design of engineering structures.
Mountains and subartic	Long term monitoring of cryosphere and sensitive ecosystem. Integrated impact studies of sensitive ecosystems including human dimensions. Impact of changes in flow regimes of mountain rivers on downstream river stretches.
Forest, grasslands, shrublands	Impacts of changing environment on stability, composition and functioning of European forests, natural grasslands and shrublands. Improved understanding of climate change impacts on major biogeochemical cycles. Relationship between climate impacts on forests and other expected large-scale changes

	in forests. Assessment of goods and services delivered by forests, grasslands and shrublands.
Biodiversity	Quantification of bio-climatic limitations of prevalent plant species. Improved monitoring to detect changes in biodiversity and ecosystems processes. Experimental research to understand the interactions between climate change and other causes of change in ecosystems, particularly air pollution.
Agriculture and fisheries	Impact studies that factor in both climate change and local environmental conditions. Better understanding of adaptation options for crops.
Energy & transport	Better understanding of overall effects of climate change on renewable energy sources. Possible impact of climate change on travel behavior and transport infrastructure. Possible impact of climate change on buildings – synergistic effects with air pollution.
Tourism and recreation	Climate change impact studies on the possible variations in the tourist demand (the loss of the feeling of comfort and safety, or the loss of attractiveness of a destination or a travel season) The generation of indicator systems is vital with regard to indicating and differentiating types of impacts according to types of areas and tourism products, especially coastal and mountain ones.
Human health	Full epidemiology of infections driven by climate change. Differences in impacts of short-term climate variability and long-term climate change. Mechanisms of heat/cold waves morbidity and interactions between harmful air pollutants and extreme weather events. Biological and ecological aspects of climate change impacts on health. Clarification of the population at risk, of the lag time of climate change impacts, of the role of respiratory infections.

Table 12.7: *Summary of the main expected impacts of climate change in Europe during the 21st Century.*

Sectors and systems	**Impact**	**Area**				
		North	**Atlantic**	**Central**	**Mediterranean**	**East**
Water resources	Floods	**	**	***	*	***
	Water availability	**	**		***	**
	Water stress	**	**	*	***	**
Coastal and marine systems	Beach, dune - low-lying coast erosion 'coastal squeeze'	***	***		**	**
	SLR and surge driven flooding	***	**		**	**
	Reduced river sediment supply to estuaries and deltas	**	*		***	
	Saltwater intrusion to aquifers	*	**		**	
	Northward migration of marine biota	*	***			
	Rising SSTs eutrophication & biosystems stressing	***	**		**	*
	Development of ICZM	**	**		**	*
	Deepening and larger inshore waters	**	**		*	**
Mountains, cryosphere	Glaciers retreat	***		***		***
	Duration of snow cover	***				
	Permafrost retreat	***				
	Tree line upward shift	***			*	***
	Nival species losses	***				
Forest, grasslands and shrublands	Forest NPP	***	**	**	* to *	*
	Northward/inland shift of tree species	***	**	**	* to *	**
	Natural disturbances (e.g., fire, insects)	*	*	*	***	**
	Change of stability of forest ecosystems	**	*	*	**	***
Wetlands and aquatic ecosystems	Drying/ transformation of wetlands	**	*	*	**	***
	Disturbance of drained peatlands	***		**	*	***
Biodiversity	Plants	**		*** **(Mt)**	***	

Sectors and systems	**Impact**	**Area**				
		North	**Atlantic**	**Central**	**Mediterranean**	**East**
	Amphibians	**	***	**	*** (SW) ** (SE)	***
	Reptiles	**		**	*** (SW) *** (SE)	***
Agriculture and fisheries	Suitable cropping area	***	**	*	**	*
	Agricultural land area	**	**	**	**	**
	Summer crops (maize, sunflower)	***	**	*	***	**
	Winter crops (winter wheat)	***	**	* to *	**	*
	Irrigation needs		* to *	**	***	*
	Energy crops	***	**	*	**	*
	Livestock	*to*	*	**	**	**
	Marine fisheries	**	*		*	
Energy and transport	Energy supply and distribution	*	**	*	*	*
	Winter energy demand	**	**	*	**	*
	Summer energy demand	*	*	**	***	**
Tourism	Winter (incl. ski) tourism	**	*	***	***	**
	Summer tourism	*	**	*	**	*
Property insurance	Flooding		**	**		
	Storms	*	**	**		
Human health	Heat waves	**	*	**	***	**
	Cold waves	*	**	**	*	***
	Floods	*	**	**	**	**
	Vector-borne diseases	*	* and *	* and *	***	**
	Food- and water-borne diseases	**	**	**	***	***
	Air pollution: ozone	*	*	**	**	**
	PM, allergens	* to *	*	**	*	*

Magnitude of impact: *, **, ***. Type of impact: blue= positive; red= negative; * to *: change in character through time. Mt= Mountains; SW= Southwest; SE= Southeast; SLR= Sea-level-raise; ICZM= Integrated coastal zone management; SST= Sea-surface temperature.

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