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Europe

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CONTENTS

EXECUTIVE SUMMARY

- The adaptation potential of socioeconomic systems in Europe is relatively high because of economic conditions (high gross national product and stable growth); a stable population (with the capacity to move within the region); and well-developed political, institutional, and technological support systems. However, adaptation potential for natural systems generally is low. [very high confidence]

- Present-day weather conditions have effects on natural, social, and economic systems in Europe in ways that reveal sensitivities and vulnerabilities to climate change in these systems. Climate change may aggravate such effects. [very high confidence, well-established evidence]

- Vulnerability to climate change in Europe differs substantially between subregions; it is particularly high in the south and in the European Arctic. This has important equity implications. More marginal and less wealthy areas will be less able to adapt. [very high confidence, established but incomplete evidence]

- Water resources and their management in Europe are under pressure now, and these pressures are likely to be exacerbated by climate change [high confidence]. Flood hazard is likely to increase across much of Europe, except where snowmelt peak has been reduced, and the risk of water shortage is projected to increase particularly in southern Europe [medium to high confidence]. Climate change is likely to widen water resource differences between northern and southern Europe. [high confidence, well-established evidence]

- Soil properties will deteriorate under warmer and drier climate scenarios in southern Europe. The magnitude of this effect will vary markedly between geographic locations and may be modified by changes in precipitation. [medium confidence, established but incomplete evidence]

- Natural ecosystems will change as a result of increasing temperature and atmospheric concentration of carbon dioxide (CO_2). Permafrost will decline, trees and shrubs will encroach northern tundra, and broad-leaved trees may encroach coniferous forests. Net primary productivity in ecosystems is likely to increase (also as a result of nitrogen deposition). Diversity in nature reserves is under threat from rapid change. Loss of important habitats (wetlands, tundra, and isolated habitats) would threaten some species (including rare/endemic species and migratory birds). Faunal shifts as a result of ecosystem changes are expected in marine, aquatic, and terrestrial ecosystems. [high confidence, established but incomplete evidence]

- In mountain regions, higher temperatures will lead to an upward shift of biotic and cryospheric zones and perturb the hydrological cycle. There will be redistribution of species, with, in some instances, a threat of extinction. [high confidence]

- Timber harvest will increase in commercial forests in northern Europe [medium confidence, established but incomplete evidence], but reductions are likely in the Mediterranean, with increased drought and fire risk. [high confidence, well-established evidence]

- Agricultural yields will increase for most crops as a result of increasing atmospheric CO_2 concentration. This effect would be counteracted by the risk of water shortage in southern and eastern Europe and by shortening of growth duration in many grain crops as a result of increasing temperature. Northern Europe is likely to experience overall positive effects, whereas some agricultural production systems in southern Europe may be threatened. [medium confidence, established but incomplete evidence]

- Changes in fisheries and aquaculture production from climate change embrace faunal shifts affecting freshwater and marine fish and shellfish biodiversity. These changes will be aggravated by unsustainable exploitation levels and environmental change. [high confidence]

- The insurance industry faces potentially costly climate change impacts through the medium of property damage, but there is great scope for adaptive measures if initiatives are taken soon. [high confidence]

- Transport, energy, and other industries will face changing demand and market opportunities. Concentration of industry on the coast exposes it to sea-level rise and extreme events, necessitating protection or removal. [high confidence]

- Recreational preferences are likely to change with higher temperatures. Outdoor activities will be stimulated in northern Europe, but heat waves are likely to reduce the traditional peak summer demand at Mediterranean holiday destinations, and less reliable snow conditions could impact adversely on winter tourism. [medium confidence]

- A range of risks is posed for human health through increased exposure to heat episodes (exacerbated by air pollution in urban areas), extension of some vector-borne diseases, and coastal and riverine flooding. Based on current evidence, climate change would result in a reduction in wintertime deaths, at least in temperate countries. [medium confidence]

- In coastal areas, the risk of flooding, erosion, and wetland loss will increase substantially—with implications for human settlement, industry, tourism, agriculture, and coastal natural habitats. Southern Europe appears to be more vulnerable to these changes, although the North Sea coast already has high exposure to flooding. [high confidence]

The foregoing conclusions are broadly consistent with those expressed in the IPCC *Special Report on Regional Impacts of Climate Change* (1998) and the Second Assessment Report (1996). This survey incorporates much more information than previously reported, corroborating previous conclusions (with which it is broadly consistent) but extending knowledge into other sectors. It is more specific about subregional effects and includes new information concerning adaptive capacity.

13.1. The European Region

13.1.1. Previous Work

Western Europe was the subject of the first multi-country assessment of climate change impacts using general circulation model (GCM)-derived climate scenarios (Meinl and Bach, 1984). This included assessment of impacts on the agricultural, water, and energy sectors in the European Union (EU). Since that time, most assessments have been of single sectors or single countries. Most countries in Europe have now conducted climate impact studies, though these studies generally are based on expert reviews rather than new research. EU-wide assessments have been completed for water (Arnell *et al.,* 1999), agriculture (Harrison *et al.,* 1995a), forestry (Kellomäki, 1999), and coastal regions (European Commission, 1999).

The IPCC synthesis of regional impacts in its *Special Report on Regional Impacts of Climate Change* (RICC) captured some of the important likely effects—for example, on water resources, coastal regions, and agriculture—but drew no conclusions concerning effects on ecosystems, soils, forestry, insurance, and mountain regions (IPCC, 1998). The present survey refers to a much more extensive literature base (about three times as much as in RICC) and is able to cover additional fields and draw more specific conclusions. The main differences between the current assessment and the previous one are its coverage of the additional sectors noted above; the distinction it is able to draw between effects on different parts of Europe, particularly between northern and southern Europe; the greater degree of quantification achieved; and its evaluation of the adaptive capacity of different sectors to climate change impacts. This assessment draws substantially on the work of a 3-year review of impacts in Europe funded by the Commission of the European Communities, with extensive additional input of material for non-EU countries (Parry, 2000).

13.1.2. What is Different about the European Region?

13.1.2.1. Geography, Population, Environment

Europe, a continent with an area of 10.5 million km², extends from the Atlantic Ocean in the west to the Eastern Ural Mountains, the River Ural, and the Caspian Sea in the east and from the Arctic Sea in the north to the Caucasus Mountains, the Black Sea, and the Mediterranean Sea in the south.

Europe consists of large areas with low relief, including one of the world's largest uninterrupted plains: the European Plain. There are several mountain ranges; the highest peak is 5,642 m (Elbrus in the Caucasus Mountains). The continent is well-watered, with numerous permanent rivers, many of which flow outward from the central part of the continent.

There are five essential types of climate in Europe: maritime, transitional, continental, polar, and Mediterranean. The five major vegetation types are tundra, coniferous taiga (boreal forest), deciduous-mixed forest, steppe, and Mediterranean. A relatively large proportion of Europe is farmed, and about one-third of the area is arable; cereals are the predominant crop.

Europe has a total population of 720 million; it has a higher population density and lower birth rate than any other continent. In several countries of central and eastern Europe, population growth is negative at present, even as low as –1.2% (World Bank, 1999). High life expectancy and low infant mortality are results of advances in health care. Life expectancy at birth is among the highest in the world, in some countries reaching more than 75 years for men and more than 80 years for women (World Bank, 1999). European nations are aging faster than those of any other continent.

Key environmental pressures that are significant at the European scale are identified in the Dobris Report (Stanners and Bourdeau, 1995). They relate to areas such as biodiversity, landscape, soil and land degradation, forest degradation, natural hazards, water management, and recreational environment, among others. Most ecosystems in Europe are managed or semi-managed; they often are fragmented and under stress from pollution and other human impacts. Social concerns include issues such as competitiveness, employment, income, and social mobility (Parry, 2000). The relative importance of these issuses varies across Europe. Southern Europe, mountains, and coastal zones have their own sets of environmental concerns, some of which will be aggravated by climate change.

13.1.2.2. Economy

The pattern of wealth distribution in the European region is strongly nonhomogeneous. Values of gross national product (GNP) per capita range from US$540 to 44,320 in Moldova and Switzerland, respectively (World Bank, 1999).

The 15 states that belong to the European Union (EU) are developed countries with stable economies and high levels of productivity. Their industry is based on modern high technology. The EU has reached a high degree of integration and common economic policy.

Until 1990, several countries in central and eastern Europe (CEE) had centrally planned economies dominated by heavy industry. Since late 1989, the CEE has undergone dramatic economic and political changes toward market economy and democracy. CEE countries labeled as "economies in transition" have been overhauling outdated, ineffective, energy- and raw material-consuming and highly polluting industries. This has been a difficult and long-term process; as a result, in 1990–1992, a large drop in GNPwas noted in all CEE countries. Subsequently, some countries have managed to achieve solid growth. Poland, for instance, has now experienced nine consecutive years of growth, and its mean annual GNP rise for 1990–1997 is 3.9% (World Bank, 1999). Yet for some other countries, mean annual GNP growth for 1990–1997 has been negative.

After the fall of the former political system in CEE, ties between these countries ceased to exist and new subregional links are being built, such as the Vysehrad Group created by Poland, the Czech Republic, Slovakia, and Hungary and the Central European Free Trade Agreement (CEFTA). Yet the tendency for many countries of CEE now is to seek access to Western institutions. Three countries—the Czech Republic, Hungary, and Poland—joined the North Atlantic Treaty Organization (NATO) in March 1999. Five countries (Czech Republic, Estonia, Hungary, Poland, and Slovenia) have started negotiations that are expected to lead to full access to the EU in a few years. Among the macro-level pressures in some countries are within-country ethnic tensions and difficulties of transition toward a democratic system with a market economy.

13.1.3. Recent Climate Variability in Europe, including Recent Warming

The climate of Europe exhibits large differences from west (maritime) to east (continental) and from north (Arctic) to south (Mediterranean). The climatic effects of the distribution of land and ocean are further complicated by numerous high mountain ranges, which act as physical barriers to atmospheric circulation and often introduce large precipitation gradients within small regions (e.g., Frei and Schär, 1998). There is no synoptic consistency to the behavior of the European atmosphere across such a heterogeneous climatic domain.

Europe possesses long instrumental data records. The central England temperature series, for example, commences in 1659 (Jones and Hulme, 1997). Reconstruction of regional climates in Europe with proxy data sets identifies the magnitudes of natural temperature variability that have occurred on even longer multi-century time scales: 1,400 years of summer temperatures from tree growth in Fennoscandia (Briffa *et al.*, 1990), 460 years of monthly temperature and precipitation patterns from hydrological and biological evidence in central Europe (Pfister, 1992), and 500 years of annual temperatures from ice cores in Greenland (Fischer *et al.,* 1998). Direct sea-level measurements are available from the 18th century. There have been several attempts at deciphering the remote past, based on proxy data (e.g., Velichko *et al.*, 1998; Zelikson *et al.*, 1998).

13.1.3.1. Temperature

Most of Europe has experienced increases in surface air temperature during the 20th century that, averaged across the continent, amount to about 0.8°C in annual temperature (see Figure 13-1) (ECSN, 1995; Beniston *et al.*, 1998; EEA, 1998). This warming has been largest over northwestern Russia and the Iberian peninsula (Nicholls *et al.*, 1996; Onate and Pou, 1996) and stronger in winter than in summer (Maugeri and Nanni, 1998; Brunetti *et al.,* 2000). An exception is Fennoscandia, which has recorded cooling in mean maximum and mean minimum temperature during 1910–1995 in winter but warming in summer (Tuomenvirta *et al.*, 1998). The past decade in Europe (1990–1999) has been the warmest in the instrumental record, annually and for winter. Increases in growing-season length also have been observed in Europe—for example, in western Russia (Jones and Briffa, 1995) and in Fennoscandia (Carter, 1998). Trends in the intensity of the growing season as measured by growing degree days, however, are more ambiguous in both of these studies. The evidence for longer growing seasons in Europe also is supported by phenological data collected in central Europe (Menzel and Fabian, 1999). These data point to increases of about 10 days in average growing-season length since the early 1960s. Other biological indicators of a changing growing season in Europe include poleward shifts of 35–240 km during this century in entire ranges of 34 different butterfly species (Parmesan *et al.,* 1999) and earlier breeding times for several species of amphibians and migratory birds during the past few decades (Forchhammer *et al*., 1997).

Warming in annual mean temperature has occurred preferentially as a result of nighttime rather than daytime temperature increases (Brazdil *et al.*, 1996; Easterling *et al.*, 1997; Tuomenvirta *et al.,* 1998), reflecting similar tendencies to those in other world regions. There has been some evidence that this reduction in the diurnal temperature range (DTR) has been associated with increased cloudiness. This is especially true over parts of the former Soviet Union (FSU—Abakumova *et al.*, 1996; Groisman *et al.*, 1996), Fennoscandia (Kaas and Frich, 1995; Tuomenvirta *et al.*, 1998), and Switzerland, where Rebetez and Beniston (1998) found that a 20th-century decrease in DTR of about 1.5°C was strongly correlated with increased cloudiness, except at high elevations. In Italy (Brunetti *et al.,* 2000), daytime warming is higher than nighttime temperature rise, with a consequent increase in DTR.

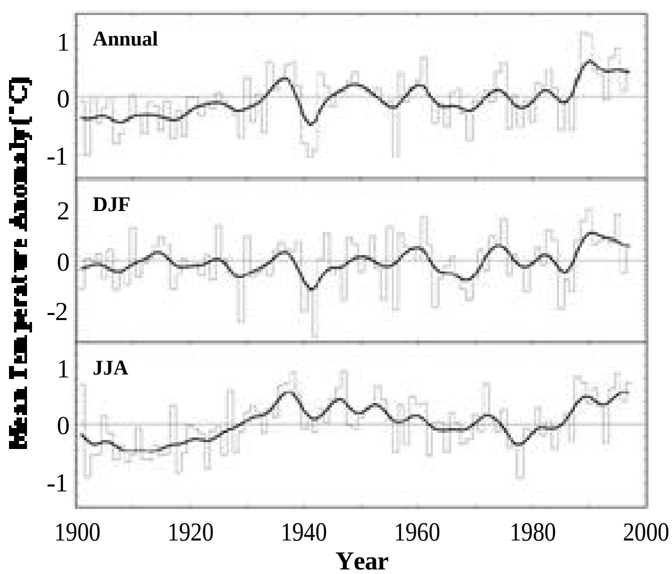

Figure 13-1: European annual mean temperature anomalies over land, 1901–1995, for the region 35°N to 75°N and 30°W to 50°E, with respect to 1961–90 mean. 10-pt filter applied. Data from IPCC Data Distribution Centre.

13.1.3.2. Precipitation

Trends in annual precipitation differ between northern Europe (wetting) and southern Europe (drying), reflecting a wider hemispheric pattern of contrasting zonal-mean precipitation trends between high and low latitudes (Dai *et al.*, 1997; Hulme *et al.*, 1998). Precipitation over northern Europe has increased by 10–40% in the 20th century, whereas some parts of southern Europe have dried by as much as 20% (see Figure 13-2). Romero *et al.* (1999) show that the numbers of days with precipitation over the Spanish southern coast and the Pyrenees region have decreased by 50 and 30%, respectively, in 1964–1993. In Italy, total precipitation in the 20th century has decreased by about 5% in the north and by about 15% in the south (Buffoni *et al*., 1999; Brunetti *et al*., 2001). Analysis of moisture extremes over Europe, using the Palmer Drought Severity Index (PDSI—Briffa *et al.*, 1994) showed strong decadal-scale variability in drought frequency; the 1940s and early 1950s experienced widespread and severe droughts—a pattern repeated in 1989 and 1990.

13.1.3.3. Extreme Events

Analyses of trends in extreme weather events in Europe generally have been limited to national studies, making it difficult to provide a continent-wide overview of changes in hot/cold day frequencies, precipitation intensities, or gale frequencies. Gruza *et al.* (1999) analyzed data over the whole of Russia, the western third of which falls into our definition of Europe, and found a slight increase over the 20th century in the Climate Extremes Index (CEI), which combines daily temperature, daily precipitation, and drought extremes. Analysis of 85 long-term maximum 1-day precipitation records in the Nordic countries indicates that there is a maximum in the 1930s and a tendency of increasing values during the 1980s and 1990s—decades with relatively high regional summer temperatures. In western Norway, the past 2 decades have been exceptional, with substantial increases in orographic precipitation during autumn, winter, and spring (Førland *et al.*, 1998). Elsewhere, daily precipitation intensities over the UK have increased in winter over recent decades (Osborn *et al.*, 1999), although not in other seasons. This increase in UK winter precipitation intensities has been paralleled by a marked decrease in the frequency of cold winter days in the UK (Jones *et al.*, 1999). Changes in storminess over the northeast Atlantic have been analyzed by Schmidt *et al.* (1998) and WASA (1998); they show that although storminess has increased in recent decades, storm intensities are no higher than they were early in the 20th century. Wave heights around the shores of northwest Europe also show large decadal variability, but no long-term trends emerge.

13.1.3.4. North Atlantic Oscillation

One important cause for interannual and perhaps interdecadal climate variability in Europe, particularly in winter, is the North Atlantic Oscillation (NAO). NAO is a measure of the strength of the westerly flow over the North Atlantic; records go back to the early 19th century (Jones *et al.*, 1997). Over the past 4 decades, the NAO pattern gradually has altered from the most extreme and persistent negative phase in the 1960s to the most extreme positive phase during the late 1980s and early 1990s—a trend that has been responsible for relatively mild and wet winters during the latter period over much of northwest Europe (Hurrell and van Loon, 1997) and can help explain the observed narrowing in DTR (Tuomenvirta *et al.*, 1998). Following its long period of amplification, the NAO index underwent a sharp decrease to a short-lived minimum in the winter of 1995–1996, with radical recognizable changes in the North Atlantic. It should be noted that the NAO appears to exert significant control on the export of ice and freshwater from the Arctic to the open Atlantic (WCRP, 1998). Since that temporary minimum, a recovery toward positive values of the NAO has been observed. NAO certainly is a more important influence on European climate than the El Niño-Southern Oscillation (ENSO), although several studies have explored the influence of ENSO on European precipitation variability, and links between NAO and ENSO are being sought. Evidence for such an influence is weak and shows phase differences through the continent (Fraedrich and Müller, 1992; Fraedrich *et al.*, 1992; Rodo *et al.*, 1997; Price *et al.*, 1998).

13.1.4. Key Sensitivities to Climate and Weather Now

The response of human activities and the natural environment to current weather perturbations provides a guide to where critical sensitivities to future climate change may lie. Even if adaptation may modify the response, analysis of present-day sensitivities helps us understand the likely impact of future climate changes on our environment and lifestyle.

The principal sensitivities in Europe to current climate and weather conditions are to:

- Extreme seasons
  - Exceptionally hot, dry summers
  - Mild winters
- Short-duration hazards
  - Windstorm (possibly associated with tidal surges)
  - Heavy rain leading to river-valley flooding and flash floods
- Slow, long-term change
  - Coastal squeeze.

Sensitivities vary across Europe as a result of differences in climate and topography, as well as the socioeconomic environment, but all of Europe is sensitive to the foregoing anomalous conditions.

13.1.4.1. Extreme Seasons

13.1.4.1.1. Exceptionally hot, dry summers

Extremely hot and dry summers were experienced in 1995 throughout much of western Europe (Palutikof *et al*., 1997)

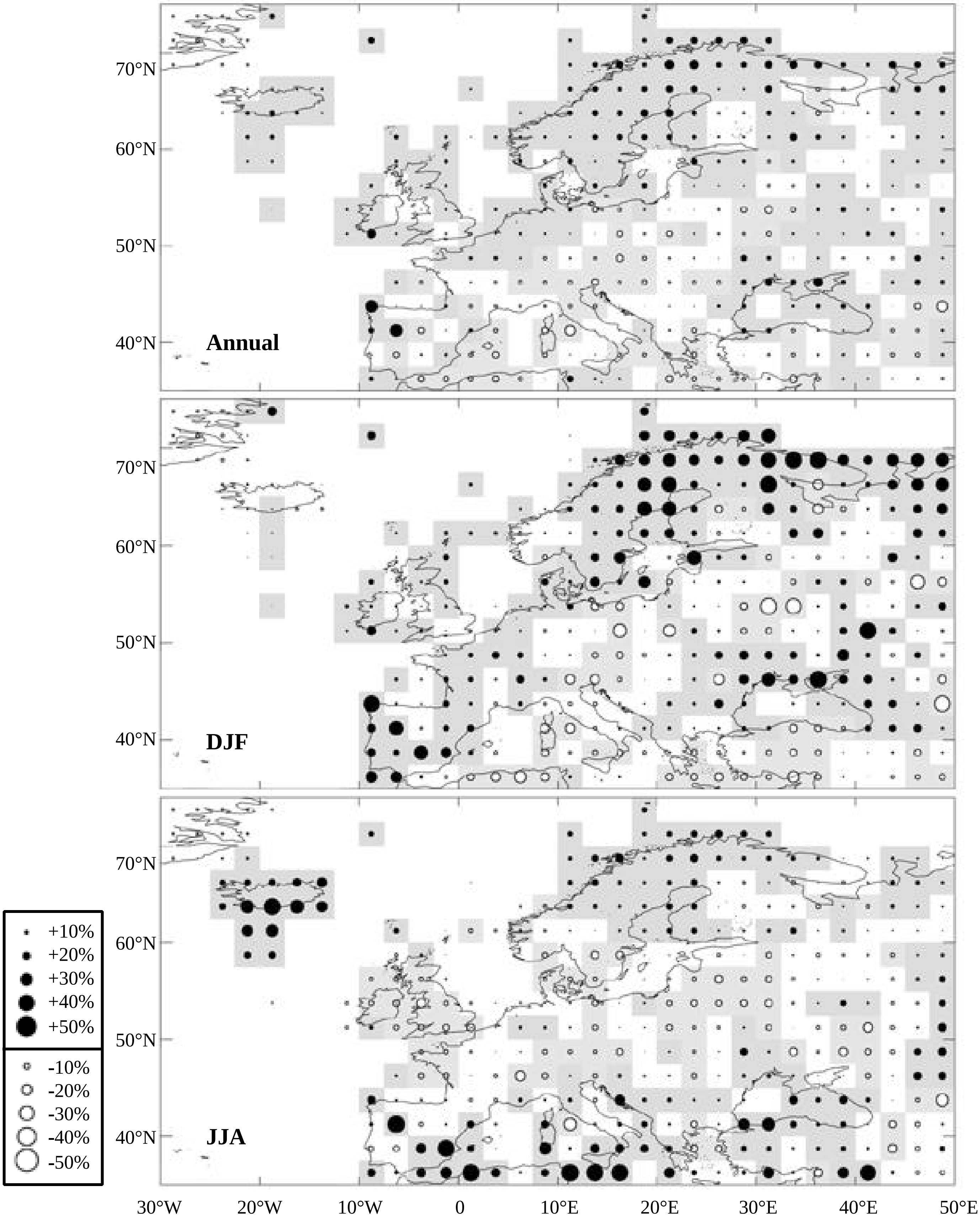

Figure 13-2: Trends in annual (top), winter (middle), and summer (bottom) precipitation expressed as % per century and calculated on 2.5° grid. Black circles denote wetting and white circles denote drying. Magnitude of trend is related to circle size. Shaded trends are significant at 90% (data from New *et al*., 1999).

and in 1992 in CEE (Schellnhuber *et al*., 1994). Summer drought conditions can have a devastating impact on the natural environment, particularly by reducing the availability of water for flora and fauna. Pollution levels may rise to high levels in the subsiding anticyclonic air, with add-on effects for human health in terms of increased numbers of asthma attacks and associated hospitalizations. High water temperatures often lead to algal blooms, which may make water bodies unusable for recreational purposes.

Agriculture and water supply are the two economic sectors that may be most severely affected by exceptional heat and drought in summer. Large proportions of the working populations in Mediterranean countries are engaged in agriculture, and even in “normal” years water shortages may be a limiting factor. These countries, therefore, appear to be more vulnerable to exceptional summer weather. An increased frequency of hot, dry summers is likely to reduce tree growth and affect timber yield and quality. Reduced tree vigor often favors outbreaks of pests and pathogens, and hot and dry conditions trigger wildfire.

13.1.4.1.2. Mild winters

Milder winters exert a major impact on the natural environment. Overwintering of species is more successful. However, failure to kill off pests and diseases that prey on wildlife, as well as failure to cull weaker members of the species—which then compete for food in the following springs and summers—in the end may be counterproductive. Cannell and Pitcairn (1993) show that during two mild winters in the UK, various life events occurred earlier—for example, insects and other animals moved about and fed more actively, causing widespread aphid damage on oak and mite damage on lime. Milder winters can affect fulfillment of chilling requirements in some plant species, which would have an impact on the formation of leaf and flower buds (e.g., Murray *et al.*, 1989). This could lead to regeneration failure; some susceptible species are common across much of Europe today (e.g., *Picea abies*) (Sykes and Prentice, 1996).

The skiing industry in Europe is vulnerable to variations in snowfall—that is, too little or too much snow. Many European ski resorts have suffered severe shortfalls in earnings when snow cover was not sufficiently deep during Christmas and winter school holidays. If temperatures remain below freezing, a more active hydrological cycle might lead to more episodes of heavy snowfall; the winter of 1998–1999 is a good proxy for this situation. Although the number of cold spells generally has decreased over the past few decades, cold spells still have a range of impacts on agriculture, settlements, the built environment, and transport.

13.1.4.2. Short-Duration Hazards

Severe windstorms affected Europe in the 1990s. The January 1990 storm (Daria) caused insured losses of about US$5.7 billion (at 1997 prices) and 95 deaths; in the following month, the storm of 26 February (Vivian) caused a further US$3.9 billion in insured losses (Swiss Re, 1998) and 64 deaths. The UK experienced a severe windstorm at Christmas 1997, causing 13 deaths and losses of US$500 million (Swiss Re, 1998).

The major impact of windstorm on the natural environment is on trees, woodland, and forest. It is estimated that 15 million trees (5 months’ production of coniferous wood and 2 years’ production of broadleaf timber production—see Quine, 1988) were blown down in the UK during the October 1987 storm.

Windstorm associated with tidal surge is a particularly deadly combination for low-lying coastal areas, as epitomized by the event of 1953. Severe northerly winds combined with an exceptionally high spring tide caused overtopping in The Netherlands and much of East Anglia, resulting in more than 2,000 deaths. Since then the policy has been to keep the sea out at all costs, and in fact several storm surges of similar size have occurred with no loss of life.

Several devastating river floods, of high severity, occurred in Europe in the 1990s (Kundzewicz and Takeuchi, 1999). Among the flood events to hit the headlines was the Odra flood in the summer of 1997, during which historic flow records were broken. The deluge caused more than 100 deaths and economic damage in excess of US$5 billion (Kundzewicz *et al*., 1999).

13.1.4.3. Coastal Squeeze

Coastal squeeze occurs when coastal habitats are “squeezed” between rising sea level and fixed hard defenses (Bijlsma *et al.*, 1996). It is occurring in most northwest European countries, and it already is a coastal management issue (Rigg *et al.*, 1997). It is considered in more detail in Sections 13.2.1.3 and 13.3.5.

13.1.5. Climate Scenarios for the Future

Most of the impact studies evaluated in this chapter have attempted to characterize the future climate of a study region by using climate change scenarios. General reviews of the development and application of climate change scenarios are provided in Chapter 3 and in TAR WGI Chapter 13. It also should be noted that many recent impact studies in Europe have followed published guidelines concerning the use of scenarios (Carter *et al.*, 1994; USCSP, 1994; Smith and Hulme, 1998). This review offers a brief summary first of the types of scenario information provided in European impact assessments and second of research to improve this information.

13.1.5.1. Scenario Provision

One or more of three broad classes of climate change scenario generally have been adopted: synthetic scenarios, palaeoclimatic analogs, and scenarios that are based on outputs from GCMs.

The impacts of these scenario changes conventionally are assessed relative to conditions under a reference or "baseline" climate that represents present-day conditions (commonly 1961–1990).

Synthetic or incremental scenarios describe techniques whereby particular climatic (or related) elements are changed by a realistic but arbitrary amount, often according to an interpretation of climate model simulations for a region. They are simple to use and can offer a useful tool for exploring the sensitivity of an exposure unit to a plausible range of climatic variations. They commonly are applied prior to the adoption of more detailed GCM-based scenarios. For example, national assessments in CEE conducted as part of the U.S. Country Studies Program adopted adjustments of present-day temperatures by +1, +2, +3, and +4°C and baseline precipitation by ±5, +10, +15, and +20% (e.g., Smith and Pitts, 1997; Kalvová, 1995; Alexandrov, 1997).

Box 13-1. Some Key Features of Climate Scenarios for Europe

Temperature

- Annual temperatures over Europe warm at a rate of between 0.1 and 0.4°C per decade. This warming of future annual climate is greatest over southern Europe (Spain, Italy, Greece) and northeast Europe (Finland, western Russia) and least along the Atlantic coastline of the continent.
- In winter, the continential interior of eastern Europe and western Russia warms more rapidly (0.15–0.6°C per decade) than elsewhere. In summer, the pattern of warming displays a strong south-to-north gradient, with southern Europe warming at a rate of between 0.2 and 0.6°C per decade and northern Europe warming between 0.08 and 0.3°C per decade.
- Winters currently classified as cold (occurring 1 year in 10 during 1961–1990) become much rarer by the 2020s and disappear almost entirely by the 2080s. In contrast, hot summers become much more frequent. Under the 2080s scenario, nearly every summer is hotter than the 1-in-10 hot summer as defined under the present climate.
- The agreement between models about these future temperature changes is greatest over southern Europe in winter. In summer, however, this region shows the greatest level of disagreement between model simulations. All model simulations show warming in the future across the whole of Europe and in all seasons.

Precipitation

- The general pattern of future change in annual precipitation over Europe is for widespread increases in northern Europe (between +1 and +2% per decade), smaller decreases across southern Europe (maximum –1% per decade), and small or ambiguous changes in central Europe (France, Germany, Hungary, Belarus).
- There is a marked contrast between winter and summer patterns of precipitation change. Most of Europe gets wetter in the winter season (between +1 and +4% per decade); the exception is the Balkans and Turkey, where winters become drier. In summer, there is a strong gradient of change between northern Europe (wetting of as much as +2% per decade) and southern Europe (drying of as much as –5% per decade).
- The areas, however, where these changes are greater than the 2-standard deviation estimate of natural 30-year time scale climate variability are limited to the later periods (2050s and 2080s) and to the scenarios with the larger rates of global warming (B2, A1, and A2).
- Only for the A2-high scenario are there substantial areas in Europe (Fennoscandia and northwest Europe) where precipitation changes by the 2020s are larger than what might occur as a result of natural climate variability. Even for this scenario with rapid global warming, not all regions in Europe have well-defined precipitation signals from GHG-induced climate change by the 2080s.
- The intermodel range of seasonal precipitation changes generally is larger than the median change, implying that sign differences frequently exist between the precipitation changes simulated by different climate models. The largest intermodel differences tend to occur in southern and northern Europe. Intermodel differences are smallest across much of central Europe.

Weather Extremes

- The scenarios do not explicitly quantify changes in daily weather extremes. However, it is very likely that frequencies and intensities of summer heat waves will increase throughout Europe; likely that intense precipitation events will increase in frequency, especially in winter, and that summer drought risk will increase in central and southern Europe; and possible that gale frequencies will increase.

Sea Level

- Global-mean sea level rises by the 2050s by 13–68 cm. These estimates make no allowance for natural vertical land movements. Owing to tectonic adjustments following the last glaciation, there are regional differences across Europe in the natural rates of relative sea-level change.

Scenarios based on GCM simulations are the most widely adopted in impact studies reported from Europe. Some of these studies employ scenarios that are based on equilibrium $2xCO_2$ model simulations that were conducted during the 1980s (e.g., Smith *et al.*, 1996; Tarand and Kallaste, 1998). The performance of some of these GCMs at simulating current climate over Europe was examined by Smith and Pitts (1997) and Kalvová and Nemesová (1997). Among the models considered, they

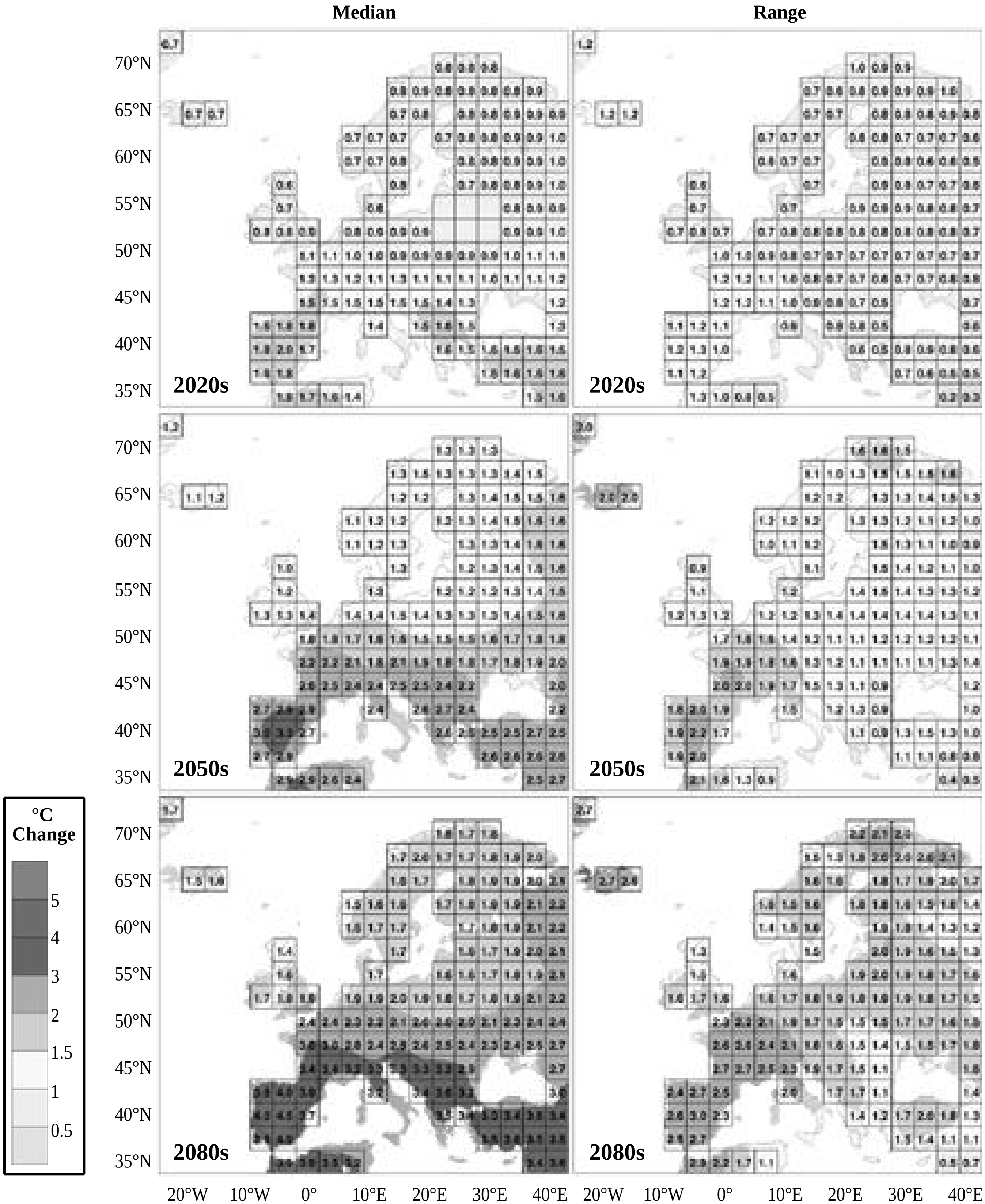

Figure 13-3: ACACIA B2 summer scenario maps (B2-mid, JJA) for mean temperature.

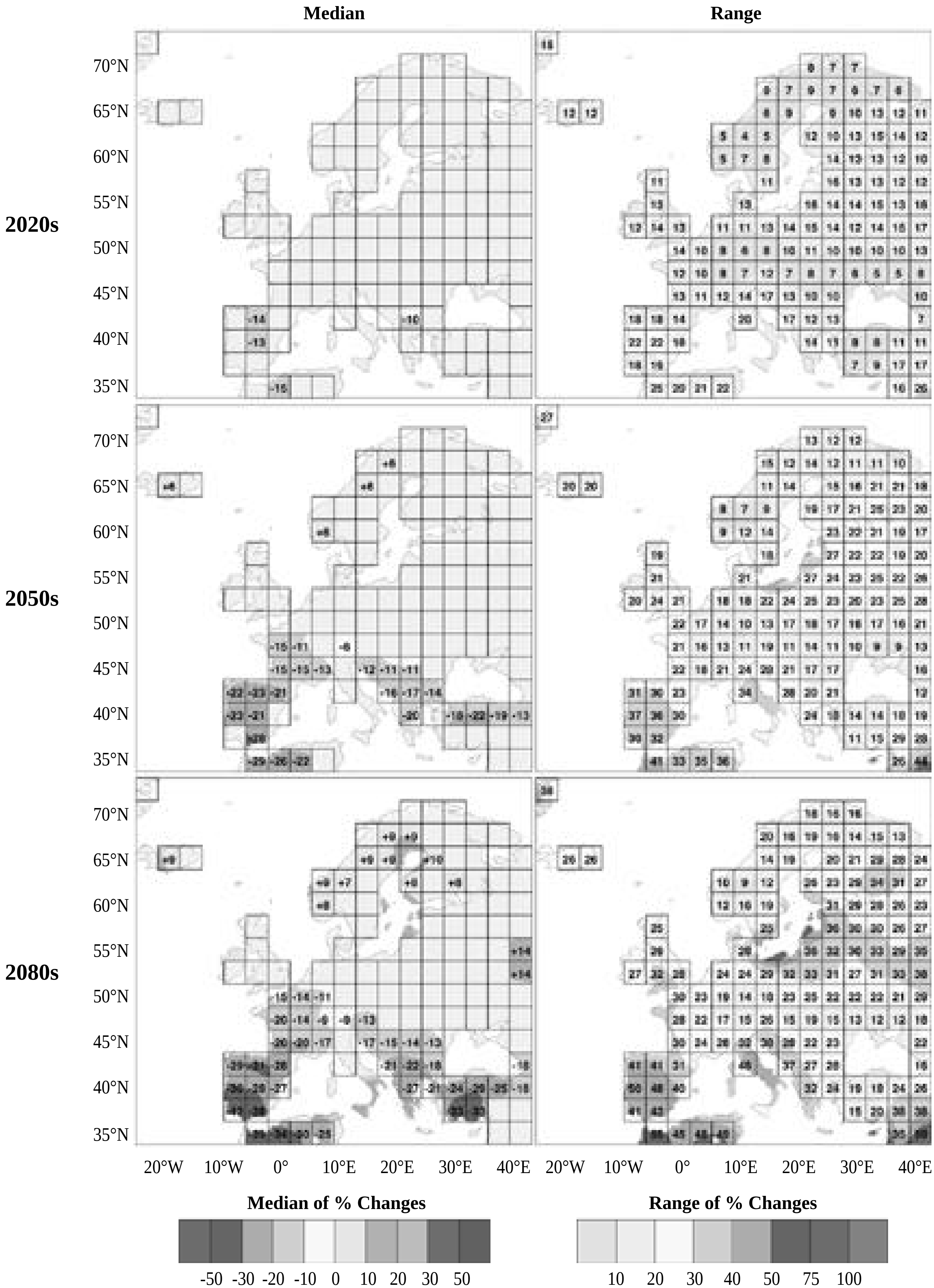

Figure 13-4: ACACIAB2 summer scenario maps (B2-mid, JJA) for precipitation.

found that the Goddard Institute for Space Studies (GISS) and Canadian Centre for Climate Modeling and Analysis (CCCM) models best simulated current temperature, whereas the GISS and UK89 models best simulated precipitation in northern regions and the CCCM model best simulated precipitation in southern regions.

Scenarios from the earliest transient-response experiments with coupled atmosphere-ocean GCMs (AOGCMs), which ignored historical greenhouse gas (GHG) forcing, were adopted in several studies that used direct model outputs (e.g., Harrison *et al.,* 1995b) or modified the outputs to account for historical forcing, using simple climate models (e.g., Carter *et al.,* 1996a; UK Department of the Environment, 1996). Scenarios from transient-response experiments that explicitly account for historical forcing have been adopted in the most recent impact studies (e.g., Arnell, 1999; Harrison and Butterfield, 1999; Hulme *et al.,* 1999). Some of these scenarios also incorporate aerosol effects, ensemble simulations, and multidecadal climatic variability. Many of these GCM results are lodged with the IPCC Data Distribution Centre (DDC) and were used in developing the European scenarios of A Concerted Action Towards A Comprehensive Climate Impacts and Adaptations Assessment for the European Union (ACACIA).

13.1.5.2. Scenarios for Europe

The climate change scenarios summarized here originally were prepared for the European ACACIA project and subsequently developed further for the IPCC (Hulme and Carter, 2000). The method by which they were developed is briefly described in Chapter 3 of this volume and more fully in Carter *et al.* (2000). These scenarios define a range of future European climates that embrace some of the major uncertainties in future climate prediction. The scenarios were placed in the context of model estimates of the natural variability of European climate. The baseline period selected was 1961–1990; changes in mean 30-year climates were calculated for the periods centered on the 2020s (2010–2039), the 2050s (2040–2069), and the 2080s (2070–2099). Each climate scenario is based on one of the four preliminary SRES98 marker emissions scenarios from the IPCC *Special Report on Emissions Scenarios* (SRES) (Nakicenovic, 2000).

For each scenario, season, variable, and time-slice, two maps were constructed (see Figures 13-3 and 13-4). One map shows the median change from the sample of eight standardized and scaled GCM responses; the other map shows the absolute range of these eight responses. The idea of signal-to-noise ratios in these regional responses was introduced by comparing median scaled-GCM changes against an estimate of natural multidecadal variability derived from the 1,400-year unforced climate simulation made with the HadCM2 model (Stott and Tett, 1998). In the maps showing median changes, only values *exceeding* the 2-standard deviation estimate of natural multidecadal variability are plotted. Figures 13-3 and 13-4 show an example of this information for the B2-mid scenario for summer temperature and precipitation. A complete set of illustrations appears in the report of the European ACACIA project (Hulme and Carter, 2000).

To condense this scenario information further, national-scale summary graphs for each European country or groups of countries have been calculated (see Figure 13-5 for an example covering Spain, Sweden, and Poland). Each country graph shows—for either winter or summer and for either the 2020s, the 2050s, or the 2080s—the distribution of mean changes in mean temperature and precipitation for each GCM simulation and for each scenario. As with the maps, these changes are compared with the natural multidecadal variability of temperature and precipitation extracted from the HadCM2 1,400-year unforced simulation. These graphs provide a quick assessment at a national scale of the likely range and significance of future climate change and the extent to which different GCMs agree with regard to their regional response to a given magnitude of global warming.

A contrasting future climate for Europe—the result of a rapid, nonlinear response of the climate system—has been suggested. This involves an abrupt collapse of the thermohaline circulation in the North Atlantic and consequent cooling in Europe at least for the first half of the 21st century (e.g., Alcamo *et al.,* 1994). Although this event has not been ruled out on theoretical grounds (see TAR WGI Chapter 11), it has not been simulated by any AOGCM (see TAR WGI Chapter 9) and therefore has not been included in this assessment.

13.1.6. Socioeconomic Scenarios for Europe

The four socioeconomic global futures (or SRES scenarios) described in Chapter 3 of this assessment have been characterized for Europe in the European ACACIA study (Jordan *et al.,* 2000), and are summarized below:

- Under a "World Market" (A1) scenario, the world becomes increasingly globalized, and materialist-consumerist social values predominate. Global societal values are primarily technocentric and short-termist. Nature therefore is assumed to be largely resilient to human stress. The emphasis is on pursuing economic growth in the narrow sense rather than sustainable development. Although rising income levels will make everyone in Europe richer, the poorest will gain relatively little. The EU functions as a single interconnected market, functionally integrated with other regional markets (e.g., in Asia and North America).
- Under a "Global Sustainability" (B1) scenario, Europe is run along more communitarian lines and within environmental resource limits. There is a strong emphasis on finding international solutions to globally interconnected problems. Thus, EU member states pool more and more of their sovereignty to address common environmental problems, the causes of which are considered to lie in the basic structure of

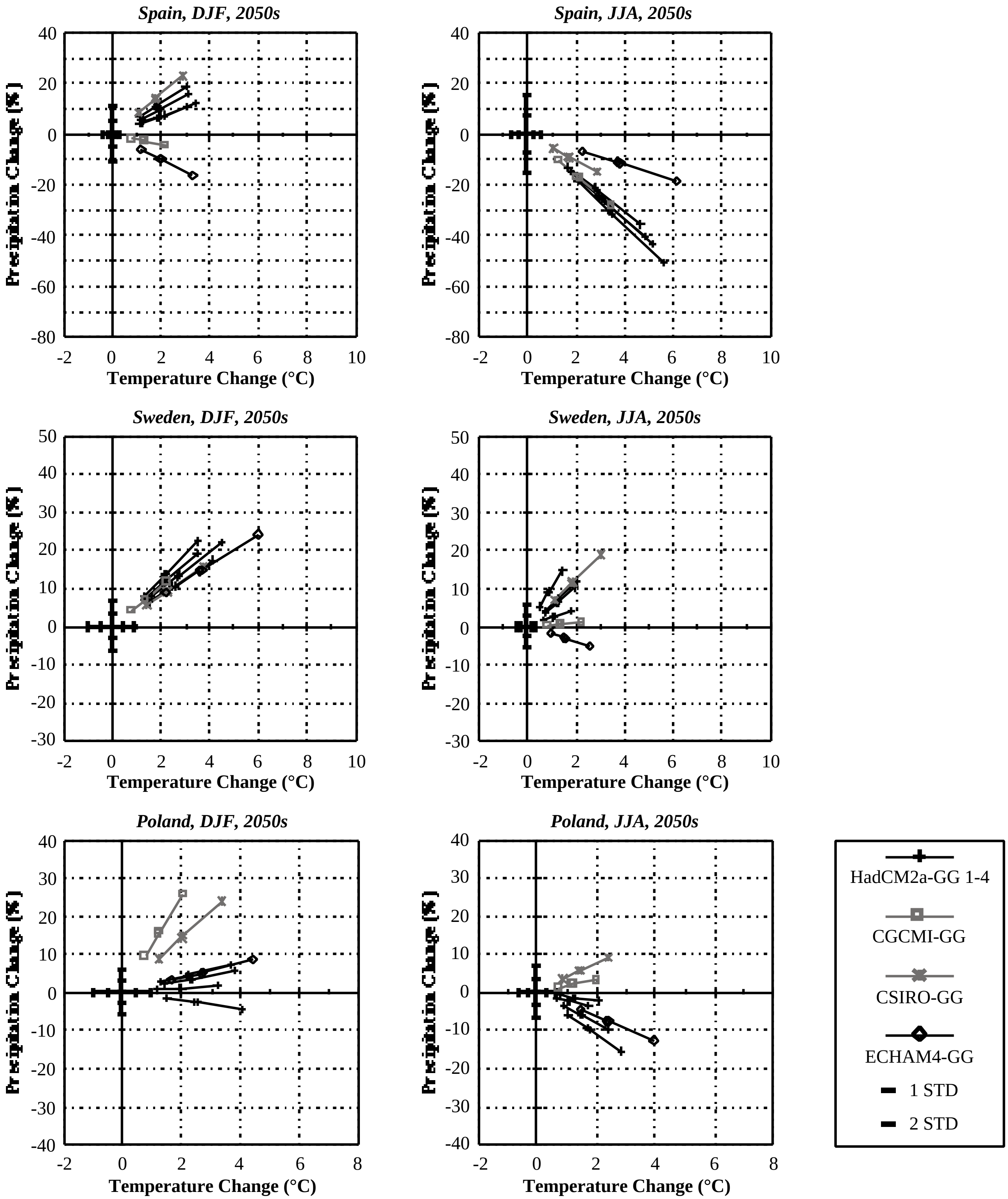

Figure 13-5: Scatter plot depicting scaled outputs of mean winter (left panels) and summer (right panels) temperature and precipitation change over land grid boxes representing Spain (top), Sweden (middle), and Poland (bottom) from each of seven GCM simulations (GFDL simulations are not shown because they extend only to 2025). Lines connect four points for each GCM simulation, each point representing standardized regional changes in climate from the GCM, linearly scaled according to global warming from each of the four ACACIAscenarios. The order of points along a line from the origin is the same for all plots: B1-low, B2-mid, A1-mid, A2-high. Also plotted are 1 and 2 standard deviation limits from 1,400-year HadCM2 unforced simulation, which is used to indicate natural multi-decadal variability.

society. The role of international institutions, including the EU, will extend from simply regulating environmental problems to tackling social inequality and social exclusion through adoption of social programs.

- In a "Provincial Enterprise" (A2) scenario, Europe is much more heterogeneous. Increasingly, the organization of society is dictated by short-term consumerist values. More policy decisions are taken at a national and subnational level. Europe adopts more protectionist economic and trade policies, which constrain innovation and stifle economic development, particularly in developing countries. Growth in global GDP is more modest than under the A1 scenario, and global inequality grows. Declining equity within and between member states of the EU produces tension and social exclusion. This typifies the uneasy tension in this scenario between the simultaneous desire for "free markets" (consumerist values) and protection of national state sovereignty. Politicians prioritize demands such as protecting the national economy and meeting short-term consumer demands for growth over environmental quality.
- In a "Local Sustainability" (B2) scenario, Europe is more committed to solving environmental problems by applying solutions that are attuned to local needs and circumstances. Thus, the dominant value system is more communitarian and ecocentric in nature, with greater commitment to longer term, strategic planning. In a sense, the shift in governance down to the local level accords with the principle of *subsidiarity*. National governments therefore are left to perform residual functions that cannot be undertaken at the subnational level. Small firms thrive under these conditions, whereas multinationals struggle to realign themselves to local needs. Overall, the world (including Europe) is more heterogeneous. Because of the lack of coordinated regional action, however, relative inequality may increase as local problems receive higher priority than those in other regions. Significantly, the environment benefits under this scenario, but not nearly as much as under B1 because of the limited extent of spatial coordination.

13.2. Key Regional Concerns

13.2.1. Water and Land Resources

13.2.1.1. Water Resources

Europe has a very diverse hydrological background, reflecting its varied climate and topography. In the south there is very significant variation in flow through the year, with long, dry summers. To the west there is less extreme variation, and in catchments underlain by absorbent aquifers flows remain reasonably constant through the year. In the north and east, much precipitation falls as snow, so much flow occurs during the spring snowmelt period. Major rivers such as the Rhine, Rhone, Po, and Danube distribute water from the "water tower" of the Alps. Superimposed on this varied hydrological base is a wide variety of water uses, pressures, and management approaches. Asuccession of floods and droughts has illustrated Europe's vulnerability to hydrological extremes. There are many other water-related pressures on Europe's environment, however (see the Dobris Assessment—Stanners and Bourdeau, 1995), such as increasing demand for water, particularly in the south, and subsequent increases in abstractions. River ecosystems and wetlands are increasingly at risk. The quality of Europe's rivers, lakes, and groundwater is being threatened by the discharge of sewage and industrial waste (often a legacy from past industrial development) and by excessive application of pesticides and fertilizers. At the same time, the institutional aspects of water resources management are changing. There is a shift in many countries from "supply-side" solutions to a "demand-side" approach, aimed at reducing demand for water or exposure to risk. Water managers in many European countries have adopted (at least in principle) a sustainable approach, and forthcoming EU directives are likely to encourage this further. Environmental demands are being taken increasingly seriously across most of Europe. Climate change adds another set of potential pressures on European water resources and their management.

13.2.1.1.1. Changes in hydrological cycle

Climate and land-use change influence the structure of the water balance (Ryszkowski and Kedziora, 1987; Ryszkowski *et al*., 1990; Olejnik and Kedziora, 1991). Calculations at the European scale (Arnell, 1999) indicate that under most climate change scenarios, northern Europe would see an increase in annual average streamflow, but southern Europe would experience a reduction in streamflow. In much of mid-latitude Europe, annual runoff would decrease or increase by about 10% by the 2050s, but the change resulting from climate may be smaller than "natural" multidecadal variability in runoff. To the south and north, it may be substantially larger (Hulme *et al*., 1999). Table 13-1 lists catchment-scale studies into potential hydrological changes in Europe that have been conducted since the IPCC's Second Assessment Report (SAR).

The consequences of climate change for the variation of flow through the year vary across Europe. In Mediterranean regions, climate change is likely to exaggerate considerably the range in flows between winter and summer. In maritime western Europe, the range also is likely to increase, but to a lesser extent. In more continental and upland areas, where snowfall makes up a large proportion of winter precipitation, a rise in temperature would mean that more precipitation falls as rain and therefore that winter runoff increases and spring snowmelt decreases. The timing of streamflow therefore alters significantly. Further east and at higher altitudes, most of the precipitation continues to fall as snow, so the distribution of flow through the year is altered little (Arnell, 1999). The substantial projected change in flow regime resulting from reduction in snowfall and snowmelt across large parts of CEE has been noted widely

Table 13-1: Catchment-scale studies into effects of climate change on runoff regimes in Europe (since SAR).

Country/Region	Reference
Albania	Bruci and Bicaj (1998)
Austria	Behr (1998)
Belgium	Gellens and Roulin (1998), Gellens *et al.* (1998)
Czech Republic	Dvorak *et al*. (1997), Hladny *et al*. (1997), Buchtele *et al*. (1998)
Danube	Starosolszky and Gauzer (1998)
Denmark	See Nordic region
Estonia	Bálint and Butina (1997), Jaagus (1998), Jarvet (1998), Roosaare (1998)
Finland	Vehviläinen and Huttunen (1997); see Nordic region
France	Mandelkern *et al*. (1998)
Germany	Daamen *et al*. (1998)
Greece	Panagoulia and Dimou (1996)
Hungary	Mika *et al*. (1997)
Latvia	Butina *et al*. (1998), Jansons and Butina (1998)
Nordic region	Sælthun *et al*. (1998)
Norway	See *Nordic region*
Poland	Kaczmarek *et al*. (1997)
Rhine basin	Grabs (1997)
Romania	Stanescu *et al*. (1998)
Russia	Kuchment (1998)
Slovakia	Pekárová (1996), Szolgay (1997), Hlavcová and Cunderlík (1998), Petrovic (1998), Hlavcová *et al*. (1999)
Spain	Avila *et al*. (1996)
Sweden	Xu (1998); see Nordic region
Switzerland	Seidel *et al*. (1998)
United Kingdom	Arnell (1996), Arnell and Reynard (1996), Reynard *et al*. (1998), Roberts (1998)

(e.g., Hladny *et al.*, 1996; Kasparék, 1998; Hlavcova and Cunderlik, 1998; Starosolszky and Gauzer, 1998).

Low-flow frequency generally will increase across most of Europe (Arnell, 1999), although in some areas where the minimum occurs during winter the absolute magnitude of low flows may increase because winter runoff increases: The season of lowest flow shifts toward summer. An implication of simulated changes in streamflow is that riverine flood risk generally would increase across much of Europe and that in some areas, the time of greatest risk would move from spring to winter. Effects on groundwater recharge (a major resource for many Europeans) are less clear because the general increase in winter rainfall may be offset by a reduction in the recharge season. Studies in the UK (Arnell and Reynard, 1999) and Estonia (Jarvet, 1998) indicate that groundwater recharge could be increased by climate change.

Implications of climate change for river water quality have been less well studied, but an increase in water temperature and widespread reductions in flow during summer are likely to lead to deterioration in many determinants of water quality (particularly dissolved oxygen concentrations). Jansons and Butina (1998) estimate nitrate and phosphate loads in a catchment in Latvia from streamflow; they use the relationships to infer an increase in nitrate and phosphate loads in winter (when flow increased) and a decrease in spring. Their model, however, did not account for possible temperature-related effects on nitrate and phosphate concentrations. Higher water temperatures are likely to increase the risk of blue-green algal blooms in rivers and lakes (e.g., Zalewski and Wagner, 1995).

13.2.1.1.2. Water management

The impacts of climate change on European water resources and their management depend not only on the change in hydrology but also (perhaps more particularly) on characteristics of the water management system. In general terms, the more stressed the system is under current conditions, the more sensitive it will be to climate change. Table 13-2 summarizes the key potential impacts on European water resources. These impacts should be considered against the background of other pressures and drivers on European water. Most of the potential impacts are self-explanatory.

Changes in the water resource base affect many sectors within Europe, including agriculture, industry, transport, power generation, the built environment, and ecosystems. Similarly, changes in many of these sectors will affect hydrology and the resource base. Changes in agricultural practices resulting from climate change, for example, will affect volumes and, more likely, quality of streamflow.

In many European countries, industrial water use has declined as a result of legislation, environmental protection, and economic change. The warmer climate may lead to significant increase in water demands in southern Europe—leading to possible overexploitation of groundwater resources, decrease of baseflow, and environmental degradation. Climate change is but one of the pressures facing European water managers. They will be played out against varying socioeconomic backgrounds, political demands for environmental improvements, and new trends in integrated water management. More detail on this and the foregoing conclusions appear in the water chapter of the European ACACIA report (Arnell, 2000).

13.2.1.2. Soils and Land Resources

Climate change will impact directly and, through land-use change, indirectly on a wide range of soil processes and properties that will determine the future ability of land to fulfill key functions that are important for all terrestrial ecosystems, as well as several socioeconomic activities, that underpin the well-being of society. The following subsections summarize key effects. Further information is summarized in the section on soils in the European ACACIAreport (Rounsevell and Imeson, 2000).

***Table 13-2**: Key impacts of climate change on European water resources.*

Sector	Potential Impacts	Sample Reference
Public water supply	– Reduction in reliability of direct river abstractions – Change in reservoir reliability (dependent on seasonal change in flows) – Reduction in reliability of water distribution network	Kaczmarek *et al*. (1996), Dvorak *et al*. (1997)
Demand for public water supplies	– Increasing domestic demand for washing and out-of-house use	Herrington (1996)
Water for irrigation	– Increasing demand – Reduced availability of summer water – Reduced reliability of reservoir systems	Kos (1993), Alexandrov (1998)
Power generation	– Change in hydropower potential through the year – Altered potential for run-of-river power – Reduced availability of cooling water in summer	Grabs (1997), Sælthun *et al*. (1998)
Navigation	– Change (reduction?) in navigation opportunities along major rivers	Grabs (1997)
Pollution risk and control	– Increased risk of pollution as a result of altered sensitivity of river system	Mänder and Kull (1998)
Flood risk	– Increased risk of loss and damage – Increased urban flooding from overflow of storm drains	Grabs (1997)
Environmental impacts	– Change in river and wetland habitats	

13.2.1.2.1. Soil physical properties

Soil water contents respond rapidly to variability in the amounts and distribution of precipitation or the addition of irrigation. Temperature changes affect soil water by influencing evapotranspiration, and plant water use is further influenced by elevated CO_2 concentrations, leading to lower stomatal conductance and increased leaf photosynthetic rates (Kirschbaum *et al.*, 1996). Soil water contents are highly variable in space (Rounsevell *et al*., 1999), so it is difficult to generalize about specific climate impacts.

Climate change can be expected to modify soil structure through the physical processes of shrink-swell (caused by wetting and drying) and freeze-thaw, as well as through changes in soil organic matter (SOM) contents (Carter and Stewart, 1996). Compaction of soils results from inappropriate timing of tillage operations during periods when the soil is too wet to be workable. Soil workability has a strong influence on the distribution and management of arable crops in temperate parts of Europe (Rounsevell, 1993; Rounsevell and Jones, 1993). Therefore, wet areas with heavy soils could benefit from climate change (MacDonald *et al*., 1994; Rounsevell and Brignall, 1994). In a similar way, grassland systems can suffer poaching by grazing livestock (i.e., damage caused by animal hooves) (Harrod, 1979). Thus, drier soil conditions for longer periods of the year would affect the distribution of intensive agricultural grassland in temperate Europe (Rounsevell *et al*., 1996a) and may result in intensification of currently wet upland grazing areas.

Soils with large clay contents shrink as they dry and swell when they become wet again, forming large cracks and fissures. Drier climatic conditions will increase the frequency and size of crack formation in soils, especially those in temperate regions of Europe, which currently do not reach their full shrinkage potential (Climate Change Impacts Review Group, 1991, 1996). Soils that shrink and swell cause damage to building foundations through subsidence, creating a problem for householders and the housing insurance industry (Building Research Establishment, 1990). Crack formation also results in more rapid and direct movement of water and solutes from surface soil to permeable substrata or drainage installations through bypass flow (Armstrong *et al.*, 1994; Flurry *et al.*, 1994). This will decrease the filtering function of soil and increase the possibility of nutrient losses and water pollution (Rounsevell *et al*., 1999).

13.2.1.2.2. Land degradation processes

Accumulation of salts in soils (salinization) results from capillary movement and dispersion of saline water because evapotranspiration is greater than precipitation and irrigation

(Vàrallyay, 1994). Such conditions, which are widespread throughout the warmer and drier regions of southern Europe, will be exacerbated by temperature rise coupled with reduced rainfall. Climate change also will increase flood incidence and salinity along coastal regions, through the influence of sea-level rise (Nicholls, 2000).

A decrease in precipitation and/or increase in temperature increases oxidation and loss of volume in lowland peat soils that are used for agriculture. It has been suggested that under climate change, the volume of peats in agricultural use will shrink by 40% (Kuntze, 1993). Some peat soils in western Europe are associated with acid sulfate conditions (Dent, 1986); strong acidity largely precludes agricultural use (Beek *et al.*, 1980). Soil acidification also can result from depletion of basic cations through leaching (Brinkman, 1990) where the soil is well drained and structurally stable and experiences high rainfall amounts and intensity—as in many upland areas of Europe. In wetter climate, soil acidification could increase if buffering pools become exhausted, although for most soils this will take a very long time.

Climate change is likely to increase wind and water erosion rates (Rosenberg and Tutwiler, 1988; Dregne, 1990; Botterweg, 1994), especially where the frequency and intensity of precipitation events grows (Phillips *et al.*, 1993). Erosion rates also will be affected by climate-induced changes in land use (Boardman *et al.*, 1990) and soil organic carbon contents (Bullock *et al.*, 1996). Relatively small changes in climate may push many Mediterranean areas into a more arid and eroded landscape (Lavee *et al*., 1998) featuring decreases in organic matter content, aggregate size, and stability and increases in sodium adsorption ratio and runoff coefficient. However, increased erosion in response to climate change cannot be assumed for all parts of Europe. For example, in upland grazed areas, erosion rates will be reduced as a result of better soil surface cover and topsoil stability arising from higher temperatures that extend the duration of the growing season and reduce the number of frosts (Boardman *et al.*, 1990).

13.2.1.2.3. Biologically mediated soil properties

Climate change will impact directly on SOM through temperature and precipitation (Tinker and Ineson, 1990; Cole *et al.*, 1993; Pregitzer and Atkinson, 1993) and indirectly (and possibly more importantly) through changing land use (e.g., Hall and Scurlock, 1991). SOM contents increase with soil water content and decrease with temperature (Post *et al.*, 1982, 1985; Robinson *et al*., 1995), although rates of decomposition vary widely between different soil carbon pools (van Veen and Paul, 1981; Parton *et al.*, 1987; Jenkinson, 1990). Changes in SOM contents depend on the balance between carbon inputs from vegetation and carbon losses through decomposition (Lloyd and Taylor, 1994); most SOM is respired by soil organisms within a few years. Net primary productivity (NPP) usually increases with increasing temperature and elevated atmospheric CO_2, leading to greater returns of carbon to soils (Loiseau *et al.*, 1994). However, increasing temperature strongly stimulates decomposition (Berg *et al.*, 1993; Lloyd and Taylor, 1994; Kirschbaum, 1995) at rates that are likely to outstrip NPPand lead to reduced SOM contents (Kirshbaum *et al.*, 1996). This effect will be strongest in cooler regions of Europe, where decomposition rates currently are slow (Jenny, 1980; Post *et al.*, 1982; Kirschbaum, 1995). Conversely, excess soil water resulting from increased precipitation will reduce decomposition rates (Kirschbaum, 1995) and thus increase SOM contents.

Plant growth and soil water use are strongly influenced by the availability of nutrients. Where climatic conditions are favorable for plant growth, the shortage of soil nutrients will have a more pronounced effect (Shaver *et al.*, 1992). Increased plant growth in a CO_2-enriched atmosphere may rapidly deplete soil nutrients; consequently, the positive effects of CO_2 increase may not persist as soil fertility decreases (Bhattacharya and Geyer, 1993). Increased SOM turnover rates over the long term are likely to cause a decline in soil organic nitrogen in temperate European arable systems (Bradbury and Powlson, 1994), although, in the short term, increased returns of carbon to soils would maintain soil organic nitrogen contents (Pregitzer and Atkinson, 1993; Bradbury and Powlson, 1994). Greater mineralization may cause an increase in nitrogen losses from the soil profile (e.g., Kolb and Rehfuess, 1997; Lukewille and Wright, 1997), although there is evidence to suggest that temperature-driven, increased nitrogen uptake by vegetation may reduce these losses (Ineson *et al*., 1998).

There is great uncertainty surrounding the response of soil community function to global change and the potential effects of these responses at the ecosystem level (Smith *et al*., 1998). Most soil biota have relatively large temperature optima and therefore are unlikely to be adversely affected by climate change (Tinker and Ineson, 1990), although some evidence exists to support changes in the balance between soil functional types (Swift *et al.*, 1998). Soil organisms will be affected by elevated atmospheric CO_2 concentrations where this changes litter supply to and fine roots in soils, as well as by changes in the soil moisture regime (Rounsevell *et al.*, 1996b). Furthermore, the distribution of individual species of soil biota will be affected by climate change where species are associated with specific vegetation and are unable to adapt at the rate of land-cover change (Kirschbaum *et al*., 1996).

13.2.1.3. Coastal Zones

Coastal zones in Europe contain large human populations and significant socioeconomic activity. They also support diverse ecosystems that provide significant habitats and sources of food. Significant inhabited coastal areas in countries such as The Netherlands, England, Denmark, Germany, Italy, and Poland already are below normal high-tide levels, and more extensive areas are vulnerable to flooding from storm surges. Hard defenses to prevent such flooding, combined with the loss of the seaward edge of coastal habitats as a result of existing rates of sea-level rise, already are causing significant coastal squeeze in many locations (e.g., Pye and French, 1993; Rigg *et al.*, 1997; Lee, 1998). Deltaic areas often are particularly threatened because they naturally subside and may have been sediment-starved by dam construction (e.g., Sanchez-Arcilla *et al.*, 1998). Other nonclimate change factors such as pollution may condition the impacts of climate change. Information further to the summary given below appears in the chapter on coasts in the European ACACIAreport (Nicholls, 2000).

Climate change could cause important impacts on coastal zones, particularly via sea-level rise and changes in the frequency and/or intensity of extreme events such as storms and associated surges. Under the SRES climate change scenarios, global sea level is expected to rise by 13–68 cm by the 2050s. Regional and local sea-level rise in Europe generally will differ from the global average because of vertical land movements (glacial isostatic rebound, tectonic activity, and subsidence). Deviations from the global mean sea level also will occur as a result of oceanic effects such as changes in oceanic circulation, water density, or wind and pressure patterns. Mediterranean sea levels have fallen by as much as 20 mm relative to the Atlantic since 1960, probably as a result of declining freshwater input and consequent seawater density increase (Tsimplis and Baker, 2000). Looking to the future, the net effect of these processes is likely to be as much as 10% of global mean change to the 2080s (Gregory and Lowe, 2000).

Sea-level rise can cause several direct impacts, including inundation and displacement of wetlands and lowlands, coastal erosion, increased storm flooding and damage, increased salinity in estuaries and coastal aquifers, and rising coastal water tables and impeded drainage (Bijlsma *et al.*, 1996). Potential indirect impacts are numerous; they include changes in the distribution of bottom sediments, changes in the functions of coastal ecosystems, and a wide range of socioeconomic impacts on human activities.

Other climate change factors also may be important. For example, rising air and sea temperatures may cause significant shifts in the timing and location of tourism (Perry, 1999) and recreational and commercial fisheries and decrease the incidence of sea ice during winter. These changes also may influence water quality through the occurrence of algal blooms, which would have adverse effects on tourism and human health (Kovats and Martens, 2000). Changes in the frequency and track of extratropical storms are less certain. It is worth noting that an analysis of the HadCM2 climate change simulations found a decrease in the number of northern hemisphere storms, but with a tendency for deeper low centers (Carnell and Senior, 1998). This would have important implications for coastal areas, including an additional increase in flood risk. Several studies suggest that storm surges in northwest Europe might change as a result of climate change (von Storch and Reichardt, 1997; Flather and Smith, 1998; Lowe and Gregory, 1998), but further investigation is required to produce definitive results. Storm occurrence has displayed significant interannual and interdecadal variability over the past 100 years (WASA, 1998); this could produce important and costly impacts without other changes (e.g., Peerbolte *et al.*, 1991) and might interact adversely with sea-level rise.

The impacts of sea-level rise would vary from place to place and would depend on the magnitude of relative sea-level rise, coastal morphology/topography, and human modifications. The most threatened coastal environments within Europe are deltas, low-lying coastal plains, islands and barrier islands, beaches, coastal wetlands, and estuaries (Beniston *et al.*, 1998). Tidal range is a key factor: In general, the smaller the tidal range, the greater the susceptibility to a given rise in sea level. The Mediterranean and Baltic coasts have a low tidal range (<1 m), which suggests that they will be more vulnerable to sea-level rise than the Atlantic Ocean and North Sea coasts (Nicholls and Mimura, 1998).

A regional/global model of flood and coastal wetland losses described by Nicholls *et al.* (1999) considers the interacting effects of sea-level rise, population growth, and improvements in protection standards. All other climate factors are assumed to be constant. This model allows the impacts of the SRES scenarios on Europe [excluding the former Soviet Union (FSU)] to be explored. Because increases in population and protection standards in Europe are minor, the major changes are caused by sea-level rise. In 1990, about 25 million people were estimated to live beneath the 1-in-1,000 year storm surge, with the largest exposure along the Atlantic/North Sea seaboard. However, these people generally are well protected from flooding now. The

Table 13-3*: Estimates of flood exposure and incidence for Europe's coasts in 1990 and the 2080s (new runs using model described by Nicholls et al., 1999). Estimates of flood incidence are highly sensitive to assumed protection standard and should be interpreted in indicative terms only. Former Soviet Union is excluded.*

		Flood Incidence	
Region	***1990*** **Exposed Population (millions)**	***1990*** Average Number of People Experiencing Flooding (thousands yr^{-1})	***2080s*** Increase due to Sea-Level Rise, Assuming No Adaptation (%)
Atlantic coast	19.0	19	50 to 9,000
Baltic coast	1.4	1	0 to 3,000
Mediterranean coast	4.1	3	260 to 120,000

***Table 13-4**: Estimated coastal wetland losses by region in Europe by the 2080s (new runs using model described by Nicholls et al., 1999). Range of losses reflects range of SRES sea-level rise scenarios and uncertainty about wetland response to sea-level rise. Losses from other causes, such as direct human destruction, are likely. Former Soviet Union is excluded.*

Region	**Minimum Wetland Stock in 1990 (km²)** Saltmarsh	Unvegetated Intertidal Areas	Total	**Range of Losses by the 2080s (%)**
Atlantic coast	2,306	6,272	8,578	0 to 17
Baltic coast	226	271	497	84 to 98
Mediterranean coast	347	136	483	31 to 100

changes in flooding, shown in Table 13-3, indicate a significant increase in the incidence of coastal flooding by the 2080s, assuming no adaptation, particularly around the Mediterranean.

Europe (excluding the FSU) is estimated to have at least 2,860 km² of saltmarshes and 6,690 km² of other unvegetated intertidal habitat, mainly composed of sites recognized in the Ramsar treaty. Based on coastal morphological type and the presence or absence of coastal flood defenses, Table 13-4 shows wetland losses resulting from sea-level rise. Wetland losses are most significant around the Mediterranean and Baltic. Under the A2-high scenario, wetlands in these regions could be eliminated. Any surviving wetlands may be substantially altered. Such losses could have serious consequences for biodiversity in Europe, particularly for wintering shorebird and marine fish populations.

Available national results emphasize the large human and ecological values that could be affected by sea-level rise. Table 13-5 shows results of national assessments in The Netherlands (Baarse *et al*.,1994; Bijlsma *et al*., 1996), Poland (Zeidler, 1997), and Germany (Sterr and Simmering, 1996; Ebenhöh *et al*., 1997) for existing development and all costs adjusted to 1990 US$. In Table 13-5, adaptation assumes protection except in areas with low population density. People at risk are the numbers of people flooded by storm surge in an average year. Adaptation/protection costs for Poland include capital and annual running costs; % GNP assumes that costs are all incurred in 1 year. Subnational and local studies from East Anglia, UK (Turner *et al*., 1995); South Coast, UK (Ball *et al.*, 1991); Rochefort sur Mer, France (Auger, 1994); Estonia (Kont *et al*., 1997); and Ukraine (Lenhart *et al.*, 1996), as well as regional reviews (Tooley and Jelgersma, 1992; Nicholls and Hoozemans, 1996) also support this conclusion. Many of Europe's largest cities—such as London, Hamburg, St. Petersburg, and Thessaloniki—are built on estuaries and lagoons (Frasetto, 1991). Such locations already are exposed to storm surges, and climate change is an important factor to consider for long-term planning and development.

Other values that may be affected include archaeological and cultural resources at the coast; these resources sometimes are being recognized only now (Fulford *et al.*, 1997; Pye and Allen, 2000). In Venice, a 30-cm relative rise in sea level in the 20th century has greatly increased the frequency of flooding and damage to this unique medieval city; solutions to this problem are the subject of a continuing debate and need to consider climate change (Consorzio Venezia Nuova, 1997; Penning-Rowsell *et al*., 1998).

13.2.1.4. Mountains and Subarctic Environments

Mountain regions are characterized by sensitive ecosystems, enhanced occurrences of extreme weather events, and natural catastrophes. Often regarded as hostile and economically nonviable regions, mountains have attracted major economic investments for tourism, hydropower, and communication routes. The projected amplitude and rate of climatic change in coming decades is likely to lead to significant perturbations of natural systems as well as the social and economic structure of mountain societies, particularly where these are marginal. Because in many instances mountains and uplands are regions of conflicting interests between economic development and environmental conservation, shifts in climatic patterns probably will exarcerbate the potential for conflict (Beniston, 2000).

Nested GCM-regional climate model (RCM) techniques for a 2xCO_2 scenario have shown that the European Alps are likely to experience slightly milder winters, with more precipitation, than recently. Summer climate, however, may be much warmer and drier than today, as a result of northward shift of the Mediterranean climatic zones (Beniston *et al.*, 1995). These conditions are likely to have adverse effects on the alpine cryosphere and ecosystems.

Impacts of climatic change on physical systems will affect water, snow, and ice, and shifts in extremes will lead to changes in the frequency and intensity of natural hazards. Water availability in some regions may decline because of a reduction in precipitation amounts and because of reduced snow-pack and shorter snow season. Changes in snow amount will lead to significant shifts in the timing and amount of runoff in European river basins, most of which originate in mountains and uplands; this will have numerous consequences for the more populated lowland regions. Floods and droughts are likely to become more frequent. Indirect impacts include changes in erosion and sedimentation patterns, perhaps disrupting hydropower plants (Beniston *et al*., 1996).

In most temperate mountain regions, the snowpack is close to its melting point, so it is very sensitive to changes in temperature. As warming progresses in the future, current regions of snow

***Table 13-5**: Impacts of sea-level rise in selected European countries, assuming no adaptation, plus adaptation costs (from Nicholls and de la Vega-Leinert, 2000).*

Country	Sea-Level Rise Scenario (m)	Coastal Floodplain Population		Population Flooded per Year		Capital Value Loss		Land Loss		Wetland Loss (km²)	Adaptation Costs	
		# 10^3	% total	# 10^3	% total	US\$ 10^9	% GNP	km²	% total		US\$ 10^9	% GNP
Netherlands	1.0	10,000	67	3,600	24	186	69	2,165	6.7	642	12.3	5.5
Germany	1.0	3,120	4	257	0.3	410	30	n.a.	n.a.	2,400	30	2.2
Poland	0.1	n.a.	n.a.	25	0.1	1.8	2	n.a.	n.a.	n.a.	0.7	2.1
Poland	0.3	n.a.	n.a.	58	0.1	4.7	5	845	0.25	n.a.	1.8	5.4
Poland	1.0	235	0.6	196	0.5	22.0	24	1,700	0.5	n.a.	4.8	14.5
Estonia	1.0	47	3	n.a.	n.a.	0.22	3	>580	>1.3	225	n.a.	n.a.
Turkey	1.0	2450	3.7	560	0.8	12	6	n.a.	n.a.	n.a.	20	10

precipitation increasingly will experience precipitation in the form of rain. For every 1°C increase in temperature, the snowline rises by about 150 m; as a result, less snow will accumulate at low elevations than today, although there could be greater snow accumulation above the freezing level because of increased precipitation in some regions. A warmer climate will lead to the upward shift of mountain glaciers, which will undergo further reductions. It is likely that in the 21st century, 30–50% of alpine glaciers will disappear (Haeberli, 1995). Permafrost also could be significantly perturbed by warming, leading to a reduction of slope stability and a consequent increase in the frequency and severity of rock and mudslides. These in turn would have adverse economic consequences for mountain communities.

According to Sætersdal and Birks (1997), mountain plants with narrow July and January temperature tolerances (typically centric species) are most vulnerable to climate warming. These species are characterized by small ranges and population sizes. Holten (1998) documents that these less common centric species have narrow altitudinal ranges—most between 400–600 m in southern Scandes (the Fennoscandian mountain range)—compared with widely distributed mountain plants that have vertical ranges of 800–1,800 m.

Temperature enhancement experiments in the northern Scandes (Henry and Molau, 1997; Molau and Alatalo, 1998) have shown disintegration of present plant communities; “arctic specialists,” such as *Cassiope tetragona* and *Diapensia lapponica,* are least responsive to warming, but soon will suffer competitive exclusion from more competitive evergreen and deciduous dwarfshrubs such as *Empetrum hermaphroditum, Vaccinium vitis-idaea, Betula nana,* and *Salix spp*. The latter species are most favored by climatic amelioration (see also Jonasson *et al.,* 1996; Graglia *et al.,* 1997). The following vegetation types are regarded as most sensitive to climate change in the Scandes:

- *High-alpine fell-field vegetation:* Present plant cover is discontinuous. With available soil resources in combination with extensive seed rain (Molau and Larsson, 2000), rapid colonization by mid-alpine vegetation is expected.
- *Mid-alpine vegetation:* Because of a longer thaw season, spatial cover of snowbed communities—including species with high sensitivity to frost and drought—is anticipated to decrease rapidly.
- *Vegetation on cryosoils:* As a result of anticipated accelerated degradation of patchy permafrost, the discontinuous vegetation of wet cryosoils (patterned ground and tussock tundra) may be replaced rapidly by low-alpine heath scrub.

As a result of a longer growing season and higher temperatures, European alpine areas will shrink because of upward migration of tree species. After several centuries of invasion of forest into the alpine Scandes, the current alpine area might be reduced by as much as 40–60% (Holten, 1990; Holten and Carey, 1992). The speed and extent of upward migration will depend on species as well as physiographic conditions and climatic regimes. Fairly quick response is expected from pioneer species such as mountain birch *(Betula pubescens ssp. tortuosa)*. However, there seem to be competing explanations for the response time of migration of the timberline in European mountain ranges and how far timberlines will shift under specific climate scenarios (Woodward, 1992). Under optimal topographic/edaphic conditions, the mountain birch, Scots pine, and Norway spruce treelines might be elevated by as much as 300 m in the continental Scandes and less on the coastal slopes. This will probably take several hundreds of years, at least for the more slowly responding Scots pine and Norway spruce (Aas and Faarlund, 1995; Kullman, 1995). The interaction between climate change, acidification, and nitrogen deposition in alpine ecosystems in the Scandes certainly is very important; to date, however, it has been more or less overlooked (Keller *et al.*, 2000).

The predicted future climate suggests that the ranges of many species will extend to higher altitudes. In the topmost zone of the Middle Mountains and the lower external Alps, competition from closed-canopy forest of Norway spruce might restrict the area of small islands of arctic-alpine tundra, destroy patterned grounds and subarctic mires, and kill relict and endemic populations of arctic-alpine organisms (Jenik, 1997). Mountain ecosystems that are particularly vulnerable to climate change in Italy include, for example, shrub vegetation with *Pinus mugo* of the Apennines (Vaccinio-Piceetalia). This grows 1,500–2,300 m above sea level on glacial residue and is closely dependent on cold continental climate with long-lasting snow cover (Second National Communication on Climate, 1997).

Evidence from past climate changes indicates that species respond by migrating rather than by adapting genetically (Huntley, 1991). According to Scharfetter (1938), the warmest interglacial periods enabled forests to climb higher toward the summits of low mountains (1,800–2,300 m), thereby reducing high-elevation orophyte populations. This is relevant for many isolated endemics and orophytes that presently are living in refugia, such as tops of low mountains in the Alps. In such habitats, they will have no possibility to migrate upward, either because they cannot move rapidly enough or because the nival zone already is absent (Gottfried *et al.*, 1994; Grabherr *et al.*, 1994, 1995).

There is broad agreement that past climatic changes have had a strong impact on the distribution ranges of species, and the same can be expected in the future (Peters and Darling, 1985; Ozenda and Borel, 1991, 1995). However, some of these biotic changes are subject to considerable inertia, especially with long-lived plants such as trees. For treelines to expand upslope, a significantly warmer climate is required for at least 100 years (Holtmeier, 1994). Based principally on palynological and macrofossil investigations, the forest limit did not extend upward more than 100–300 m during the warmest periods of the Boreal and Atlantic periods in the Holocene (e.g., Bortenschlager, 1993; Lang, 1993; Wick and Tinner, 1997). An increase in mean annual temperature of 1–2°C may not shift the present forest limit upward by much more than 100–200 m in the Alps.

An increase of 1–2°C is still likely to be in the range of tolerance of most alpine and nival species (Körner, 1995; Theurillat, 1995), whereas a greater increase (3–4°C) may not be (Theurillat, 1995; Lischke *et al.*, 1998; Theurillat *et al.*, 1998). This is particularly relevant for endemics and orophytes with widespread distributions throughout the Alps. Where ranges of species already are fragmented they may become even more fragmented, with regional disappearances if they cannot persist, adapt, or migrate. Some categories of vulnerable plants—for instance, isolated arctic, stenoicous, relict species that are pioneers in wet habitats—may disappear. Specialists in distinct relief situations can suffer from habitat loss through lack of suitable escape routes, as observed from modeling studies (Pauli *et al.*, 1999; Gottfried *et al.*, 2000). Such effects can be pronounced—for instance, in the northeastern Alps, where high numbers of endemics occur in narrow altitudinal ranges (Grabherr *et al.*, 1995).

Biogeographically, the Pyrenees are on the edge between the alpine, central European, and Mediterranean regions. In the eastern Pyrenees around Puigmal (2,910 m), some oro-Mediterranean communities occur, as well as some pasture types with the rude *Festuca supina* (Baudiere and Serve, 1974). On windier and drier areas, an ecological substitution is taking place: Alpine dense pastures are turning to discontinuous oro-Mediterranean communities. There is ongoing degradation of formerly stable soils and communities as a result of periglacial phenomena, including increased cryoturbation (Baudiere and Gauquelin, 1998). With regard to timberlines in the Pyrenees, Montserrat (1992) demonstrates that they have been moving upward in the postglacial period up to the present. Over 1940–1985, an increase in mean annual temperatures is suggested by changes in animal behavior. In Estangento Lake (eastern Pyrenees, 2,035 m), this happens especially in winter months, when the minimum temperatures reach 3°C. This phenomenon affects the hibernation time of a common bat *(Miniopterus shreibersi)*, so that populations enter the caves 1.5 months later than they did 20 years ago. Caves are regarded as stable environments that reflect only general climatic trends (White and Martinez Rica, 1996).

13.2.2. Semi-Natural Ecosystems and Forests

13.2.2.1. Forests

European forests belong to an important economic sector that is potentially affected by climate change and changes in atmospheric CO_2 concentrations. Forests also have important interactions with global change processes as a result of their sink potential.

Primarily, temperature and the availability of soil moisture limit the natural range of European tree species. Some forests (particularly in the north) also are nutrient-limited. The structure and composition of many forests is further influenced by the natural disturbance regime (e.g., fire, insects, windthrow). Most European forests are managed for one or several purposes, such as timber production, water resources, or recreation. This management has reduced forest area or strongly modified forest structure in most of Europe, and presently existing forests often consist of species that are different from those that would occur naturally.

In northern Europe, boreal forests are dominated by *Picea abies* and *Pinus sylvestris*, and these species grow well across most of their current distribution ranges. Under warmer conditions, these species are likely to invade tundra regions (Sykes and

Prentice, 1996). In the southern boreal forests, these species are expected to decline because of a concurrent increase of deciduous tree species (Kellomäki and Kolström, 1993). Most climate change scenarios suggest a possible overall displacement of the climatic zone that is suitable for boreal forests by 150–550 km over the next century (Kirschbaum *et al*., 1996). This shift in climatic conditions would occur more rapidly than most species have ever migrated in the past (20–200 km per century—see Davis, 1981; Birks, 1989). Also questionable is whether soil structural development would be able to follow. Turnover of current tree populations may be enhanced, however, by changes in management practices and changing disturbance regimes, such as increased fire frequency or increased strong winds in late autumn and early spring (Solantie, 1986; Peltola *et al*., 1999).

Under most recent climate change scenarios, winters are likely to be still cold enough to fulfill the chilling requirements of the main boreal tree species (Myking and Heide, 1995; Leinonen, 1996; Häkkinen *et al*., 1998), but earlier budburst can be expected. If summer and winter precipitation increase (as indicated by some scenarios), boreal forests would become less susceptible to fire damages, which currently affect about 0.05% of forests yr^{-1} (Zackrisson and Östlund, 1991).

At present, cold winters in boreal and some temperate regions protect forests from many insects and fungi that are common further south (Straw, 1995). High summer temperatures and associated drought increase the growth of existing insect populations through enhanced physiological activity and turnover of insect populations. Throughout Europe, forests seem to be quite well buffered against new species coming from outside Europe, but the risk exists. A good example of new organisms with large potential to damage trees is *Bursaphelenchus xylophilus*, which originates in North America. This pine nematode is easily transported in fresh timber, but its success is related to temperature. Low summer temperatures and short growing seasons have effectively limited the success of this species in northern Europe (Tomminen and Nuorteva, 1987), although it frequently has occurred in imported timber. Reductions in these limitations may result in increased damage to trees.

In western and central Europe, the current forest structure and, in part, tree species composition are determined mainly by past land use and management rather than by natural factors (Ellenberg, 1986). Site-specific assessments of the future composition of near-natural forests suggests that conifers (e.g., *Picea abies*) may be replaced by deciduous species (e.g., *Fagus sylvatica*) at some sites (e.g., Kräuchi, 1995). Until recently, our capability to assess long-term forest dynamics at the regional scale was quite limited. Lindner *et al*. (1997) provided the first assessment of regional-scale patterns of forest composition under current and future climates. Their study suggests that future near-natural forests in the state of Brandenburg (east Germany) would be much more uniform, with little of the differentiation across different site types that shape today's landscape. Atemperature increase of 1–3°C would advance budburst of many tree species by several weeks (Murray *et al*., 1989). Introduction of phenologically suitable ecotypes or new species has been among the main tools to increase forest growth (Lines, 1987). Minimum winter temperatures seem to be critical for the survival of exotic species with insufficient winter frost hardiness—for example, *Nothofagus procera* in Britain (Cannell, 1985). Therefore, higher winter temperatures could broaden the potential distribution range of such species in Europe.

In southern Europe, most forests consist of sclerophyllous and some deciduous species that are adapted to summer soil water deficit. Climate scenarios indicate reduced water availability in the summer months and associated responses in forests (e.g., Gavilán and Fernández-González, 1997), although the interactions of this effect with enhanced CO_2 concentrations is uncertain. Temperature changes may allow expansion of some thermophilous tree species (e.g., *Quercus pyrenaica)* when water availability is sufficient. In the Pyrenees, a northward and upward movement of Mediterranean ecotypes is likely to occur with warming accompanied by drier conditions.

13.2.2.1.1. Growth trends

Forest growth has increased during the past several decades in northern forests (Lakida *et al.*, 1997; Lelyakin *et al.*, 1997; Myneni *et al*., 1997) and elsewhere in Europe (Spiecker *et al*., 1996). Climate warming, increasing CO_2, increased nitrogen deposition, and changes in management practices are factors that are assumed to be behind the increase. The impacts of temperature and CO_2 have been shown in experiments and are extrapolated by model calculations. For example, under an assumed increase of CO_2 by 3.5 µmol mol^{-1} yr^{-1} and temperature by 0.04°C yr^{-1} over 100 years, productivity of *Pinus sylvestris* increased by 5–15% as a result of the temperature elevation, 10–15% as a result of the increased CO_2, and 20–30% as a result of combined temperature and CO_2 (Kellomäki and Väisänen, 1997). In northern Europe, the effects of precipitation changes are likely to be much less important than the effects of temperature changes (Kellomäki and Väisänen, 1996; Talkkari and Hypén, 1996). Based on model computations that assume a seasonally uniform temperature increase, Proe *et al.* (1996) have suggested that growth of *Picea sitchensis* in Scotland could increase by 2.8 m^3 ha^{-1} yr^{-1} for each 1°C rise in temperature.

In Russian boreal forests, some studies predict large shifts in distribution (up to 19% area reduction) and productivity (e.g., Kondrashova and Kobak, 1996; Krankina *et al*., 1997; Izrael, 1997; Raptsun, 1997). It could be concluded that climate change and CO_2 increase would be favorable for northern forests (e.g., as a result of increased regeneration capacity). Indeed, some studies suggest a significant increase in productivity of forests in higher latitudes. The largest changes are expected for forest tundra and the northern taiga, reaching 12–15% additional growth per 1°C warming (e.g., Karaban *et al*., 1993; Shvidenko *et al*., 1996; Lelyakin *et al*., 1997). The same studies estimate the impact in more southern forest zones (southern taiga, mixed and deciduous forests) to be less: 3–8% per 1°C.

In central and southern Europe, limited moisture resulting from increasing temperature and (possibly) reduced summer rainfall may generate productivity declines regionally, but this cannot be predicted because of uncertain rainfall scenarios. In addition, CO_2 enrichment is likely to increase water-use efficiency (WUE), which makes growth less drought-sensitive. Forest growth conditions in the southern parts of eastern Europe (Russia, Ukraine, Moldova) are likely to decline as a result of increased drought, specifically in the steppe. Secondary problems could arise in the protective shelterbelts in the south of the forest-steppe zone that now covers about 3 Mha.

13.2.2.1.2. Disturbance regimes

In the Mediterranean region, elevation of summer temperature and reduction of precipitation may further increase fire risk. Colacino and Conte (1993a,b) examined the pattern of forest fires in the Mediterranean region in connection with the number of heat waves. An increase of 70% in the number of heat waves was recorded in the period 1980–1985 with respect to the period 1970–1975, and a similar increase was recorded in the extent of forest burned. In temperate eastern Europe, forest fire increase is less likely, but very dry and warm years could occur more frequently and promote pest and pathogen development. Large areas of pine forests in Ukraine, Belarus, and central regions of Russia might face some increased risk.

Increased forest fire risk is a crucial factor in the survival of boreal forests in Russia. Most dangerous are large forest fires, which occur during extremely dry and warm years. Such climatic conditions occur periodically (every 15–20 years) in parts of the Russian boreal zone. Currently these large fires account for about 1–2% of the total number of forest fires, but burned areas reach 70–80% and losses are as much as 90% of the total values. Most climate scenarios indicate that the probability of large fires will increase.

Estimates of the possible influence of climate change on insect infestation are uncertain because of complex interactions between forests, insects, and climate. The probability of outbreaks of pests such as *Dendrolimus sibirica* or *Limantria dispar* is expected to increase, especially in monocultures. Short-period warming also could promote infestation with new pest species that presently do not occur in the boreal zone. Increases of climate aridity would promote occurrence of some diseases (e.g., root and stem fungi decays).

13.2.2.2. Grasslands and Rangelands

Permanent grassland and heathland occupy a large proportion of the European agricultural area. The type of grassland varies greatly, from grass and shrub steppes in the Mediterranean region to moist heathland in western Europe. The annual cycle of many temperate grasses is limited by low temperature during the winter and spring and by water stress during the summer. Climate change can affect the productivity and composition of grasslands in two ways: directly through the effects of CO_2, or indirectly through changes in temperature and rainfall. Different species will differ in their responses to CO_2 and climate change, resulting in alterations in community structure (Jones and Jongen, 1996). Legumes, which are frequent in these communities, may benefit more from a CO_2 increase than nonfixing species (Schenk *et al*., 1995).

Intensively managed and nutrient-rich grasslands will respond positively to the increase in CO_2 concentration and to rising temperature, as long as water resources are sufficient (Thornley and Cannell, 1997). The direct effect of doubling CO_2 concentration by itself may cause a 20–30% increase in productivity in nutrient-rich grasslands (Jones *et al*., 1996; Cannell and Thornley, 1998). The importance of water management (including drainage) may be even more important, however, under changed climatic conditions in northern Europe (Armstrong and Castle, 1992). This positive effect of increased CO_2 on biomass production and WUE can be offset by climate change, depending on local climate and soil conditions (Topp and Doyle, 1996a; Riedo *et al*., 1999). These effects also will determine the spatial distribution of agricultural grassland. An analysis by Rounsevell *et al*. (1996a) showed that grassland production in England and Wales is resilient to small perturbations in temperature and precipitation, but larger temperature increases may cause drought stress and reduced suitability for grassland production.

There is a greater controversy regarding the response of nitrogen-poor and species-rich grassland communities. Experimental studies in such grasslands have shown little response or even a reduction in production with CO_2 enrichment (Körner, 1996). On the other hand, simulation studies have shown that this could be just a transient response and that the long-term response of nitrogen-poor grassland ecosystems may be relatively larger than that of nitrogen-rich systems (Cannell and Thornley, 1998). This effect is caused by a reduction in nutrient losses and an increase in nitrogen fixation at elevated CO_2.

Because of its impacts on primary productivity and community structure, the long-term effect of elevated CO_2 on grasslands is an additional carbon sink. By contrast, increasing temperatures alone are likely to turn grasslands into a carbon source because soil respiration would be accelerated more than NPP. The net effect of current scenarios for CO_2 and temperature is likely to be a small carbon sink in European grasslands (Thornley and Cannell, 1997).

Arid and semi-arid environments (e.g., certain steppe-like habitats), which are well represented in the Mediterranean area, are crucial for the preservation of rich species diversity in this region. These regions seem to be the only places within Europe that certain insect species, such as *Lepidoptera*, can inhabit because of the abundant availability of their foodplants. Furthermore, the lack of winter climatic stress makes arid lands quite suitable as wintering grounds for birds. Overgrazing, fire, urbanization, and changes in land use can be considered the main threats to these regions. The potential distribution of these semi-arid environments may increase under drier and warmer climatic conditions, leading to landscape fragmentation at the local scale and consequent local extinctions (del Barrio and Moreno, 2000).

13.2.2.3. Freshwater Ecosystems: Inland Wetlands, Lakes, and Streams

European freshwater ecosystems encompass a varied assemblage of systems: lakes of various sizes and depth; streams with different hydrological characteristics; and wetlands, which by definition occupy a spatial continuum between aquatic and terrestrial environments. Wetlands are heterogeneous systems ranging from open-water surfaces to densely vegetated areas. Some wetlands are forested; shrubs, grasses, or mosses dominate others. European freshwater systems have been heavily subjected to and modified by damming, channeling, drainage, and other hydrological alterations; they also are influenced by humans through land and water use, pollution, erosion, and other factors.

The fundamental requirement for the existence of freshwater ecosystems is the spatial and temporal distribution of water in the landscape. The impacts of climate change on the future distribution and extent of these systems are analogous to those discussed in Section 13.2.1.1. However, apart from these impacts, changes in climatic parameters also will impact a range of chemical and biological functions, which combine with physical parameters to create the integrated ecological characteristics of future freshwater ecosystems in Europe. During the past 150 years, the winter ice cover of streams and lakes has declined, and in the northern hemisphere there has been a steady trend toward later freeze and earlier ice breakup (Magnuson *et al.*, 2000). Climate warming is likely to exaggerate this trend, and the timing and duration of freeze and breakup of ice in freshwater systems greatly affect inherent biological and ecological processes.

In the arctic and subarctic, freshwater systems are particularly sensitive to climate change—and most climate change scenarios indicate that the highest and most rapid temperature increases will occur in these regions. Increases in temperature may lead to changes in permafrost distribution (Anisimov and Nelson, 1996, 1997), with concomitant impacts on hydrology. In many wetland areas, permafrost acts as a drainage seal and promotes wetland development. However, Camill and Clark (1998) suggest that high-latitude systems might show lagged and complex dynamics in response to global warming, and local factors may exert more direct control over permafrost than regional ones. The estimated effect of climate change on average runoff in tundra regions is highly uncertain, but if water levels decrease, connections between tundra lakes could be severed. This would result in changes in community structure and possibly elimination of seasonal migrants to shallow, ice-covered winterkill lakes. Climate change impacts on ice breakup timing and intensity also will influence limnological characteristics by regulating the supply and flux of nutrients (Lesack *et al.*, 1991). Furthermore, such changes impact the influx of sunlight, which is a key factor in controlling primary productivity but also can have far-reaching effects on higher trophic levels. The populations of arctic char (and presumably other extreme coldwater fish species) are expected to decrease, especially in low-altitude, shallow lakes (Lehtonen, 1998).

In the boreal areas, scenarios typically display warmer winters (e.g., a shorter season of sub-zero temperatures). This would affect snow-cover conditions and lead to changes in the timing and intensity of snowmelt events and runoff characteristics, which would affect the ecological functions of freshwater systems. Wetland development might benefit if larger fractions of precipitation fell as rain, but the impact would depend on how temperature-induced higher evapotranspiration rates would counteract this effect, as well as topographical characteristics of the landscape. In response to higher temperatures, northern boreal populations of cyprinid and percid fish species are expected to increase at the expense of coldwater, salmonid species (Lehtonen, 1996). Shallow lakes would be most susceptible to these changes because of their lack of thermal stratification. Total freshwater fish production is expected to increase, but with the projected changes in the composition of fish fauna, the recreational and commercial value of catches will decrease (Lehtonen, 1996). A reduction in the spatial and temporal extent of lake and stream ice cover as a result of warmer winters can decrease light attenuation, which is a major limiting factor for production in boreal aquatic systems. Such a change could be expected to cause shifts in the biota of lakes and streams. It also can reduce winter anoxia that typically occurs in shallow lakes. Haapalea and Lepparänta (1997) modeled future ice-cover distribution in the Baltic Sea (which contains freshwater communities in the north). Simulations with a warming of 3.6°C to 2050 reduced the extent of ice cover from 38 to 10%, and a 6.6°C warming to 2100 resulted in no ice cover. The projected increase in biomass productivity in terrestrial systems also would affect lakes and streams because of alterations in the amount and quality of water and solid material inputs. Organic matter inputs are expected to increase when plant productivity increases and would be beneficial for heterotrophic organisms. Increases in organic matter concentrations also result in effects such as reduced light penetration (including damaging UV-B radiation—Schindler and Curtis, 1997) and changes in the vertical distribution of solar heating (Schindler *et al.*, 1996). In lakes, increased summer temperatures could lead to more pronounced thermal stratification, resulting in reduced secondary productivity as well as anoxic conditions in the hypolimnion. Warmer surface water can reduce the nutritional value of edible phytoplankton, but it also may shift primary production toward green algae and cyanobacteria, which are less favored by secondary consumers.

The dominating wetland types in the boreal regions are peatlands. Typically, the vegetation pattern and composition of boreal peatlands are governed by moisture regime rather than temperature and show high spatial variability in plant communities caused by variation in topography. It follows that a change in water balance could affect the function of boreal wetlands, including their carbon sequestering and carbon storage functions. A study in Finland suggests that very nutrient-poor peatlands can increase their long-term soil carbon accumulation after drainage (Minkkinen and Laine, 1998). In more nutrient-rich peatlands, however, soil carbon sequestering rates decrease and could shift to potential sources of atmospheric CO_2. Cao *et al.* (1998) have suggested that a temperature increase of less than 2°C could enhance methane (CH_4) emission rates from boreal wetlands, but greater warming might lead to reduction of fluxes because of decreasing soil moisture. Furthermore, field manipulation and laboratory experiments in Finland have shown that enhanced CO_2 concentrations (560 ppm) can lead to a 10–20% increase in CH_4 efflux from oligotrophic mire lawn communities (Saarnio and Silvola, 1999; Saarnio *et al.*, 2000). It is likely that boreal peatlands will expand further north into subarctic/arctic areas where the topography after permafrost disintegration still supports wetland formation.

In temperate Europe, the potential for precipitation decreases that result in lower flow rates could have major implications for lakes and streams. This could lead to changes in habitat and breeding locations of aquatic flora and fauna. These hydrological changes have the potential to be more significant for freshwater organisms than a temperature increase. The effect of warmer winters that lead to less extensive ice cover of lakes is expected to affect Europe's temperate lakes and streams as discussed above. Wetlands in the temperate regions of CEE are regarded as vulnerable to climate change (in combination with other anthropogenic threats—Best *et al*., 1993; Hartig *et al*., 1997). In the past, wetlands have been extensive in this area—for example, in the basins of the Pechora, Severnaya Dvina, and Upper Dnieper Rivers and in Karelia they have occupied 10–30% of the area. Now, many of them have been converted to agriculture, are affected by agricultural drainage, or are used in other ways, such as growing reed for thatch and livestock feed or collecting peat as a fuel for heating and cooking.

In the Mediterranean, the risk of acute water shortage in response to global warming would have severe impacts on freshwater ecosystems in the region. Hydrologically isolated systems, such as wetlands in topographical depressions, would be the most vulnerable, whereas those situated along larger rivers and lake shores might be less sensitive (Mortsch, 1998), although the extent of the latter may decrease as a result of lower flow rates. Increased competition for diminishing water resources also poses a potential threat to freshwater ecosystems. Although precipitation may increase during the winter—which is the main season for the seasonal wetlands in this area—this probably will be accompanied by comparably large increases in temperature, thus affecting net water availability. Summers are predicted to become warmer and drier, which would lead to deterioration of freshwater ecosystems (Haslam, 1997). Seasonal systems that presently can cope with occasional or periodic drought will experience additional stress that some species might not be able to survive (Brock and van Vierssen, 1992). The fact that wetlands in many parts of southern and central Europe are scattered in their location may prevent species migration to suitable climate conditions. In general, wetland plants with short life cycles are better adapted for geographical migration, indicating that this response is likely to occur faster in nonforested wetlands than in forested ones.

The risk of increased fire disturbance of terrestrial biota also will have consequences for lakes and streams in southern Europe. Freshwater systems adjacent to burned areas will receive an initial increase in solute input after fire; if the fire generates canopy gaps, the water bodies will be more influenced by wind mixing, inducing changes in thermal and chemical stratification characteristics.

13.2.2.4. Biodiversity and Nature Conservation

Europe is predominantly a region of fragmented natural or semi-natural habitats in a highly urbanized, agricultural landscape. A significant proportion of surviving semi-natural habitats of high conservation value is enclosed within protected sites, which are especially important as refuges for threatened species (Plowman, 1995). Nature reserves form a similarly important conservation investment across the whole of Europe. However, species distributions are projected to change in response to climate change (Huntley and Webb, 1989), and valued communities within reserves may disassociate, leaving species with nowhere to go (Peters and Darling, 1985; Peters and Lovejoy, 1992),

The impact of climate change on a particular reserve will depend on its location in relation to the climatic requirements of the species it accommodates. Sites that lie near the current maximum temperature limits of particular species could expect that if climate warms beyond those limits, species would become extinct at that site. Conversely, sites that lie close to the minimum temperature limits of species may assume greater importance for such species as the climate warms (Huntley, 1999). In Europe, nature reserves tend to form habitat "islands" for species in landscapes that are dominated by other land uses. The possibility of species colonizing other habitat islands could be limited. As a result of climate change, reserve communities may lose species at a faster rate than potential new species can colonize, leading to a long period of impoverishment for many reserves.

The requirements of a future conservation strategy in the advent of climate change have been considered by Huntley *et al.* (1997). They suggest that for Europe, where large-scale range changes are projected, a network of habitats and habitat corridors will be required to facilitate migration.

Questions that urgently must be asked are as follows: To what extent do rare and vulnerable species in Europe rely on protected areas for their survival in the present day? Do current policy measures being implemented throughout Europe under the Biodiversity Convention take into account the potential impacts of climate change? It will become increasingly important for conservation strategies to be developed on a pan-European scale to protect species in parts of their ranges that are least likely to be negatively impacted by climate change. Reevaluation of conservation priorities and the role of reserves is required for individual sites and in relation to national and international conservation strategies (Hendry and Grime, 1990; Parsons, 1991).

13.2.2.5. Migratory Animals

Insects: Parmesan *et al.* (1999) analyzed data for 35 nonmigratory butterflies with northern range limits in Great Britain, Sweden, Finland, or Estonia and southern boundaries in southeastern France, Catalonia (Spain), Algeria, Tunisia, or Morocco. More than 60% were found to have shifted north by 35–240 km in the 20th century, consistent with the 120-km northward shift of climatic isotherms reported in the SAR. This finding is contrary to the trend that might have been expected as a result of land-use change: Habitat loss has been greater in northern European countries over this period than southern ones. Scientific knowledge of butterfly biology supports the inference that this shift is in response to increased temperatures. Population eruptions of several species of forest lepidoptera in central Europe in the early 1990s, including the gypsy moth *Lymantria dispar*, have been linked to increased temperatures (Wulf and Graser, 1996), as have northward range expansions of several species of *Odonata* and *Orthoptera* (Kleukers *et al.*, 1996).

Insect pests: Most studies concur that insect pests are likely to become more abundant in Europe as temperature rises, as a result of increased rates of population development, growth, migration, and overwintering (Cannon, 1998). There has been little or no reported research at the level of pest population dynamics, however, about potential responses of insect pests to increased CO_2 (Cannon, 1998). Although changes in rainfall also could have a substantial effect (Lawton, 1995), this is difficult to quantify, particularly given uncertainties with regional precipitation scenarios. Migratory species may be able to extend their ranges as crop distributions change. For example, a 3°C rise in temperature would advance the limit for grain maize across much of Europe, which could be followed by a northward range expansion by the European corn borer *Ostrinia nubilalis* of as much as 1,220 km (Parry *et al.*, 1990; Porter *et al.*, 1991; Porter, 1995).

Birds: Climate change in Europe already has been demonstrated to be affecting migratory wild bird populations. In the UK, 20 of 65 species, including long-distance migrants, significantly advanced their egg-laying dates by 8 days, on average, between 1971 and 1995 (Crick *et al.*, 1997; Crick and Sparks, 1999). In general, species show advancement in average arrival and laying dates of about 3–5 days per 1°C. It is quite likely that birds will be able to adapt faster than most taxa to such changes, given their mobility and genetic variability (e.g., Berthold and Helbig, 1992). However, increased aridity in the Mediterranean region may be detrimental to the trans-Saharan migrants that use the area for foraging en route. Potentially great problems face the internationally important populations of waterfowl that use a relatively limited number of sites for wintering or while on passage in Europe. Where sea-level rise causes coastal squeeze on the availability of intertidal feeding areas (because sea defenses prohibit encroachment onto currently dry land), feeding resources available to wintering waterbirds may become limited and lead to population declines (Norris and Buisson, 1994). Arctic-breeding shorebirds are predicted to benefit in the short term as warmer temperatures increase the numbers of their insect food supplies, but in the long term they may suffer from the disappearance of their habitat as vegetation zones move northward toward the limit of any land (Lindström and Agrell, 1999).

13.2.3. Agriculture and Fisheries

13.2.3.1. Agriculture

Agriculture accounts for only a small part of GDP in Europe. Therefore, the vulnerability of the overall economy to changes that affect agriculture is low (Reilly, 1996). Locally, however, effects on society may be large. Europe as a whole is noted for its substantial output of arable crops and animal products (FAOSTAT, 1998).

Trends in European agriculture are dominated by the EU's Common Agricultural Policy (CAP). This occurs because EU member states account for a large proportion of agricultural production in Europe and because several countries currently are seeking membership in the EU and in this process are adjusting their policy to match the CAP. The EU seeks to integrate concerns for environmental protection and countryside livelihood into the CAP.

Many studies have assessed the effects of climate change on agricultural productivity (e.g., Ryszkowski and Kedziora, 1993; Harrison *et al.*, 1995b; Semenov and Porter, 1995; Alexandrov, 1999; Cuculeanu *et al.*, 1999; Harrison *et al.*, 1999). Relatively little work, however, has been done to link these results across sectors to identify vulnerable regions and farming systems. Such assessments are needed to identify appropriate policy responses to climate change. More extensive information than the summary presented in this section appears in the agriculture chapter of the European ACACIA report (Bindi and Olesen, 2000).

Cereals of different species and varieties are grown throughout Europe. Climatic warming will expand the area of cereals cultivation (e.g., wheat and maize) northward (Kenny *et al.*, 1993; Harrison and Butterfield, 1996; Carter *et al.*, 1996a). For wheat, a temperature rise will lead to a small yield reduction, whereas an increase in CO_2 will cause a large yield increase; the net effect of both for a moderate climate change is a large yield increase (Nonhebel, 1996; Harrison and Butterfield, 1999). Drier conditions and increasing temperatures in the Mediterranean region and parts of eastern Europe may lead to lower yields and the need for new varieties and cultivation methods. Yield reductions have been estimated for eastern

Europe, and yield variability may increase, especially in the steppe regions (Alexandrov, 1997; Sirotenko *et al.*, 1997). Figure 13-6a shows the response of wheat yields to change of climate and CO_2 concentration for a GCM scenario for 2050 that resembles the A1 scenario. The largest increases in yield occur in southern Europe—particularly northern Spain, southern France, Italy, and Greece. Relatively large yield increases (3–4 t ha^{-1}) also occur in Fenno-Scandinavia. In the rest of Europe, yields are 1–3 t ha^{-1} greater than at present. There are small areas where yields are predicted to decrease by as much as 3 t ha^{-1}, such as in southern Portugal, southern Spain, and Ukraine. For maize, future climate scenario analyses carried out for selected sites in Europe suggest mainly increases in yield for northern areas and decreases in southern areas (Wolf and van Diepen, 1995). This is a result of a small effect of increased CO_2 concentration on growth (maize is a C_4 plant that responds less positively to CO_2 increases than C_3 plants such as wheat and barley) and a negative effect of temperature on the duration of growing season. The latter effect, however, can be largely prevented by growing other maize varieties (Wolf and van Diepen, 1995).

Seed crops generally are determinate species, and the duration to maturity depends on temperature and day length. A temperature increase therefore will shorten the length of the growing period and possibly reduce yields (Peiris *et al.*, 1996). At the same time, the cropping areas of cooler season seed crops (e.g., pea, faba bean, and oilseed rape) probably will expand northward into Fenno-Scandinavia, leading to increased productivity of seed crops there. There also will be northward expansion of warmer season seed crops (e.g., soybean and sunflower). Harrison and Butterfield (1996) estimate this northward expansion for sunflower; they also found a general decrease in water-limited yield of sunflower in many regions, particularly in western Europe. Analysis of the effect of climatic change on soybean yield for selected sites in western Europe suggests mainly increases in yield (Wolf, 2000a). This is a result of a positive effect of CO_2 concentration on growth and only a small effect of temperature on crop duration.

Vegetables cover a wide range of species with a large variation in type of yield components, including leaves, stalks, inflorescence, bulbs, roots, and tubers. Most vegetables are high-value crops that are grown under ample water and nutrient supply. Their response to changes in temperature and CO_2 varies among species, mainly depending on the type of yield component and the response of phenological development to temperature change. For determinate crops such as onions, warming will reduce the duration of crop growth and hence yield (Harrison *et al.*, 1995b), whereas warming stimulates growth and yield in indeterminate crops such as carrots (Wheeler *et al.*, 1996). Onion yields are sensitive to the degree of warming (Harrison *et al.*, 1995b), with a yield decrease for warmer scenarios and a yield increase for cooler scenarios. There also is a spatial gradient, with yield increases in northwest Europe to decreases in southeast Europe. For lettuce, temperature has been found to have little influence on yield, whereas yield is stimulated by increasing CO_2 (Pearson *et al.*, 1997). For cool-season vegetable crops such as cauliflower, large temperature increases may decrease production during the summer period in southern Europe because of decreased yield quality (Olesen and Grevsen, 1993).

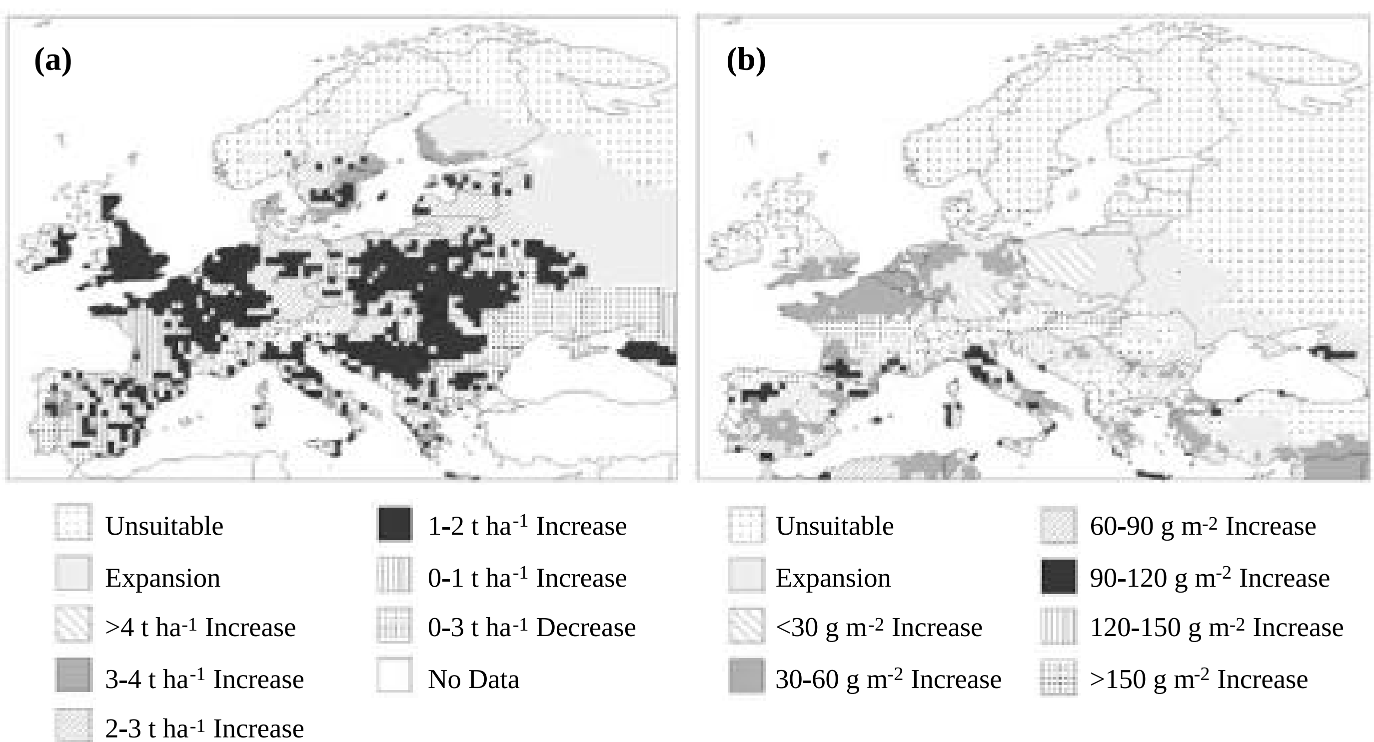

Figure 13-6: Change in water-limited yield for wheat (a) and potential yield for grapevine (b), using HadCM2 scenario for 2050 (Harrison and Butterfield, 1999).

Root and tuber crops are expected to show a large response to rising atmospheric CO_2 because of their large underground sinks for carbon and apoplastic mechanisms of phloem loading (Farrar, 1996; Komor *et al.*, 1996). On the other hand, warming may reduce the growing season and enhance water requirements, with consequences for yield. Climate change scenario studies performed with crop models show increases in potato yields in northern Europe and decreases or no change in the rest of Europe (Wolf, 2000b). Simulation results show an increase in potato yield variability for the whole of Europe, which enhances the risk for this crop. However, crop management strategies (e.g., advanced planting and cultivation of earlier varieties) seem to be effective in overcoming these changes (Wolf, 2000b). Indeterminate root crops such as sugar beet may be expected to benefit from warming and the increase in CO_2 concentrations. A study performed by Davies *et al.* (1996) for England and Wales indicates that the area of suitability for the growth of the crop moves westward.

Forage crops, including maize and whole crop cereals for silage, as well as root crops such as sugar beet and some Brassica species, also are described under cereals and root crops. When these crops are grown as forage crops, yield components and quality may change. Thus, there is a larger emphasis on total biomass yield and on digestability of biomass. The effects on production and quality of wheat whole crop silage will depend on the relative magnitudes of changes in CO_2 and temperature (Sinclair and Seligman, 1995). Yields of the different forage crop types will be affected differentially. Yields of indeterminate crops such as sugar beet and silage maize can be expected to show a larger increase than the yields of whole crop cereals, especially in northern Europe. This probably will lead to changes in the types of forage crops grown. Studies indicate an increase in suitability of the north and west UK to forage maize (Cooper and McGeechan, 1996; Davies *et al.*, 1996).

Perennial crops (e.g., grapevine, olive, and energy crops) have been relatively less studied in the context of climate change impacts. A study on the potential cultivation of grapevine in Europe under future climate scenarios has shown that there is potential for expansion of the wine-growing area in Europe and an increase in yield (see Figure 13-6b). Yet detailed predictions made for the main EU viticultural areas have shown an increase in yield variability (fruit production and quality). The quality of wine in good years is not guaranteed, and the demand for wine in poor years is not met, implying a higher economic risk for growers (Bindi *et al.*, 1996; Bindi and Fibbi, 2000). For olive, it was shown that in a $2xCO_2$ case, the suitable area for olive cultivation could be enlarged in France, Italy, Croatia, and Greece as a result of changes in temperature and precipitation patterns (Bindi *et al.*, 1992). For indeterminate energy crops that are favored by the longer growing season and by increased WUE resulting from higher CO_2 levels, higher temperatures and CO_2 concentrations generally would be favorable. A study of willow production in the UK found that warming generally would be beneficial for production, with increases in yield of as much as 40% for a temperature increase of 3°K (Evans *et al.*, 1995).

Livestock systems may be influenced by climate change directly by means of its effects on animal health, growth, and reproduction and indirectly through its impacts on productivity of pastures and forage crops. Heat stress has several negative effects on animal production, including reduced reproduction and milk production in dairy cows and reduced fertility in pigs (Furquay, 1989). This may negatively affect livestock production in summer in currently warm regions of Europe. Warming during the cold period for cooler regions is likely to be beneficial as a result of reduced feed requirements, increased survival, and lower energy costs. Impacts probably will be minor for intensive livestock systems where climate is controlled. Climate change may affect requirements for insulation and air-conditioning, however, and thus change housing expenses (Cooper *et al.*, 1998). The impact of climate change on grasslands will affect livestock living on these pastures. In Scotland, studies of the effect on grass-based milk production indicate that these effects vary by locality. For herds grazed on grass-clover swards, milk output may increase regardless of site, as a result of the CO_2 effect on nitrogen fixation (Topp and Doyle, 1996b).

Pest-disease-weed-host relationship can be affected by climate change in different ways. Pests, diseases, and weeds that currently are of minor significance may become key species, thereby causing serious losses. The distribution and intensity of current key pest, diseases, and weeds may be affected, leading to changed effects on yield and on control measures such as pesticides and integrated pest management. Competitive abilities in weed-plant interactions may be affected through changes in ecophysiology (i.e., CO_2 fertilization effects on C_3 and C_4 species). Pests and diseases generally will migrate as crops migrate (e.g., Lipa, 1997, 1999).

13.2.3.2. Fisheries

Detailed analyses of fish physiological response to water temperature have shown that the potential impact of climate change on freshwater and marine fish is large (Wood and McDonald, 1997). Unfortunately, current knowledge appears to be limited mostly to single key species, abstracted from the wider ecosystem context that supports fisheries production. It is likely that extrapolation from biological first principles will provide only limited foresight at a fisheries level in that context. However, it is likely that in the short term, fish will move to new habitats to find conditions to which they have adapted.

Two first-order effects—changes in biodiversity and changes in fisheries and aquaculture productivity—are examined. For each of these, key impacts in the European region are discussed with respect to temperature rise and other factors that are linked to climate change. For marine systems, these key factors are sea-level rise and changes in ice cover, salinity, and ocean currents; for inland waters, factors such as hydrological changes (e.g., dams, water abstraction), hydrochemical changes (including anoxia, water acidity, pollution and toxicity events), and eutrophication are key.

13.2.3.2.1. Freshwater and marine biodiversity

It has been possible, for the better-known species, to obtain a rough first picture of likely faunal movements and range shifts that would result from the temperature rise currently forecast for the European region.

This has been done, for example, for wild Atlantic salmon (*Salmo salar*), which sustains important recreational and commercial fisheries over most of northern Europe and has a high conservation indicator value over its entire range. Atlantic salmon spends its early and juvenile life in freshwater slowly moving away from the headwater spawning grounds in rivers out to sea, to grow and mature. Looking at the direct and indirect influence of temperature on protein synthesis on all life-cycle stages, McCarthy and Houlihan (1997) suggest that there will be a northward shift in the geographic distribution of Atlantic salmon in Europe, with likely local extinction at the southern edge of the current range and new habitats colonized in the north. The influence of temperature on overwintering survival of 1- and 2-year-old salmon and the distribution of post-smolts in the North Sea area already is apparent (Friedland *et al*., 1998).

High sensitivity to water temperature of fish larval and juvenile stages, combined with the higher susceptibility of headwaters and smaller rivers to air temperature rise, implies important effects of climate change on cold and temperate anadromous species such as the sea trout, alewife (*Alosa alosa* Atlantic and Mediterranean), and sturgeon (Atlantic, Black Sea, Caspian Sea). Similar impacts are likely for all salmonid species in Europe, including those that do not migrate to sea. Fish species are likely to extend their range northward (e.g., Brander, 1997). To identify impacts on recreational fisheries and conservation efforts that can be attributed to climate change, changes in local species presence will need to be assessed at a pan-European level, beyond watershed and national levels.

Global environmental change and introduction of species make it difficult to identify impacts of climate change in freshwater systems. Direct evidence of species shift and long-range movement often is physically limited between watersheds; introductions of alien species and genotypes—either voluntary or accidentally—have been very extensive. The influence of global warming on marine fish species and migratory species that reproduce and spend their early life history in marine waters (catadromous fish—e.g., eel) is more complex to foresee because of the various spatial and long temporal scales involved, as well as the feedback loop between air and ocean temperatures.

Some insight may be gained by reviewing historical shifts in the geographical distribution of European fish species to gain a better estimation of how fast and how far species may change their distributions. For example, the period of warming between 1920 and 1940 resulted in widespread changes in the distribution of terrestrial and marine species from Greenland to the Barents Sea.

13.2.3.2.2. Fisheries and aquaculture productivity

Future impacts on aquatic systems productivity from climate change are mostly uncertain because of other, related or independent, pressures. Resource overexploitation appears to be the single most important factor directly threatening the sustainability of many commercial fisheries in Organisation for Economic Cooperation and Development (OECD) countries (OECD, 1997). Overexploitation increases the vulnerability of fisheries to climate variability because so few fish are left in the stock to grow and multiply in a year of poor recruitment. The North Sea cod fishing industry, for example, now relies on only 1- or 2-year classes (Cook *et al*.,1997) and therefore is vulnerable to a year or two of poor recruitment caused by adverse climatic conditions.

Productivity of some fish stocks may benefit from warming trends. For example, recruitment of cod in the Barents Sea is higher in warm years. This probably comes about as a result of indirect effects (on capelin and zooplankton) as much as through direct effects.

Cod in the North Sea are at the warm end of their thermal range, and their recruitment therefore seems to benefit during cold periods, such as the 1960s and 1970s (Dippner, 1997; Brander, 2000). The temperature and wind regime of the North Sea are strongly influenced by the NAO, records of which go back more than a century. Some of the variability in catches of North Sea cod may be explained by trends in the NAO, but changes in exploitation are a major factor.

Other factors are likely to combine with changes in temperature and decrease fish and shellfish productivity. Chronic levels of pollution are known to reduce marine and freshwater fish fecundity (Kime, 1995), decrease freshwater supply (which exacerbates low dissolved-oxygen concentrations), increase solid transport from erosion, and increase habitat fragmentation in inland waters. Development of marine aquaculture may be slowed by a decreasing availability of sites with cool enough surface water temperature and by increased susceptibility to disease.

The consequences of fisheries collapse are complex. For example, the North Sea herring fishery collapsed in 1977 and was closed for 5 years. Although the rapid recovery of the resource surprised fisheries biologists, the most dramatic effect on the industry resulted from a permanent change of consumer preferences (Bailey and Steele, 1992) away from kippers and fresh and pickled herring. The fishery recovered, but the market did not.

Finally, the dramatic effect of climate change on fisheries production is well documented (Durand, 1998) for the world's four main upwelling systems: the California current, the Peru current, the Canary current (off northwest Africa and southern Spain and Portugal), and the Benguela current (off the Atlantic coast of southern Africa). Although these currents are mostly outside European waters, the effects on Europe's distant water fishing fleet, fishing sector investments, and import prices for human consumption and aquaculture feed cannot be ignored.

13.2.4. Other Impact Areas

13.2.4.1. Energy

Increasing temperatures will have a direct impact on energy use, especially in the domestic sector, as Palutikof *et al*. (1997) note for the unusually warm year of 1995 in the UK. The main effects of climate variability are on markets for space-heating fuels and on the amount of electricity used for air conditioning and refrigeration. Air conditioning has become universal in new office buildings, and there is a strong likelihood that it may spread to new markets such as houses and flats in future years. The relationship between climate change and the "take up" of new air conditioning installations is largely unknown, especially in areas where the practice currently is not widely used.

Requirements for heating and cooling can be estimated from the change in the number of heating and cooling degree days per year. In general, we can expect increased temperatures in Europe to lead to an increase in space cooling and a decrease in space heating requirements (Climate Change Impacts Review Group, 1991, 1996). Very mild winters in the EU, such as those experienced between 1988 and 1990, resulted in a 2% drop of energy demand. Milbank (1989) estimates that for northern Europe, a 4.5°C temperature rise would more than double summer electricity consumption by air conditioning and refrigeration systems.

13.2.4.2. Insurance

The insurance industry in Europe has an annual turnover of 600 billion EUR, with assets of 4,000 billion EUR. The common view is that the sectors that are most germane to climate change impacts and adaptation are property insurance and reinsurance. There will be lesser effects on other branches, such as casualty, life, and pensions, and the industry also could be affected in its investment activities by shifts in the economics of other industries that are impacted by mitigation policies (Dlugolecki and Berz, 2000). Essentially, the insurance industry "recycles" other sectors' monetary risks, thereby focusing information on such impacts. However, there is a wide variety of insurance systems in place in Europe, so international comparisons or extrapolations are difficult. In addition, many economic risks are not handled through insurance currently—for example, standing crops, flood damage, and "pure" economic losses where no physical damage has occurred. Weather affects insurers through the medium of property damage caused by a variety of extreme events; storm, flood, freeze, drought, and hail are the prime ones (Dlugolecki and Berz, 2000).

In early 1990, a series of storms in northwest Europe resulted in insured damage of 10 billion EUR. Despite the use of reinsurance, much of this risk remains within the European insurance industry. The risk will continue to rise because of pressure from economic growth and economic wealth. The industry's assets are sufficiently large to cope with purely European climate change impacts. The industry's main vulnerability is likely to arise outside Europe, from events such as hurricanes, earthquakes, or a global stock-market collapse. Human health impacts will be minimal for insurers as employers or suppliers.

This analysis assumes that there will be no major change in the scope of insurance services to include impacts that currently are not insured, such as standing crops, flood (in many countries), and pure economic losses. Establishment of the common market will help to reduce national differences in insurance services, but only slowly.

13.2.4.3. Industry and Transport

Asophisticated transport system has evolved in Europe to move people and goods. Efficient, rapid, reliable, and dependable transport is an essential part of the continent's infrastructure, and disruptions and dislocations to transport systems have a rapid impact on most industrial and commercial activities. Air transport probably is the most sensitive sector to weather and climate change and rail transport the most tolerant. In manufacturing and retailing, "just-in-time" distribution systems are quickly disrupted by adverse weather conditions. Changes in consumer demand for many products, which influence indices of retail sales (Agnew and Thornes, 1995), are likely to accompany climate change.

Significant changes in the frequency of short-term climatic extremes such as windstorms impact transportation (Perry and Symons, 1994). The impact of wind and windstorms includes the effect on land-based terminals such as seaports and airports, as well as in-transit delays and damage to the means of transport itself. Instances of wind shear associated with summer thunderstorms, which pose a hazard to aircraft during takeoff and landing, could become more common in Europe. Increases in rainfall and increasing frequency of temperature oscillating around the freezing point can be expected to lead to higher levels of corrosion of transport infrastructures. Flooding in rivers and low water levels lead to interruptions of river navigation.

Coastal transport infrastructure can be damaged by a combination of sea-level rise and increased storminess. In many countries, a significant percentage of manufacturing industry is located along coastlines and estuaries and may require expensive coastal protection schemes. Transport infrastructure in river valleys also may be damaged or destroyed during floods. There are management implications for winter maintenance activities on roads and railways. Savings may be possible, especially in western Europe as winter temperatures rise, but more freeze-thaw activity is expected in CEE as winter minimum temperatures oscillate around the freezing point. Analysis of the levels of saving that can be expected in different areas are required, together with cost-benefit studies to examine whether further investment in comprehensive ice-detection systems can be justified.

Comprehensive studies of the likely impacts of climate change on transport are in their infancy in many countries. Broad-scale assessments are needed of likely climate-induced demands for transport as lifestyles and residential and migration patterns change. The evidence that currently is available (summarized in the Europe ACACIA report), suggests that fewer severe winters would be beneficial to the manufacturing industry, reducing disruption at all stages from the supply of raw materials through processing to marketing of finished goods. However, an increase in the frequency of hot summers could disrupt some industrial processes that use large quantities of water. There may be some absolute limiting factors in some countries, such as lack of water for power stations, that can be overcome only through massive capital investment or new technology (Perry, 2000).

13.2.4.4. Tourism

The tourist industry in Europe is expected to continue to grow, in part as a result of higher incomes and more leisure time. Predominant tourist flows presently are from north to south; at present these flows help to transfer capital. Changes in recreational habits and preferences will lead to opportunities for tourist investment in new areas, but existing major tourist flows to the Mediterranean might be weakened if summer heat waves increase in frequency or if prolonged droughts result in water supply problems and forest fires. Giles and Perry (1998) have shown that summers as good as that of 1995 in northern Europe can lead to a drop in the numbers of outbound tourists from countries such as the UK to traditional Mediterranean sun destinations.

Changing demographic patterns—particularly an aging, wealthy population—may lead to an increase in winter and shoulder season tourism to Mediterranean resorts and expansion of retirement to attractive areas, particularly coasts. “Health tourism” to spas and mountains is likely to increase in Europe. In northern Europe, short breaks are likely to be taken over a longer season as temperatures rise.

The coastal zone is the primary tourist resource of Europe, and associated tourist infrastructure is at risk from sea-level rise, including unique tourist attractions such as the city of Venice (Perry, 1999). Beaches, wetlands, and estuaries also are tourist resources that are at risk. Already, many tourist amenities, such as coastal golf courses and hotels, require protection. The need to maintain coastal amenity values, as well as protect infrastructure, is an important factor that is encouraging a shift from hard, rigid defenses to softer approaches, including sediment management and nourishment (Penning-Rowsell *et al.*, 1992; Hamm *et al.*, 1998).

Heat stress and poor urban air quality may render cities undesirable locations in summer, with more tourist traffic to the country and the coast. Outdoor recreational spending is likely to increase.

Mountainous zones are used extensively for recreation and are the main sites of the European winter sports industry, which is based on snow resources that are vulnerable to climate change. Mohnl (1996) has shown that there is a statistically significant trend in snow-cover reduction in the Alps over recent years. Abegg and Froesch (1994) have suggested that assuming a 3°C rise in mean temperatures, the snow line in winter will rise by 300 m in the central Alps, the first snowfall of the season will be delayed, and below an altitude of 1,200 m there will not be continuous winter snow cover. As the season contracts, there will be a need to bolster winter tourism with increased use of artificial snow and more alternatives to outdoor skiing. In Scotland, the skiing industry is likely to experience more frequent snow-deficient winters, with adverse impacts on the financial viability of the industry.

Jaagus (1997) analyzed the impact of climate change on the snow-cover pattern in Estonia, where snow cover is important for winter sports and tourism. Indications are that a considerable drop in snow-cover duration will take place on islands and in the coastal region of west Estonia.

13.2.4.5. Migrations

Migration caused by soil degradation is a very important issue in the Mediterranean region, the southern part of which is mostly arid and vulnerable to climate change. With perhaps 24% of total drylands in Africa in the process of desertification and 0.3% of the African population permanently displaced largely as a result of environmental degradation (LeHouerou, 1992), consequent in-migration pressures on neighboring regions such as southern Europe can be substantial (Goria, 1999).

13.2.5. Human Health

Climate change will influence human health in several ways. Impacts will reflect the conditions of the ecological and social environments in which humans live. The impacts of projected changes in climate will depend on current and future public health defenses. Difficult economic conditions during the past decade have had serious implications for the delivery of health care and the public health infrastructure in some countries in CEE. These countries are most at risk from potential health impacts of climate change.

13.2.5.1. Thermal Stress and Air Pollution

One can expect an increase in the frequency of heat waves, as well as warmer summers and milder winters. Analyses in European cities show that total mortality rises as summer temperatures increase (Katsouyanni *et al.*, 1993; Kunst *et al.*, 1993; Jendritzky *et al.*, 1997). Episodes of extreme high temperatures (heat waves) also have significant impacts on health. Heat waves in July 1976 and July–August 1995 were associated with a 15% increase in mortality in greater London (McMichael and Kovats, 1998; Rooney *et al*., 1998). A major heat wave in July 1987 in Athens was associated with 2,000 excess deaths (Katsouyanni *et al*., 1988, 1993). Much of the excess mortality attributable to heat waves is from cardiovascular, cerebrovascular, and respiratory disease, and the elderly are particularly vulnerable to heat-related illness and death (Faunt *et al.*, 1995; Sartor *et al.*, 1995).

In cold and temperate locations, daily deaths increase as daily wintertime temperature decreases (Khaw, 1995; Laake and Sverre, 1996). Based on current evidence, climate change (increase in mean winter temperatures) is likely to result in a reduction in wintertime deaths, at least in temperate countries. Langford and Bentham (1995) estimate that 9,000 wintertime deaths yr^{-1} could be avoided by the year 2025 in England and Wales under a 2.5°C increase in average winter temperature. A meta-analysis by Martens (1997) estimates that an increase in global temperature could result in a reduction in winter cardiovascular mortality in Europe, leading to a decrease in mortality rates in regions with cold/temperate climates. At this time, the literature does not enable quantitative comparison between changes in summer and winter mortality.

Climate change also is likely to affect air quality in urban areas. Formation (and destruction) of secondary air pollutants, such as ozone, increases at higher temperatures and increased levels of sunlight. Studies in the United States indicate that climate change would entail an increase in average ambient concentrations of ozone and an increase in the frequency of ozone pollution "episodes" (USEPA, 1989). Experiments with the Hadley Centre climate model indicate significant increases in baseline ozone concentrations in Europe. Ozone and other air pollutants have significant impacts on health; these pollutants are considered to be one of the most important environmental health problems in Europe. Finally, climate change is likely to change the seasonality of pollen-related disorders such as allergic rhinitis (hay fever) (Emberlin, 1994).

13.2.5.2. Vector-Borne Diseases

Climate plays a dominant role in determining the distribution and abundance of insects and tick species—directly, through its effects on vector and parasite development, and indirectly through its effects on host plants and animals and land-use changes (McMichael *et al.*, 1996). Therefore, it is anticipated that climate change will have an effect on the geographical range and seasonal activity of vector species and, potentially, disease transmission (Bradley, 1993; Martens *et al.*, 1997; Martens, 1998).

As a result of deterioration of health systems, the recent resurgence of malaria in eastern Europe is now a growing cause for concern. Climate change could exaggerate this increased risk. In regions of southern Europe, climate change would increase the current very small risk of local (autochthonous) transmission. A few such cases are reported in the Mediterranean area under current climate conditions (e.g., in Italy—Balderi *et al*., 1998). Concomitant with increases in the volume of international travel, all countries in Europe have seen a steady increase in the number of imported cases of malaria, which provide the source of the pathogen (WHO, 1997). In the UK, however, local vectors are physiologically unable to transmit the most lethal form of malaria (falciparum) (Marchant *et al.*, 1998). Although localized outbreaks are more likely to occur under climate change, in northern and western Europe existing public health resources and a lack of breeding habitats necessary to maintain high densities of mosquitoes make re-emergent malaria unlikely.

Dengue currently is not present in Europe, although it has been present in the past (Gratz and Knudsen, 1996). However, one of the vectors (*Ae. albopictus*) currently is extending its range in Europe, and climate change could facilitate this expansion (Knudsen *et al*., 1996). This vector has been reported in Italy since 1990 and in Albania since 1979.

In all countries bordering the Mediterranean, cutaneous and visceral leishmaniasis are transmitted to humans and dogs by phebotomine sandflies (Dedet *et al.*, 1995). Higher temperatures are likely to change the geographical distribution of the important sandfly vector species and accelerate maturation of the protozoal parasite, thereby increasing the risk of infection (Rioux *et al.*, 1985). Increased incidences of visceral leishmaniasis, unrelated to immune suppression, have been reported from regions of Italy and coastal Croatia (Gabutti *et al.*, 1998; Punda-Polic *et al.*, 1998). Several imported cases of canine leishmaniasis are reported in Germany, Switzerland, and Austria every year (Gothe *et al.*, 1997). Thus, imported canine cases are a potential source of the pathogen, if the vectors expand further north with climate change.

Ixodid ticks (e.g., *Ixodes ricinus* and *I. persulcatus*) are widely distributed in temperate regions and transmit tick-borne diseases in Europe, of which Lyme disease (Berglund *et al*., 1995) and tick-borne encephalitis (TBE) are the most important (Tälleklint and Jaenson, 1998). In Sweden, TBE incidence has increased after milder winters, in combination with extended spring and autumn seasons during 2 successive years (Lindgren, 1998). There also is some evidence that the northern limit of the distribution of ticks in Sweden has moved northward between 1980 and 1994 as a result of the increased frequency of milder winters (Tälleklint and Jaenson, 1998; Lindgren *et al*., 2000). Climate change may extend the length of the transmission season of tick-borne diseases and facilitate spread to higher latitude and altitudes in northern Europe. However, a model-based study indicates that overall the region suitable for TBE transmission may contract significantly (Randolph and Rogers, 2001).

13.2.5.3. Water-Related Diseases

Climate change could have a major impact on water resources and sanitation in situations where water supply is effectively reduced. Some populations in eastern Europe with restricted access to water in the home would be vulnerable to any climate-related decreases in freshwater availability. Decreased water availability also could lower the efficiency of local sewage systems and may necessitate use of poorer quality sources of freshwater, such as rivers. All of these factors could result in an increased incidence of water-borne diseases.

The most significant water-borne disease associated with the public water supply in western Europe is cryptosporidiosis. Increases in the frequency or intensity of extreme precipitation events can increase the risk of outbreaks of this disease. Cases of cercarial dermatitis (water-based parasitic disease) may increase if the climate becomes more favorable for the host—a water snail (de Gentile *et al*., 1995).

13.2.5.4. Food-Borne Diseases

Warmer climate in combination with inappropriate food behavior may contribute to increased incidences of food-borne diseases. A study of food-borne illness in the UK found a strong relationship between incidence and temperature in the month preceding the illness (Bentham and Langford, 1995). The distribution and activity of flies, cockroaches, and rodents could change in response to climatic changes. These species are carriers of food-borne pathogens and are considered to be major hygienic pests in the domestic environment.

13.2.5.5. Health Implications of Floods

The risk of flooding (coastal and riverine) is likely to increase in Europe under climate change. With this risk comes additional risk to people's health as a consequence of flooding (Menne *et al.*, 1999). Some floods in Europe have been associated with an increased risk of leptospirosis—for example, outbreaks were reported following floods in Ukraine and the Czech Republic in 1997 (Kriz, 1998: Kriz *et al*., 1998) and in Portugal in 1967 (Simoes, 1969). Many cases of post-flood food poisoning were noted during and after the Odra flood in 1997.

Some of the effects of flooding on mortality and ill health in developed countries is attributable to the distress and psychological effects of the event (Bennett, 1970). This was demonstrated in the Easter 1998 flooding in parts of England (the worst since 1947); the majority of flood victims interviewed cited stress associated with the event and post-flood recovery as the worst aspect of their experience (Tapsell and Tunstall, 2000). Cases of post-traumatic stress disorder, including 50 flood-linked suicides, were reported in the 2 months following the major floods in Poland in 1997 (IFRC, 1998). The health effects of flooding are complex and can result from a combination of factors. The impact of flooding on mental health therefore may be significant.

13.3. Adaptation Potential

In this section, our analysis is restricted to adaptation in the major primary sectors (water, soils, ecosystems, agriculture) and in coastal regions. These are the main sectors where adaptation will be needed.

13.3.1. Water

There are, broadly, two different approaches to adaptation in the water sector: "supply side" (change the water supply) and "demand side" (alter exposure to stress). Table 13-6 summarizes some supply-side and demand-side techniques that are available to cope with adverse impacts in the water sector and may be appropriate in the face of climate change.

Table 13-6*: Adaptive techniques in the water sector: some examples.*

Impact	Supply Side	Demand Side
Reduced water-supply potential	– Change operating rules – Increased interconnections between sources – New sources – Improved seasonal forecasting	– Reduce demand (through pricing, publicity, statutory requirements, etc.)
Increased stress on irrigation water	– New sources (e.g., on-farm ponds storing winter runoff)	– Increase irrigation efficiency – Change cropping patterns
Increased flood risk	– Increase flood protection	– Accept higher risk of loss – Reduce exposure by relocation
Reduced navigation opportunities	– Enhance water-level management – Increase dredging	– Smaller ships
Reduced power generation opportunities	– Install/increase water storage	– Increase cooling water-use efficiency

"Supply-side" techniques to address water resources and risks are most widely known and used at present. In terms of water supply, these strategies include building new supply and distribution infrastructure and managing existing sources more efficiently. There is an increasing tendency toward conjunctive use of different sources within a region. Supply-side techniques in flood management are termed structural adjustments; they involve actions to lessen flood peaks and keep floodwaters away from at-risk property. Demand-side techniques historically have been less well used but are the focus of increasing attention. In terms of water supply, the most obvious demand-side approach is to reduce the demand (or slow the increase in demand) for the water resource through a range of measures, including differential pricing, public awareness campaigns, or statutory requirements for WUE (e.g., for domestic appliances).

Attention to date has been concentrated on supply-side options; demand-side techniques are less well-known and the subject of considerable technological advance. Although there is a good deal of awareness of broad options, there has been less research into applying these options in an uncertain future: How, for example, can a water distribution network be designed so that it can be incrementally updated as more information on climate change appears, rather than built to a single fixed standard?

An adaptation in one aspect of the water environment or in one area might have a severe effect on another aspect or area. For example, increased use of a river to maintain supplies may impact the instream environment. Increased storage of water in a reservoir over the winter might reduce its ability to prevent flooding. Finally, the time scales over which adaptation can occur vary. Some adaptive strategies can be implemented with little warning and can be easily amended. Others take longer to implement and, once completed, are harder to change. For example, it typically takes decades for a reservoir to move from the planning stage to completion. Urban storm drainage has a relatively short lead time but a very long design life. An ideal adaptive strategy is one that can be altered as more information becomes available. However, the adaptive response by a water management agency to climate change will depend on procedures for considering strategies, as well as adaptive capacity.

13.3.2. Soils

The use of land management techniques in adaptation to climate change will seek to maintain soil functions. A summary of appropriate techniques and their relationships to the soil functions and properties discussed earlier in this chapter is given in Table 13-7.

13.3.3. Ecosystems

Tundra areas have practically no adaptive options available. The only possible response is to better protect areas with particular value (e.g., for bird life) from other stresses such as land exploitation and tourism.

In boreal regions, many effects of climate change and CO_2 increase, as noted above, are positive in terms of productivity. Areas that are under threat (e.g., low-productivity mountain forests) have no adaptive options available. If changing water tables present a significant problem, boreal wetlands could receive technical measures for controlling water level, but such measures are unlikely to be technically and economically feasible in many areas. Other approaches to adaptation can include establishment of buffer areas around wetlands, promotion of sustainable uses of wetlands to minimize additional stresses brought on by climate change, and restoration of already destroyed wetland habitats (Hartig *et al.*, 1997).

Water shortage in parts of the temperate zone may be compensated to some extent by additional irrigation or river management. To achieve any large-scale effect, however, such measures would have to be applied in economically infeasible dimensions. Most other areas will have positive effects and therefore no adaptive problems.

In the Mediterranean, many landscapes face an acute management problem already without climate change because bush encroachment in earlier agricultural areas is affecting many ecosystems with respect to species richness and susceptibility to fire. Climate change may aggravate these developments in some areas. It is not likely that there are direct ways to adapt to these trends.

With regard to forests, the central problem is that any potential adaptation requires long-term planning. Essentially, adaptation to climate would require planting trees today that will be suitable for such a future climate. However, given our uncertainties in the prediction of future climate and the formulation of models that are used to assess its ecological impacts, it is unlikely that adaptation measures will be put into practice in a timely manner.

13.3.4. Agriculture

To avoid or at least reduce negative effects and exploit possible positive effects, several economic and agronomic adaptation strategies for agriculture have been suggested. Economic strategies are intended to render the agricultural costs of climate change small by comparison with overall expansion of agricultural products. Agronomic strategies intend to offset the loss of productivity caused by climate change, either partially or completely. Agronomic strategies include short-term adjustments and long-term adaptations.

13.3.4.1. Short-Term Adjustments

Short-term adjustments to climate change are efforts to optimize production with major system changes. They are autonomous in the sense that no other sectors (e.g., policy, research) are needed for their development and implementation. Thus, short-term adjustment can be considered the first defense tool against

Table 13-7: *Land management options to mitigate impact of climate change on soils.*

Function	Impact	Management/Adaptation Options
Land production	– Salinization – Peat wastage – Acidification – Erosion – Compaction – Soil biodiversity	– Improved technology for application, better water quality, better water scheduling – No drainage of lowland peat soils – Soil pH management – Soil conservation techniques (expand) – Better timing of field operation, use of new tillage equipment – ???
Land regulation	– Soil water – Soil organic matter – Soil nutrients – Polluting chemicals – Soil temperature – Soil material resources	– Irrigation (with improved technology and scheduling) – Use of manures, reduced tillage, improved farming system methods, crop rotation management – Sustainable use of fertilizers/manures, crop rotation management – Limits on use of polluting chemicals, clean-up of contaminated land – Mulching – No adaptation possible
Land carrier	– Water movement and soil structure – Nitrate leaching – Volatilization – Carbon dioxide fluxes – Methane fluxes – Nitrous oxide fluxes	– Management of vertisols(?), timing of manure and sewage sludge applications – Change in fertilizer application rates, precision farming, crop selection (i.e., with different N requirements), breeding nitrogen-fixing crops, breeding crops to improve N-use efficiency (e.g., lower requirements, more efficient uptake), irrigation management, soil pH management, nitrification inhibitors, release rates (e.g., slow or timed release, coatings to limit or retard water solubility), improved fertilizer placement and timing (e.g., band placement, foliar applications), application placement (e.g., slurry injection), application timing, application amounts (e.g., controlled rate systems) – See management options appropriate to reduce nitrate leaching – Land-use change for carbon sequestration – Increased sink through fertilizer management – See management options appropriate to reduce nitrate leaching
Land information	– Historical record	– Conserve intact soil profiles and representative reference sites
Land consumption	– Shrink/swell damage	– Underpinning of building foundations, insure differently (e.g., location restrictions)

climate change. A large range of such adjustments have been reported, including:

- *Changes in planting dates and cultivars:* For spring crops, climate warming will allow earlier planting or sowing than at present. Crops that are planted earlier are more likely to have already matured when extreme high temperatures, such as in the middle of summer, can cause injury. Earlier planting in spring increases the length of the growing season; thus, earlier planting and use of long-season cultivars will increase yield potential, provided moisture is adequate and the risk of heat damage is low. Otherwise, earlier planting combined with a short-season cultivar would give the best assurance of avoiding heat and water stresses. Deeper planting of seeds also will contribute to making seed germination more likely. For winter crops (i.e., cereals), this approach may cause problems because their cycle length often is linked with cold temperature requirements (vernalization) that may not be completely fulfilled during warmer winters. Late cultivars also may not be able to escape heat and drought risks in the summer. Winter cereals must have a specific growth stage before the onset of winter to ensure winter survival, and they often are sown when temperatures approach the time when vernalization is most effective (Harrison and Butterfield, 1996). This may mean later sowings in northern Europe under climatic warming.
- *Changes in external inputs:* External inputs are used to optimize production of crops in terms of productivity and profitability. The use of fertilizers generally is adjusted to fit the removal of nutrients by the crop and any losses of nutrients that may occur during or between growing seasons. A change in yield level therefore, all other things being equal, will imply a corresponding change in fertilizer inputs. Projected

increases in atmospheric CO_2 concentration will cause a large nitrogen uptake by the crop and thus larger fertilizer applications. On the other hand, climatic constraints on yields may lead to less demand for fertilizers. Changes in climate also may cause larger (or smaller) losses of nitrogen through leaching or gaseous losses. This also may lead to changes in the demand for fertilizer. Global warming will lead to a higher incidence of weeds, pests, and diseases in many areas and thus to potentially increased use of chemical control measures (e.g., pesticides). These inputs can be kept low through adoption of integrated pest management systems, which adjust control measures to the observed problem and also take a range of influencing factors (including weather) into account. Current fertilizer and pesticide practices are based partly on models and partly on empirical functions obtained in field experiments. These models and functions are updated regularly with new experimental evidence. This process probably will capture the response of changes in the environment through CO_2 and climate. It is important, however, that agricultural researchers and advisors are aware of the possible impact of global change on the use of external inputs, so that older empirical data are used with proper caution.

- *Practices to conserve moisture:* Several water-conserving practices are commonly used to combat drought. These also may be used to reduce climate change impacts (Easterling, 1996). Such practices include conservation tillage and irrigation management. Conservation tillage (the practice of leaving some of the previous season's crop residues on the soil surface) may protect the soil from wind and water erosion and retain moisture by reducing evaporation and increasing infiltration of precipitation into the soil. Irrigation management can be used to improve considerably the utilization of applied water through proper timing of the amount of water distributed. For example, with irrigation scheduling practices, water is applied only when the crop needs it. This tunes the proper timing and amount of water to actual field conditions, allowing a reduction in water use as well as the cost of production.

13.3.4.2. Long-Term Adaptations

Long-term adaptations refer to major structural changes to overcome adversity caused by climate change. These may include:

- *Changes in land use* result from the differential response of crops to climate change. Studies reported by Parry *et al.* (1988) for central Europe show an "optimal land use" in which the area cultivated with winter wheat, maize, and vegetables increases while the allocation to spring wheat, barley, and potato, decreases. Changes in land allocation also may be used to stabilize production. In this case, crops with high interannual variability in production (e.g., wheat) may be replaced by crops with lower productivity but more stable yields (e.g., pasture).
- *Biotechnology* offers another possibility to adapt to stresses (heat, water, pests and disease, etc.) that are enhanced by climate change by allowing development of "designer cultivars" (Goodman *et al.*, 1987)—considering strictly the principles of biosafety to avoid possible negative impacts of this technique. Species that have not been used previously for agricultural purposes may be identified and others already identified may be more quickly brought into use.
- *Crop substitution* also may be useful for conservation of soil moisture. Some crops use a low amount of water and are more water- and heat-resistant, so they tolerate dry weather better than others do. For example, sorghum is more tolerant of hot and dry conditions than maize.
- *Microclimate modification* may be used to improve WUE in agriculture. Windbreaks, for example, reduce evaporative demand from the plants they shelter. Sheltered plants remain better hydrated and thus are better able to carry out photosynthesis (Rosenberg, 1979). A wide array of intercropping, multi-cropping, relay cropping, and other techniques provide greater production per unit area occupied and can be useful to improve WUE. Irrigation efficiency can be improved considerably with new land-field techniques (laser-leveling of fields, minimum tillage, chiseling compacted soils, stubble mulching, etc.) or new management strategies (irrigation scheduling, monitoring soil moisture status, etc.) (Kromm and White, 1990).
- *Changes in farming systems* may be necessary in some areas for farming to remain viable and competitive. Specialized arable farms with production of vegetables, cereals, seed crops, fruits, and other crops often have only a few species on the farm, depending on soil and climate conditions. These specialized farms, especially dairying and arable, may be more affected by climate change than mixed farms. Mixed farms with both livestock and arable production have more options for change and thus larger resilience to change in the environment.

Studies on adapting farming systems to climate change need to consider all of the agronomic decisions made at the farm level (Kaiser *et al*., 1993). Economic considerations are very important in this context (Antle, 1996). Results of farm-level analyses on the impacts of climate change generally have shown a large reduction in adverse impacts when adaptation is fully implemented. However, this will result in land-use changes (Parry *et al*., 1999).

13.3.5. Coastal Regions

Three broad response strategies are distinguished (Klein *et al.*, 2000):

- Reduce the risk of the event by decreasing its probability of occurrence

- Reduce the risk of the event by limiting its potential effects
- Increase society's ability to cope with the effects of the event.

These strategies have been termed "protect," "retreat," and "accommodate," respectively. Protection usually is associated with coastal squeeze and hence a decline in natural functions and values, although soft protection approaches may not raise this problem.

The actual strategy chosen will depend on local and national circumstances, including the economic and ecological importance of the coastline, technical and financial capabilities, and the legislative and political structure of the countries concerned. Although optimum response strategies have yet to be developed, it is likely that a range of responses will be the norm within any country (Bijlsma *et al*., 1996). Turner *et al.* (1995) analyzed protection in East Anglia, England. At the aggregated scale of East Anglia, protection can be justified for the entire coast given a 50-cm rise in sea level by 2050. However, this is not the scale at which coastal management decisions are made. When the 113 individual flood compartments are evaluated independently, 20% optimally would be abandoned even for present rates of relative sea-level rise (10-cm rise in sea level by 2050). This analysis assumes that there is no interaction between flood compartments—which may not always be the case. However, it reinforces the conclusion that a range of responses will be appropriate.

Some national estimates of protection costs are given in Table 13-5, primarily for a 1-m rise in sea level. In terms of relative costs, Poland appears to be more vulnerable than Germany and The Netherlands. The absolute costs for Germany are larger than for The Netherlands, reflecting the much longer German coastline.

Adapting successfully to climate change requires more than a list of options. Klein *et al.* (1999) argue that successful adaptation must consider several issues, including recognizing the need for adaptation, planning, implementation, and evaluation. Although there is increasing recognition of the need for adaptation in some countries, this is not uniform across Europe (e.g., Nicholls and Hoozemans, 1996). It also is clear that coastal adaptation to climate change must happen in the broader context of coastal management.

Response options may be hindered by resource constraints. In Cyprus, the coast is no longer receiving new supplies of sand as a result of catchment regulation and management (Nicholls and Hoozemans, 1996). Erosion is expected in response to sea-level rise, but there are no ready sources of sand available for beach nourishment. Yet maintaining the beach is critical to the tourist industry. Although this problem has not been analyzed in detail, external (and hence costly) sources of sand may be required for beach nourishment. Many other Mediterranean islands appear to have similar problems, including those in Greece, Italy, France, and Spain.

Some adaptation that anticipates climate change already is being implemented, and this seems to be raising important questions about long-term coastal management (Klein *et al*., 1999). The Netherlands is highly threatened by sea-level rise (see Table 13-5): About 60% of the country (23,600 km^2) is in the potential impact zone (Baarse *et al*., 1994). A new national law "outlaws" erosion and mandates maintenance of the present shoreline position via ongoing beach nourishment (Koster and Hillen, 1995). However, a debate about the optimum response continues; some people advocate a more dynamic response, including a mixture of holding the line, allowing some retreat, and coastal advancement in areas where more land is required (de Ruig, 1998; Klein *et al*., 1998). The debate includes explicit consideration of maintaining and enhancing coastal resilience.

In Britain, coastal cells have become the basis of shoreline management; about 40 shoreline management plans that cover the entire coastline of England and Wales are finished or nearing completion (UK Ministry of Agriculture, Fisheries, and Food, 1995; Leafe *et al*., 1998). Managed realignment of sea defenses in estuaries also is attracting increasing attention, including some trial experiments (Klein *et al*., 1999). Low-grade agricultural land is given up to the sea as flood defenses are abandoned or relocated inland. If managed realignment is practiced at a large scale, it will help to maintain natural values as well as the flood protection benefits of coastal wetlands under a rising sea level. However, there will be a corresponding net loss of freshwater ecosystems in the protected areas (Lee, 1998). About 100 ha yr^{-1} of land would need to be released just to counter present rates of salt marsh loss resulting from sea-level rise. Although the economic analysis of Turner *et al.* (1995) would suggest that there are many suitable sites available, this requires strategic planning to be put in place as part of shoreline management planning (UK Ministry of Agriculture, Fisheries, and Food, 1995; Leafe *et al*., 1998). Political acceptance of managed retreat remains to be assessed.

Around the Mediterranean, models of deltaic response to sea-level rise and frameworks to analyze vulnerability and sustainability are being developed (e.g., Sanchez-Arcilla *et al*., 1998). This raises the prospect of a dynamic management approach that harnesses natural inputs and processes within deltas to counter global and local (as a result of subsidence) sea-level rise, rather than a move to hard defenses.

One pertinent issue is cross-border transport of sediment, which has costs within the country of origin but reduces the vulnerability of the receiving country to sea-level rise. For instance, coastal erosion on the east coast of England provides mud that helps to sustain the Wadden Sea in The Netherlands and Germany under rising sea level (Dyer and Moffat, 1998; Nicholls and Mimura, 1998). This suggests a need for a regional perspective on the coastal impacts of sea-level rise.

In conclusion, a common problem across Europe is developing strategic management approaches that allow both continued human utilization of the coastal zone and preservation of coastal ecosystems, given sea-level rise (Nicholls, 2000). Slow but steady degradation of the coastal fringe in much of Europe has gone largely unnoticed until recently, and this will continue and accelerate with sea-level rise. Developing methods to balance protection of people and the economy against the costs of degradation of the coastal environment will require multidisciplinary research.

13.4. Synthesis

13.4.1. Key Impacts

Two important messages emerge from this review:

- Potential impacts on key resources (land, ecosystems, and particularly water) are significant.
- Even in prosperous Europe, adverse climate change impacts may aggravate equity issues.

Climate change in Europe will involve losses and gains to the natural resource base; in some cases, these changes have begun. These impacts will vary substantially from region to region (they will be particularly adverse in the south) and within regions, from sector to sector as well as within sectors. The significance of these effects, however, will depend to a considerable extent on nonclimatic drivers of environmental change, socioeconomic development, and policy evolution within Europe. The most significant impacts (and opportunities) that will require greatest attention with respect to policies of response may be summarized in general terms as follows (a fuller precis appears in the Executive Summary at the beginning of this chapter). Climate changes as characterized by the scenarios described in Chapter 3 of this report, if not adequately responded to through effective adaptation and policy development, would lead in Europe to:

- Increased pressures on water resources, particularly in the south
- Aggravated flood hazard
- Deterioration in soil quality
- Altered natural eosystems, with loss of some habitats and potential loss of species
- Increased productivity of northern commercial forests but reductions in the south
- Increased forest fire risk
- Positive effects on agriculture in the north but broadly negative effects in the south
- Altered fisheries potential
- Increased property damage
- Relatively minor effects on the transport, energy, and manufacturing sectors, some of which may be positive (though substantial effects may derive from policies of mitigation that are necessary to reduce impacts elsewhere)
- Changing tourist potential
- A range of human health implications
- Increased risk of flooding, erosion, wetland loss, and degradation in coastal zones
- Upward shift of biotic zones and snowlines in mountain regions.

In general, more adverse effects may be expected to occur in regions of Europe that are economically less developed because adaptive capacity will be less developed there. These areas would include more marginal areas of the EU and regions outside the EU such as the Balkans.

13.4.2. Uncertainty

The ability to adapt to adverse impacts and exploit opportunities as they emerge is significant. However, present uncertainties with regard to the magnitude and even the sign of the impacts, which characterize almost all of the conclusions reported in this chapter, often will hinder such efforts. These uncertainties stem from uncertainties concerning how climate may change in the future (a subject considered in Chapter 3) and how the

Table 13-8*: Minimum, maximum, and median estimates of changes in water-limited wheat yield (t ha^{-1}) from baseline climate derived from running 24 climate change scenarios for 2050 through EuroWheat model. Estimates are summaries for selected regions in Europe (Harrison and Butterfield, 1999). Result for HadCM2 scenario also is shown.*

	Summary of 24 Scenarios			
Region	Minimum	Maximum	Median	**HadCM2**
Nordic countries	0.7	3.5	2.1	2.8
British Isles	0.9	2.6	1.7	1.8
Germany + Benelux	0.7	2.5	1.7	2.1
Alpine countries	1.5	3.2	2.1	2.8
France	-1.5	3.0	1.3	1.5
Portugal + Spain	-0.9	4.5	1.4	1.2
Italy + Greece	0.7	3.6	1.7	1.8
Poland	-0.5	2.2	1.3	1.7
Central Europe	-1.7	2.6	1.7	1.7
Bulgaria + Romania	-2.9	2.3	1.0	0.8

natural resource base may respond to such changes. In some cases, the combination of these uncertainties may mean that we are unsure about whether the total effect is broadly positive or negative. To illustrate, Table 13-8 shows the estimated effect of a wide range of possible climate futures on wheat yields in different regions of Europe. In half of the regions, yield responses range from negative to positive.

Low-probability/high-consequence events (sometimes termed "surprises") such as collapse of the thermohaline circulation of the North Atlantic (Hulme and Carter, 2000) also need to be considered (see Chapters 3 and 19). Therefore, caution must be exercised in interpreting currently available information, and there must be recognition that much more research is needed. This might include identifying flexible actions that are robust to a range of possible futures.

13.4.3. Research Needs

Further investigation is needed to understand how European climate is likely to change under various emission trends, as well as what the implications of these changes would be for Europe's human and ecological systems. There is a need to analyze outputs from climate models that relate to extreme events. The biophysical impacts of climate change on European water, soil, and land resources have been quite thoroughly researched, but we know less about their socioeconomic consequences (e.g., in agriculture, fisheries, nature conservation, transport systems, and tourism). Improved knowledge of European coastal systems is required for their sustainable management. A key research challenge is to evaluate the feasibility, costs, and benefits of potential adaptation options, measures, and technologies. In general, research programs could benefit from more integration between basic studies of the Earth system, climate change modeling, impact and adaptation assessments, and mitigation/policy analysis. Key research challenges include:

- Transboundary regional impact assessment of various natural and socioeconomic systems
- Transboundary monitoring of impacts on sensitive ecosystems
- Better understanding of likely changes in extreme weather events
- Quantification of natural and technological hazards resulting from climate change (especially flooding)
- Guidelines for water management decisions for different regions under climatic uncertainty
- Changes in European legislation for adaptation to and/or mitigation of climate change impacts.

13.4.4. Regional Issues

13.4.4.1. Extreme Events

One of the most important continent-wide issues is the effect of climate change on future water resources, particularly on extreme events—whether abundance or scarcity of water will increase in severity. A tendency toward increases in the frequency of extreme events is likely but largely unquantified. The implications of changes in the characteristics of extreme hydrological events extend beyond the water sector into agriculture, industry, settlements, coastal zones, transport, tourism, health, and insurance. Climate change is likely to lead to increased winter flows in much of Europe. In Mediterranean Europe, it is likely to increase variability in flow through the year, with summer flows reduced. In coastal areas, the risk of flooding and erosion will increase substantially. Instability of thermohaline circulation is a process whose probability of occurrence in the 21st century is low (see Chapters 3 and 19), yet potential consequences of this on the changing heat budget in Europe are very great.

13.4.4.2. Subregional Impacts

Climatic observations and the scenarios presented here suggest that southern Europe will be more adversely affected than northern Europe. Ashift in climate-related resources from south to north may occur in sectors such as tourism, agriculture, and forestry. In particular, the Mediterranean region appears likely to be adversely affected. Among likely adverse effects are increased variability of river flow; increased flood risk; decreased summer runoff and recharge of aquifers; and reduced reliability of public water supply, power generation, and irrigation. Increased fire hazards affecting populated regions and forests and heat stress to humans, crops, and livestock may occur. Even a change of tourist destinations is possible if the present optimal summertime climate shifts northward, and heat waves and water shortages may jeopardize the attractiveness of the present southern summer destinations.

13.4.4.3. Sustainability and Equity

Sustainable development (understood as relaying natural capital to future generations in a nondepleted state) has been in jeopardy in Europe from several existing pressures, mostly nonclimatic (e.g., land-use change, environmental pollution, atmospheric deposition). Yet climate change adds an important element to the threat to the environment. Sea-level rise threatens coastal habitats with a squeeze between hard defenses and rising water levels. Most (50–90%) of the alpine glaciers could disappear by the end of the 21st century, and there may be local extinctions of species that require cold habitats for their survival (e.g., subarctic and montane species). Many ecosystems will respond to climate change via migration and change; a policy challenge is how to manage these changes.

Finally, climate change impacts will be differently distributed among different regions, generations, age classes, income groups, occupations, and genders. This has important equity implications, although these implications have not been investigated in detail. For example, elderly and sick people suffer more in heat waves. There is greater vulnerability, in general, in southern than in northern Europe. Mediterranean and mountain farmers are likely to be worse off in a warmer world. This presents a challenge to existing regional policies within the EU that are aimed at leveling up less-developed areas (peripheral Europe versus core Europe). In general, the more marginal and less wealthy areas will be less able to adapt, so climate change without appropriate policies of response may lead to greater inequity.

Possible climate change impacts on key resources are sufficient to warrant early consideration by European policymakers to ensure sustainable development. In general, the adaptation potential of socioeconomic systems in much of Europe is high because of economic conditions, a stable population with the capacity to move within the region, and well-developed political, institutional, and technological support systems.

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