# 23 Europe

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## Executive Summary

**Observed climate trends and future climate projections show regionally varying changes in temperature and rainfall in Europe (*high confidence*), {23.2.2}** in agreement with Fourth Assessment Report (AR4) findings, with projected increases in temperature throughout Europe and increasing precipitation in Northern Europe and decreasing precipitation in Southern Europe. {23.2.2.2} Climate projections show a marked increase in high temperature extremes (*high confidence*), meteorological droughts (*medium confidence*), {23.2.3} and heavy precipitation events (*high confidence*), {23.2.2.3} with variations across Europe, and small or no changes in wind speed extremes (*low confidence*) except increases in winter wind speed extremes over Central and Northern Europe (*medium confidence*). {23.2.2.3}

**Observed climate change in Europe has had wide ranging effects throughout the European region including the distribution, phenology, and abundance of animal, fish, and plant species (*high confidence*) {23.6.4-5; Table 23-6}; stagnating wheat yields in some sub-regions (*medium confidence*, limited evidence) {23.4.1}; and forest decline in some sub-regions (*medium confidence*). {23.4.4}** Climate change has affected both human health (from increased heat waves) (*medium confidence*) {23.5.1} and animal health (changes in infectious diseases) (*high confidence*). {23.4.2} There is less evidence of impacts on social systems attributable to observed climate change, except in pastoralist populations (*low confidence*). {23.5.3}

**Climate change will increase the likelihood of systemic failures across European countries caused by extreme climate events affecting multiple sectors (*medium confidence*). {23.2.2.3, 23.2.3, 23.3-6, 23.9.1}** Extreme weather events currently have significant impacts in Europe in multiple economic sectors as well as adverse social and health effects (*high confidence*). {Table 23-1} There is limited evidence that resilience to heat waves and fires has improved in Europe (*medium confidence*), {23.9.1, 23.5} while some countries have improved their flood protection following major flood events. {23.9.1, 23.7.3} Climate change is *very likely* to increase the frequency and intensity of heat waves, particularly in Southern Europe (*high confidence*), {23.2.2} with mostly adverse implications for health, agriculture, forestry, energy production and use, transport, tourism, labor productivity, and the built environment. {23.3.2-4, 23.3.6, 23.4.1-4, 23.5.1; Table 23-1}

**The provision of ecosystem services is projected to decline across all service categories in response to climate change in Southern Europe (*high confidence*). {23.9.1; Box 23-1}** Both gains and losses in the provision of ecosystem services are projected for the other European sub-regions (*high confidence*), but the provision of cultural services is projected to decline in the Continental, Northern, and Southern sub-regions (*low confidence*). {Box 23-1}

**Climate change is expected to impede economic activity in Southern Europe more than in other sub-regions (*medium confidence*) {23.9.1; Table 23-4}, and may increase future intra-regional disparity (*low confidence*). {23.9.1}** There are also important differences in vulnerability within sub-regions; for example, plant species and some economic sectors are most vulnerable in high mountain areas due to lack of adaptation options (*medium confidence*). {23.9.1} Southern Europe is particularly vulnerable to climate change (*high confidence*), as multiple sectors will be adversely affected (tourism, agriculture, forestry, infrastructure, energy, population health) (*high confidence*). {23.9; Table 23-4}

**The impacts of sea level rise on populations and infrastructure in coastal regions can be reduced by adaptation (*medium confidence*). {23.3.1, 23.5.3}** Populations in urban areas are particularly vulnerable to climate change impacts because of the high density of people and built infrastructure (*medium confidence*). {23.3, 23.5.1}

**Synthesis of evidence across sectors and sub-regions confirm that there are limits to adaptation from physical, social, economic, and technological factors (*high confidence*). {23.7; Table 23-3}** Adaptation is further impeded because climate change affects multiple sectors. {23.7} The majority of published assessments are based on climate projections in the range 1°C to 4°C global mean temperature per century. Limited evidence exists regarding the potential impacts in Europe under high rates of warming (>4°C global mean temperature per century). {23.9.1}

### *Impacts by Sector*

**Sea level rise and increases in extreme rainfall are projected to further increase coastal and river flood risk in Europe and, without adaptive measures, will substantially increase flood damages (people affected and economic losses) (*high confidence*). {23.3.1, 23.5.1}** Adaptation can prevent most of the projected damages (*high confidence*, based on *medium evidence*, *high agreement*) but there may be constraints to building flood defenses in some areas. {23.3.1, 23.7.1} Direct economic river flood damages in Europe have increased over recent decades (*high confidence*) but this increase is due to development in flood zones and not due to observed climate change. {23.3.1.2; SREX 4.5} Some areas in Europe show changes in river flood occurrence related to observed changes in extreme river discharge (*medium confidence*). {23.2.3}

**Climate change is projected to affect the impacts of hot and cold weather extremes on transport leading to economic damage and/or adaptation costs, as well as some benefits (e.g., reduction of maintenance costs) during winter (*medium confidence*). {23.3.3}** Climate change is projected to reduce severe accidents in road transport (*medium confidence*) and adversely affect inland water transport in summer in some rivers (e.g., the Rhine) after 2050 (*medium confidence*). Damages to rail infrastructure from high temperatures may also increase (*medium confidence*). Adaptation through maintenance and operational measures can reduce adverse impacts to some extent.

**Climate change is expected to affect future energy production and transmission. {23.3.4}** Hydropower production is *likely* to decrease in all sub-regions except Scandinavia (*high confidence*). {23.3.4} Climate change is *unlikely* to affect wind energy production before 2050 (*medium confidence*) but will have a negative impact in summer and a varied impact in winter after 2050 (*medium confidence*). Climate change is *likely* to decrease thermal power production during summer (*high confidence*). {23.3.4} Climate change will increase the problems associated with overheating in buildings (*medium confidence*). {23.3.2} Although climate change is *very likely* to decrease space heating demand (*high confidence*), cooling demand will increase (*very high confidence*) although income growth mostly drives projected cooling demand up to 2050 (*medium confidence*). {23.3.4} More energy-efficient buildings and cooling systems as well as demand-side management will reduce future energy demands. {23.3.4}

**After 2050, tourism activity is projected to decrease in Southern Europe (*low confidence*) and increase in Northern and Continental Europe (*medium confidence*).** No significant impacts on the tourism sector are projected before 2050 in winter or summer tourism except for ski tourism in low-altitude sites and under limited adaptation (*medium confidence*). {23.3.6} Artificial snowmaking may prolong the activity of some ski resorts (*medium confidence*). {23.3.6}

**Climate change is *likely* to increase cereal yields in Northern Europe (*medium confidence*, disagreement) but decrease yields in Southern Europe (*high confidence*). {23.4.1}** In Northern Europe, climate change is *very likely* to extend the seasonal activity of pests and plant diseases (*high confidence*). {23.4.1} Yields of some arable crop species like wheat have been negatively affected by observed warming in some European countries since the 1980s (*medium confidence*, limited evidence). {23.4.1} Compared to AR4, new evidence regarding future yields in Northern Europe is less consistent regarding the magnitude and sign of change. Climate change may adversely affect dairy production in Southern Europe because of heat stress in lactating cows (*medium confidence*). {23.4.2} Climate change has contributed to vector-borne disease in ruminants in Europe (*high confidence*) {23.4.2} and northward expansion of tick disease vectors (*medium confidence*). {23.4.2, 23.5.1}

**Climate change will increase irrigation needs (*high confidence*) but future irrigation will be constrained by reduced runoff, demand from other sectors, and by economic costs. {23.4.1, 23.4.3}** By the 2050s, irrigation will not be sufficient to prevent damage from heat waves to crops in some sub-regions (*medium confidence*). System costs will increase under all climate scenarios (*high confidence*). {23.4.3} Integrated management of water, also across countries' boundaries, is needed to address future competing demands among agriculture, energy, conservation, and human settlements. {23.7.2}

**As a result of increased evaporative demand, climate change is *likely* to significantly reduce water availability from river abstraction and from groundwater resources (*medium confidence*)**, in the context of increased demand (from agriculture, energy and industry, and domestic use) and cross-sectoral implications that are not fully understood. {23.4.3, 23.9.1} Some adaptation is possible through uptake of more water-efficient technologies and water-saving strategies. {23.4.3, 23.7.2}

**Climate change will change the geographic distribution of wine grape varieties (*high confidence*) and this will reduce the value of wine products and the livelihoods of local wine communities in Southern and Continental Europe (*medium confidence*) and increase production in Northern Europe (*low confidence*). {23.4.1, 23.3.5, 23.5.4; Box 23-2}** Some adaptation is possible through technologies and good practice. {Box 23-2}

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**Climate warming will increase forest productivity in Northern Europe (*medium confidence*), {23.4.4}** although damage from pests and diseases in all sub-regions will increase due to climate change (*high confidence*). {23.4.4} Wildfire risk in Southern Europe (*high confidence*) and damages from storms in Central Europe (*low confidence*) may also increase due to climate change. {23.4.4} Climate change is *likely* to cause ecological and socioeconomic damages from shifts in forest tree species range (from southwest to northeast) (*medium confidence*), and in pest species distributions (*low confidence*). {23.4.4} Forest management measures can enhance ecosystem resilience (*medium confidence*). {23.4.4}

**Observed warming has shifted marine fish species ranges to higher latitudes (*high confidence*) and reduced body size in species (*medium confidence*). {23.4.6}** There is limited and diverging evidence on climate change impacts on net fisheries economic turnover. Local economic impacts attributable to climate change will depend on the market value of (high temperature tolerant) invasive species. {23.4.6} Climate change is *unlikely* to entail relocation of fishing fleets (*high confidence*). {23.4.6} Observed higher water temperatures have adversely affected both wild and farmed freshwater salmon production in the southern part of their distribution (*high confidence*). {23.4.6} High temperatures may increase the frequency of harmful algal blooms (*low confidence*). {23.4.6}

**Climate change will affect bioenergy cultivation patterns in Europe by shifting northward their potential area of production (*medium confidence*). {23.4.5}** Elevated atmospheric carbon dioxide ($CO_2$) can improve drought tolerance of bioenergy crop species due to improved plant water use, maintaining high yields in future climate scenarios in temperate regions (*low confidence*). {23.4.5}

**Climate change is *likely* to affect human health in Europe.** Heat-related deaths and injuries are *likely* to increase, particularly in Southern Europe (*medium confidence*). {23.5.1} Climate change may change the distribution and seasonal pattern of some human infections, including those transmitted by arthropods (*medium confidence*), and increase the risk of introduction of new infectious diseases (*low confidence*). {23.5.1}

**Climate change and sea level rise may damage European cultural heritage**, including buildings, local industries, landscapes, archaeological sites, and iconic places (*medium confidence*), and some cultural landscapes may be lost forever (*low confidence*). {23.5.4; Table 23-3}

**Climate change may adversely affect background levels of tropospheric ozone (*low confidence*; *limited evidence*, *low agreement*), assuming no change in emissions, but the implications for future particulate pollution (which is more health-damaging) are very uncertain. {23.6.1}** Higher temperatures may have affected trends in ground level tropospheric ozone (*low confidence*). {23.6.1} Climate change is *likely* to decrease surface water quality due to higher temperatures and changes in precipitation patterns (*medium confidence*), {23.6.3} and is *likely* to increase soil salinity in coastal regions (*low confidence*). {23.6.2} Climate change may also increase soil erosion (from increased extreme events) and reduce soil fertility (*low confidence*, limited evidence). {23.6.2}

**Observed climate change is affecting a wide range of flora and fauna, including plant pests and diseases (*high confidence*) {23.4.1, 23.4.4, 23.6.4} and the disease vectors and hosts (*medium confidence*). {23.4.2}** Climate change is *very likely* to cause changes in habitats and species, with local extinctions (*high confidence*) and continental-scale shifts in species distributions (*medium confidence*). {23.6.4} The habitat of alpine plants is *very likely* to be significantly reduced (*high confidence*). {23.6.4} Phenological mismatch will constrain both terrestrial and marine ecosystem functioning under climate change (*high confidence*), {23.6.4-5} with a reduction in some ecosystem services (*low confidence*). {23.6.4; Box 23-1} The introduction and expansion of invasive species, especially those with high migration rates, from outside Europe is *likely* to increase with climate change (*medium confidence*). {23.6.4} Climate change is *likely* to entail the loss or displacement of coastal wetlands (*high confidence*). {23.6.5} Climate change threatens the effectiveness of European conservation areas (*low confidence*), {23.6.4} and stresses the need for habitat connectivity through specific conservation policies. {23.6.4}



### *Adaptation*

**The capacity to adapt in Europe is high compared to other world regions, but there are important differences in impacts and in the capacity to respond between and within the European sub-regions.** In Europe, adaptation policy has been developed at international (European Union), national, and local government levels, {23.7} including the prioritization of adaptation options. There is limited systematic information on current implementation or effectiveness of adaptation measures or policies. {Box 23-3} Some adaptation planning has been integrated into coastal and water management, as well as disaster risk management. {23.7.1-3} There is limited evidence of adaptation planning in rural development or land use planning. {23.7.4-5}

**Adaptation will incur a cost**, estimated from detailed bottom-up sector-specific studies for coastal defenses, energy production, energy use, and agriculture. {23.7.6} The costs of adapting buildings (houses, schools, hospitals) and upgrading flood defenses increase under all scenarios relative to no climate change (*high confidence*). {23.3.2} Some impacts will be unavoidable owing to limits (physical, technological, social, economic, or political). {23.7.7; Table 23-3}

**There is also emerging evidence regarding opportunities and unintended consequences of policies, strategies, and measures that address adaptation and/or mitigation goals. {23.8}** Some agricultural practices can reduce greenhouse gas (GHG) emissions and also increase resilience of crops to temperature and rainfall variability. {23.8.2} There is evidence for unintended consequences of mitigation policies in the built environment (especially dwellings) and energy sector (*medium confidence*). {23.8.1} Low-carbon policies in the transport and energy sectors to reduce emissions are associated with large benefits to human health (*high confidence*). {23.8.3}

## 23.1. Introduction

This chapter reviews the scientific evidence published since the IPCC Fourth Assessment Report (AR4) on observed and projected impacts of anthropogenic climate change in Europe and adaptation responses. The geographical scope of this chapter is the same as in AR4 with the inclusion of Turkey. Thus, the European region includes all countries from Iceland in the west to the Russian Federation (west of the Urals) and the Caspian Sea in the east, and from the northern shores of the Mediterranean and Black Seas and the Caucasus in the south to the Arctic Ocean in the north. Impacts above the Arctic Circle are addressed in Chapter 28 and impacts in the Baltic and Mediterranean Seas in Chapter 30. Impacts in Malta, Cyprus, and other island states in Europe are discussed in Chapter 29. The European region has been divided into five sub-regions (see Figure 23-1): Atlantic, Alpine, Southern, Northern, and Continental. The sub-regions are derived by aggregating the climate zones developed by Metzger et al. (2005) and therefore represent geographical and ecological zones rather than political boundaries. The scientific evidence has been evaluated to compare impacts across (rather than within) sub-regions, although this was not always possible depending on the scientific information available.

### 23.1.1. Scope and Route Map of Chapter

The chapter is structured around key policy areas. Sections 23.3 to 23.6 summarize the latest scientific evidence on sensitivity climate, observed impacts and attribution, projected impacts, and adaptation options, with respect to four main categories of impacts:

- Production systems and physical infrastructure
- Agriculture, fisheries, forestry, and bioenergy production
- Health protection and social welfare
- Protection of environmental quality and biological conservation.

The benefit of assessing evidence in a regional chapter is that impacts across sectors can be described, and interactions between impacts can be identified. Further, the cross-sectoral decision making required to address climate change can be reviewed. The chapter also includes sections that were not in AR4. As adaptation and mitigation policy develops, the evidence for potential co-benefits and unintended consequences of such strategies is reviewed (Section 23.8). The final section synthesizes the key findings with respect to: observed impacts of climate change, key vulnerabilities, and research and knowledge gaps.

The chapter evaluates the scientific evidence in relation to the five sub-regions highlighted above. The majority of the research in the Europe region is for impacts in countries in the European Union due to targeted research funding through the European Commission and national governments, which means that countries in Eastern Europe and the Russian Federation are less well represented in this chapter. Further, regional assessments may be reported for the EU15, EU27, or EEA (32) group of countries (Table SM23-1).

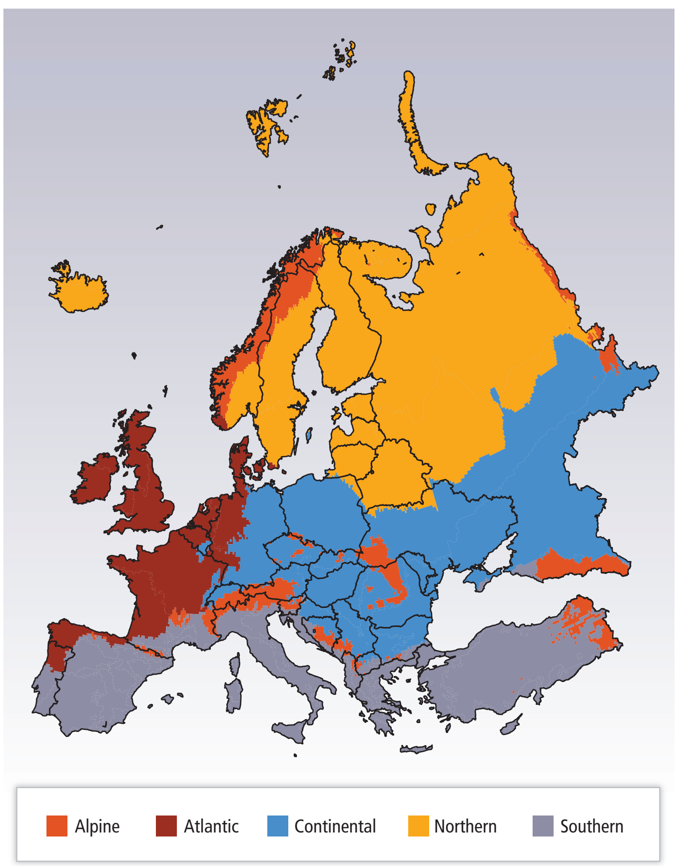



**Figure 23-1 |** Sub-regional classification of the IPCC Europe region. Based on Metzger et al., 2005.

### 23.1.2. Policy Frameworks

Since AR4, there have been significant changes in Europe in responses to climate change. More countries now have adaptation and mitigation policies in place. An important force for climate policy development in the region is the European Union (EU). EU member states have mitigation targets, as well as the overall EU target, with both sectoral and regional aspects to the commitments.

Adaptation policies and practices have been developed at international, national, and local levels although research on implementation of such policies is limited. Owing to the vast range of policies, strategies, and measures it is not possible to describe them extensively here. However, adaptation in relation to cross-sectoral decision making is discussed in Section 23.7 (see also Box 23-3 on national adaptation policies). The European Climate Adaptation Platform (Climate-ADAPT) catalogs adaptation actions reported by EU Member States (EC, 2013a). The EU Adaptation Strategy was adopted in 2013 (EC, 2013b). See Chapter 15 for a more extensive discussion of institutions and governance in relation to adaptation planning and implementation.

### 23.1.3. Conclusions from Previous Assessments

AR4 documented a wide range of impacts of observed climate change in Europe (WGII AR4 Chapter 12). The IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) confirmed increases in warm days and warm nights and decreases in cold days and cold nights since 1950 (*high confidence*; SREX Section 3.3.1). Extreme precipitation increased in part of the continent, mainly in winter over Western-Central Europe and European Russia (*medium confidence*; SREX Section 3.3.2). Dryness has increased mainly in Southern Europe (*medium confidence*; SREX Section 3.3.2). Climate change is expected to magnify regional differences within Europe for agriculture and forestry because water stress was projected to increase over Central and Southern Europe (WGII AR4 Section 12.4.1; SREX Sections 3.3.2, 3.5.1). Many climate-related hazards were projected to increase in frequency and intensity, but with significant variations within the region (WGII AR4 Section12.4).

The AR4 identified that climate changes would pose challenges to many economic sectors and was expected to alter the distribution of economic activity within Europe (*high confidence*). Adaptation measures were evolving from reactive disaster response to more proactive risk management. A prominent example was the implementation of heat health warning systems following the 2003 heat wave event (WGII AR4 Section 12.6.1; SREX Section 9.2.1). National adaptation plans were developed and specific plans were incorporated in European and national policies (WGII AR4 Sections 12.2.3, 12.5), but these were not yet evaluated (WGII AR4 Section 12.8).

## 23.2. Current and Future Trends

### 23.2.1. Non-Climate Trends

European countries are diverse in both demographic and economic trends. Population health and social welfare have improved everywhere in Europe, with reductions in adult and child mortality rates, but social inequalities both within and between countries persist (Marmot et al., 2012). Population has increased in most EU27 countries, primarily as a result of net immigration (Eurostat, 2011a), although population growth is slow (total and working age population; Rees et al., 2012). Aging of the population is a significant trend in Europe. This will have both economic and social implications, with many regions experiencing a decline in the labor force (Rees et al., 2012). Since AR4, economic growth has slowed or become negative in many countries, leading to a reduction in social protection measures and increased unemployment (Eurostat, 2011b). The longer term implications of the financial crisis in Europe are unclear, although it may lead to a modification of the economic outlook and affect future social protection policies with implications for adaptation.

Europe is one of the world's largest and most productive suppliers of food and fiber (Easterling et al., 2007). Agriculture is an important land use across the European region; for example, it covers about 35% of the total land area of western Europe (Rounsevell et al., 2006). After 1945, an unprecedented increase in agricultural productivity occurred, but also declines in agricultural land use areas. This intensification had several negative impacts on the ecological properties of agricultural systems, such as carbon sequestration, nutrient cycling, soil structure and functioning, water purification, and pollination. Pollution from agriculture has led to eutrophication and declines in water quality in some areas (Langmead et al., 2007). Most scenario studies suggest that agricultural land areas will continue to decrease in the future (see also Busch, 2006, for a discussion). Agriculture accounts for 24% of total national freshwater abstraction in Europe and more than 80% in some Southern European countries (EEA, 2009). Economic restructuring in some Eastern European countries has led to a decrease in water abstraction for irrigation, suggesting the potential for future increases in irrigated agriculture and water use efficiency (EEA, 2009).

Forest in Europe covers approximately 34% of the land area (Eurostat, 2009). The majority of forests now grow faster than in the early 20th century as a result of advances in forest management practices, genetic improvement, and, in Central Europe, the cessation of site-degrading practices such as litter collection for fuel. Increasing temperatures and carbon dioxide ($CO_2$) concentrations, nitrogen deposition, and the reduction of air pollution (sulfur dioxide ($SO_2$)) have also had a positive effect on forest growth. Scenario studies suggest that forested areas will increase in Europe in the future on land formerly used for agriculture (Rounsevell et al., 2006). Soil degradation is already intense in parts of the Mediterranean and Central-Eastern Europe and, together with prolonged drought periods and fires, is already contributing to an increased risk of desertification. Projected risks for future desertification are the highest in these areas (EEA, 2012).

Urban development is projected to increase all over Europe (Reginster and Rounsevell, 2006), but especially rapidly in Eastern Europe, with the magnitude of these increases depending on population growth, economic growth, and land use planning policy. Although changes in urban land use will be relatively small in area terms, urban development has major impacts locally on environmental quality. Outdoor air quality has, however, been improving (Langmead et al., 2007). Peri-urbanization is an increasing trend in which residents move out of cities to locations with a rural character, but retain a functional link to cities by commuting to work (Reginster and Rounsevell, 2006; Rounsevell and Reay, 2009). Several European scenario studies have been undertaken to describe European future trends with respect to socioeconomic development (de Mooij and Tang, 2003), land use change (Verburg et al., 2010; Haines-Young et al., 2012; Letourneau et al., 2012), land use and biodiversity (Spangenberg et al., 2011), crop production (Hermans et al., 2010), demographic change (Davoudi et al., 2010), economic development (Dammers, 2010), and European policy (Lennert and Robert, 2010; Helming et al., 2011). Many of these scenarios also account for the effects of future climate change (see Rounsevell and Metzger, 2010, for a review). Long-term projections (to the end of the century) are described under the new Shared Socioeconomic Pathway scenarios (SSPs) (Kriegler et al., 2010). Detailed country and regional scale socioeconomic scenarios have also been produced for the Netherlands (WLO, 2006), the UK (UK National Ecosystem Assessment, 2011), and Scotland (Harrison et al., 2013). The probabilistic representation of socioeconomic futures has also been developed for agricultural land use change (Hardacre et al., 2013). There is little evidence to suggest, however, that probabilistic futures or scenarios more generally are being used in policy making (Bryson et al., 2010).

### 23.2.2. Observed and Projected Climate Change

#### 23.2.2.1. Observed Climate Change

The average temperature in Europe has continued to increase, with regionally and seasonally different rates of warming being greatest in high latitudes in Northern Europe (Chapter 28). Since the 1980s, warming has been strongest over Scandinavia, especially in winter, whereas the Iberian Peninsula warmed mostly in summer (EEA, 2012). The decadal average temperature over land area for 2002–2011 is 1.3° ± 0.11°C above the 1850–1899 average, based on Hadley Centre/Climatic Research Unit gridded surface temperature data set 3 (HadCRUT3; Brohan et al., 2006), Merged Land-Ocean Surface Temperature (MLOST; Smith et al., 2008), and Goddard Institute of Space Studies (GISS) Temp (Hansen et al., 2010). See WGI AR5 Section 2.4 for a discussion of data and uncertainties and Chapter 21 for observed regional climate change.

Since 1950, high-temperature extremes (hot days, tropical nights, and heat waves) have become more frequent, while low-temperature extremes (cold spells, frost days) have become less frequent (WGI AR5 Section 2.6; SREX Chapter 3; EEA, 2012). The recent cold winters in Northern and Atlantic Europe reflect the high natural variability in the region (Peterson et al., 2012; see also WGI AR5 Section 2.7), and do not contradict the general warming trend. In Eastern Europe, including the European part of Russia, summer 2010 was exceptionally hot, with an amplitude and spatial extent that exceeded the previous 2003 heat wave (Barriopedro et al., 2011). Table 23-1 describes the impacts of major extreme events in Europe in the last decade.

Since 1950, annual precipitation has increased in Northern Europe (up to +70 mm per decade), and decreased in parts of Southern Europe (EEA, 2012, based on Haylock et al., 2008). Winter snow cover extent has a high interannual variability and a nonsignificant negative trend over the period 1967–2007 (Henderson and Leathers, 2010). Regional observed changes in temperature and precipitation extremes are also described in Table 3-2 of SREX and in Berg et al. (2013). Mean wind speeds have declined over Europe over recent decades (Vautard et al., 2010) with *low confidence* because of problematic anemometer data and climate variability (SREX Section 3.3). Bett et al. (2013) did not find any trend in windspeed using the Twentieth Century Reanalysis.

Europe is marked by increasing mean sea level with regional variations, except in the northern Baltic Sea, where the relative sea level decreased due to vertical crustal motion (Haigh et al., 2010; Menendez and Wood-Worth, 2010; Albrecht et al., 2011; EEA, 2012). Extreme sea levels have increased due to mean sea level rise (*medium confidence*; SREX Section 3.5; Haigh et al., 2010; Menendez and WoodWorth, 2010). Variability in waves is related to internal climate variability rather than climate trends (SREX Section 3.5; Charles et al., 2012).

### 23.2.2.2. Projected Climate Changes

Sub-regional information from global (see Chapter 21 supplementary material; see also WGI AR5 Section 14.8.6, Annex I) and regional high-resolution climate model output (Chapters 21, 23; see also WGI AR5 Section 14.8.6) provide more knowledge about the range of possible future climates under the *Special Report on Emissions Scenarios* (SRES) and Representative Concentration Pathway (RCP) emission scenarios. Within the recognized limitations of climate projections (Chapter 21; WGI AR5 Chapter 9), new research on inter-model comparisons has provided a more robust range of future climates to assess future impacts. Since AR4, climate impact assessments are more likely to use a range for the projected changes in temperature and rainfall. Access to comprehensive and detailed sets of climate projections for decision making exist in Europe (SREX Section 3.2.1; Mitchell et al., 2004; Fronzek et al., 2012; Jacob et al., 2013).

Climate models show significant agreement for all emission scenarios in warming (magnitude and rate) all over Europe, with strongest warming projected in Southern Europe in summer, and in Northern Europe in winter (Goodess et al., 2009; Kjellström et al., 2011). Even under an average global temperature increase limited to 2°C compared to preindustrial times, the climate of Europe is simulated to depart significantly in the next decades from today's climate (Van der Linden and Mitchell, 2009; Jacob and Podzun, 2010).

Precipitation signals vary regionally and seasonally. Trends are less clear in Continental Europe, with agreement in increase in Northern Europe and decrease in Southern Europe (*medium confidence*; Kjellström et al., 2011). Precipitation is projected to decrease in the summer months up to southern Sweden and increase in winter (Schmidli et al., 2007), with more rain than snow in mountainous regions (Steger et al., 2013). In Northern Europe, a decrease of long-term mean snowpack (although snow-rich winters will remain) toward the end of the 21st century (Räisänen and Eklund, 2012) is projected. There is lack of information about past and future changes in hail occurrence in Europe. Changes in future circulation patterns (Ulbrich et al., 2009; Kreienkamp et al., 2010) and mean wind speed trends are uncertain in sign (Kjellström et al., 2011; McInnes et al., 2011).

Regional coupled simulations over the Mediterranean region provide a more realistic characterization of impact parameters (e.g., snow cover, aridity index, river discharge), which were not revealed by Coupled Model Intercomparison Project Phase 3 (CMIP3) global simulations (Dell'Aquila et al., 2012).

For 2081–2100 compared to 1986–2005, projected global mean sea level rises (meters) are in the range 0.29 to 0.55 for RCP2.6, 0.36 to 0.63 for RCP4.5, 0.37 to 0.64 for RCP6.0, and 0.48 to 0.82 for RCP8.5 (*medium confidence*; WGIII AR5 Chapter 5). There is a *low confidence* on projected regional changes (Slangen et al., 2012; WGI AR5 Section 13.6). Low-probability/high-impact estimates of extreme mean sea level rise projections derived from the SRES A1FI scenario for the Netherlands (Katsman et al., 2011) indicate that the mean sea level could rise globally between 0.55 and 1.15 m, and locally (Netherlands) by 0.40 to 1.05 m, by 2100. Extreme (*very unlikely*) scenarios for the UK vary from 0.9 to 1.9 m by 2100 (Lowe et al., 2009).

### 23.2.2.3. Projected Changes in Climate Extremes

There will be a marked increase in extremes in Europe, in particular, in heat waves, droughts, and heavy precipitation events (Beniston et al., 2007; Lenderink and Van Meijgaard, 2008; see also Chapter 21 supplementary material). There is a general *high confidence* concerning changes in temperature extremes (toward increased number of warm days, warm nights, and heat waves; SREX Table 3-3). Figure 23-2c shows projected changes in the mean number of heat waves in May to September for 2071–2100 compared to 1971–2000 for RCP4.5 and

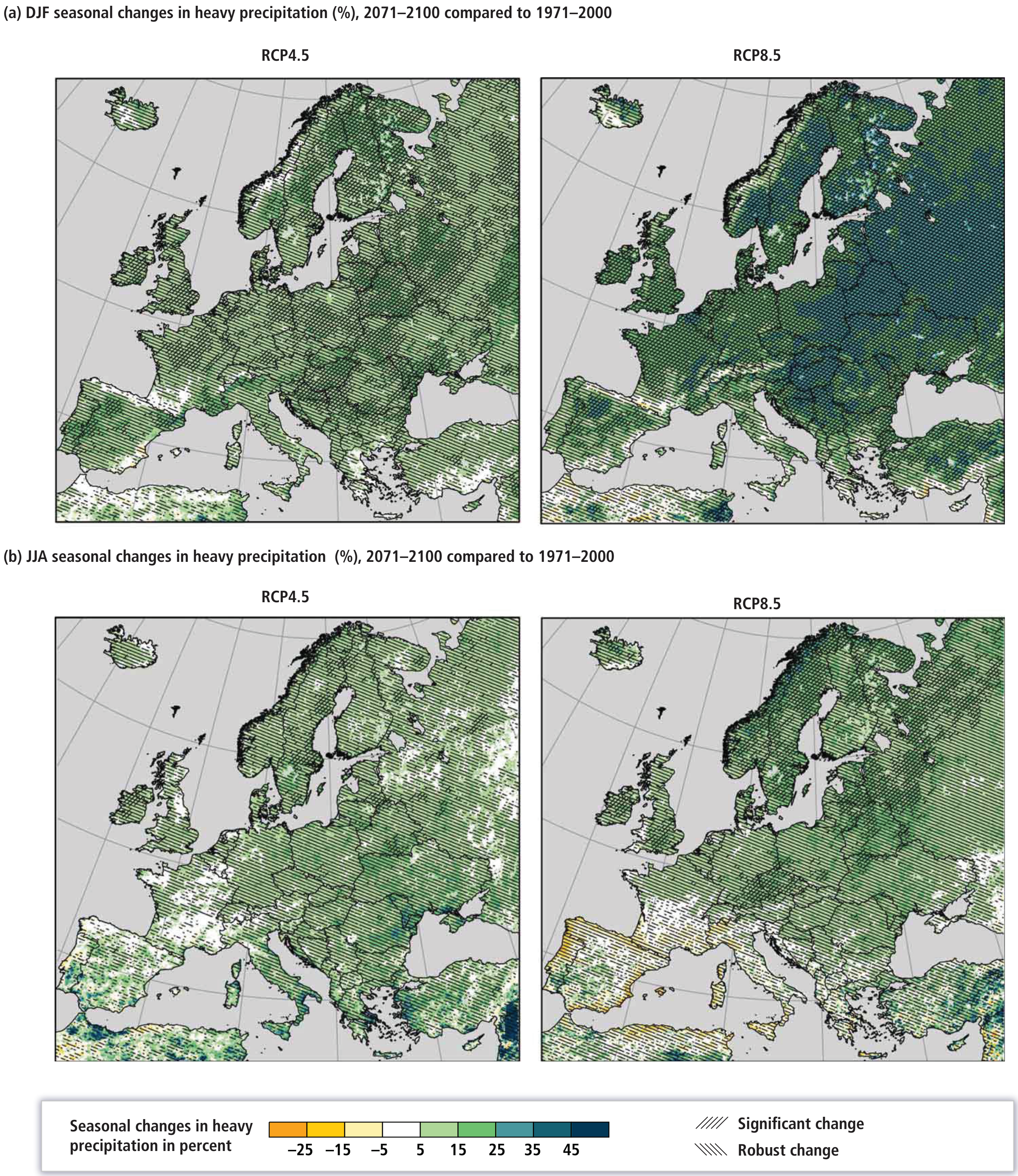
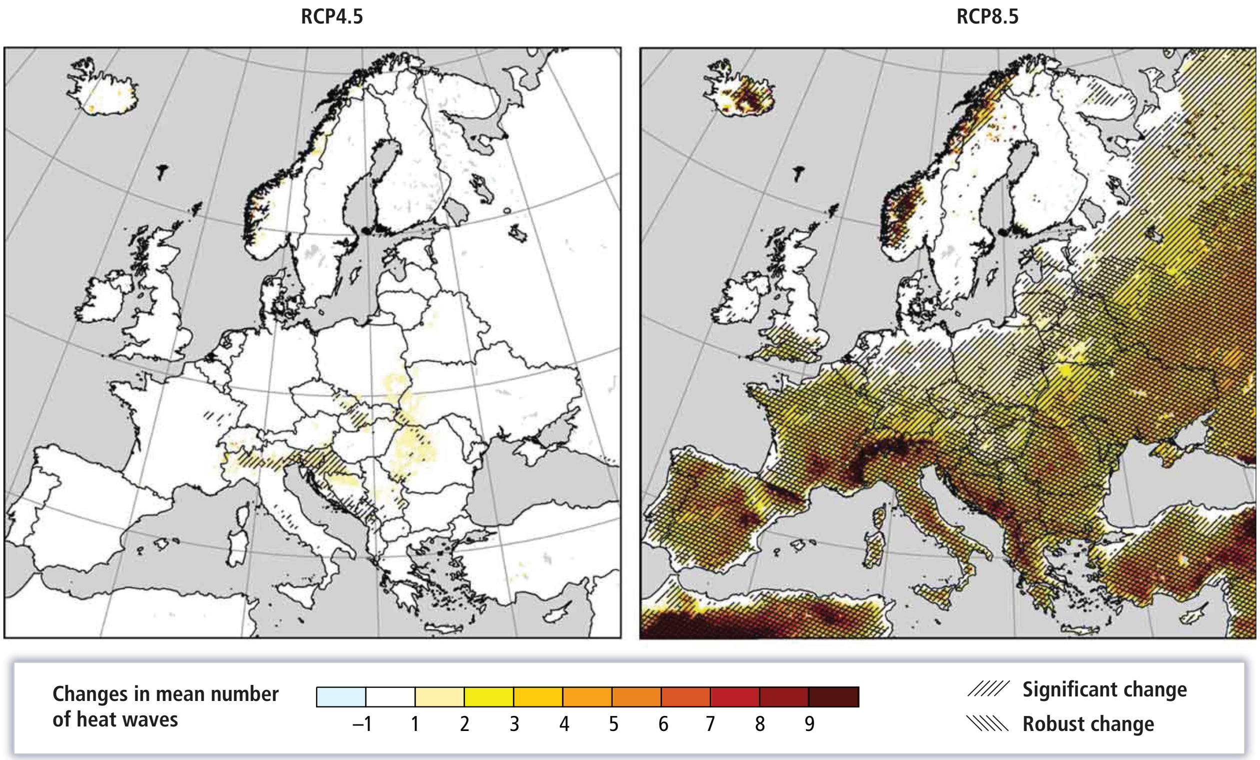



**Figure 23-2 |** (a) and (b): Projected seasonal changes in heavy precipitation defined as the 95th percentile of daily precipitation (only days with precipitation >1 mm day$^{-1}$ are considered) for the period 2071–2100 compared to 1971–2000 (in %) in the months December to February (DJF) and June to August (JJA). (c) Projected changes in the mean number of heat waves occurring in the months May to September for the period 2071–2100 compared to 1971–2000 (number per 30 years). Heat waves are defined as periods of more than 5 consecutive days with daily maximum temperature exceeding the mean maximum temperature of the May to September season of the control period (1971–2000) by at least 5°C. (d) Projected changes in the 95th percentile of the length of dry spells for the period 2071–2100 compared to 1971–2000 (in days). Dry spells are defined as periods of at least 5 consecutive days with daily precipitation below 1 mm. Hatched areas indicate regions with robust (at least 66% of models agree in the sign of change) and/or statistically significant change (significant on a 95% confidence level using Mann–Whitney U test). For the eastern parts of Black Sea, eastern Anatolia, and southeast Anatolia (Turkey), no regional climate model projections are available. Changes represent the mean over 8 (RCP4.5, left side) and 9 (RCP8.5, right side) regional model simulations compiled within the Coordinated Downscaling Experiment – European Domain (EURO-CORDEX) initiative. Adapted from Jacob et al., 2013.

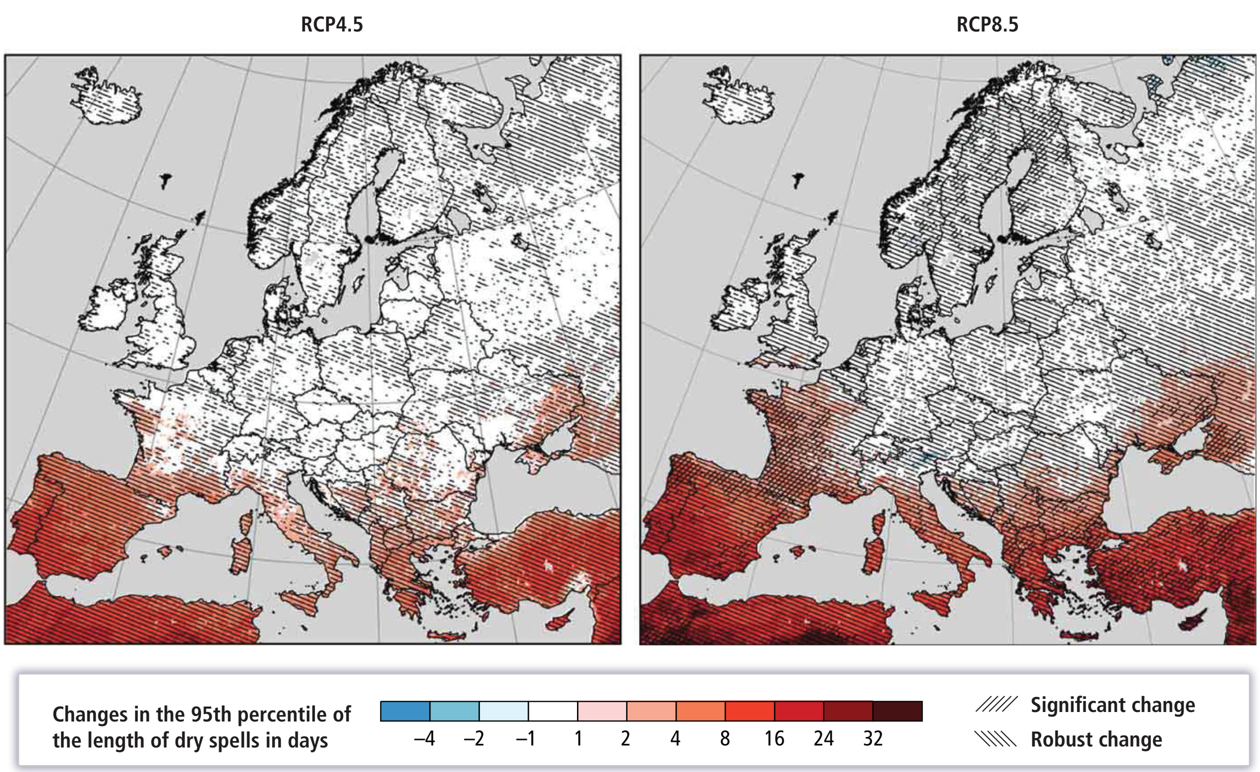
Continued next page →

**Figure 23-2 (continued)**

**(c) Changes in mean number of heat waves for MJJAS, 2071–2100 compared to 1971–2000**




**(d) Changes in the 95th percentile of the length of dry spells (days) 2071–2100 compared to 1971–2000**



RCP8.5 with large differences depending on the emission scenario. The increase in likelihood of some individual events due to anthropogenic change has been quantified for the 2003 heat wave (Schär and Jendritzky, 2004), the warm winter of 2006/2007, and warm spring of 2007 (Beniston, 2007).

Changes in extreme precipitation depend on the region, with a *high confidence* of increased extreme precipitation in Northern Europe (all seasons) and Continental Europe (except summer). Future projections are regionally and seasonally different in Southern Europe (SREX Table 3-3). Figure 23-2a,b shows projected seasonal changes of heavy precipitation events for 2071–2100 compared to 1971–2000 for RCP4.5 and RCP8.5.

Projected changes of spatially averaged indices over the European sub-regions are described in the supplemental information (Tables SM23-2 and SM23-3 for sub-regions, and Table SM23-4 for three Alpine areas).

In winter, small increases in extreme wind speed are projected for Central and Northern Europe (*medium confidence*; Section 21.3.3.1.6; SREX Figure 3-8; Beniston et al., 2007; Rockel and Woth, 2007; Haugen and Iversen, 2008; Rauthe et al., 2010; Schwierz et al., 2010), connected to changes in storm tracks (*medium confidence*; Pinto et al., 2007a,b, 2010; Donat et al., 2010). Other parts of Europe and seasons are less clear in sign with a small decreasing trend in Southern Europe (*low confidence*; Donat et al., 2011; McInnes et al., 2011).

Extreme sea level events will increase (*high confidence*; WGI AR5 Section 13.7; SREX Section 3.5.3), mainly dominated by the global mean sea level increase. Storm surges are expected to vary along the European coasts. Significant increases are projected in the eastern North Sea (increase of 6 to 8% of the 99th percentile of the storm surge residual, 2071–2100 compared to 1961–1990, based on the B2, A1B, and A2 SRES scenarios; Debernard and Rÿed, 2008) and west of UK and Ireland (Debernard and Rÿed, 2008; Wang et al., 2008), except south of Ireland (Wang et al., 2008). There is a *medium agreement* for the south of North Sea and Dutch coast where trends vary from increasing (Debernard and Rÿed, 2008) to stable (Sterl et al., 2009). There is a *low agreement* on the trends in storm surge in the Adriatic Sea (Planton et al., 2006; Jordà et al., 2012; Lionello et al., 2012; Troccoli et al., 2012b).

### 23.2.3. Observed and Projected Trends in Riverflow and Drought

Streamflows have decreased in the south and east of Europe and increased in Northern Europe (Stahl et al., 2010; Wilson et al., 2010; see also Section 3.2.3). In general, few changes in flood trends can be attributed to climate change, partly owing to the lack of sufficiently long records (Kundzewicz et al., 2013). European mean and peak discharges are highly variable (Bouwer et al., 2008); for instance, in France, upward trends in low flows were observed over 1948–1988 and downward trends over 1968–2008 (Giuntoli et al., 2013). Alpine glacier retreat during the last 2 decades caused a 13% increase in glacier contribution to August runoff of the four main rivers originating in the Alps, compared to the long-term average (Huss, 2011). Increases in extreme river discharge (peak flows) over the past 30 to 50 years have been observed in parts of Germany (Petrow et al., 2007, 2009), the Meuse River basin (Tu et al., 2005), parts of Central Europe (Villarini et al., 2011), Russia (Semenov, 2011), and northeastern France (Renard et al., 2008). Decreases in extreme river discharge have been observed in the Czech Republic (Yiou et al., 2006), and no change observed in Switzerland (Schmocker-Fackel and Naef, 2010), Germany (Bormann et al., 2011), and the Nordic countries (Wilson et al., 2010). River regulation possibly partly masks increasing peak flows in the Rhine (Vorogushyn et al., 2012). One study (Pall et al., 2011) suggested that the UK 2000 flood was partly due to anthropogenic forcing, although another showed a weaker effect (Kay et al., 2011).

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Climate change is projected to affect the hydrology of river basins (Chapter 4; SREX Chapter 3). The occurrence of current 100-year return period discharges is projected to increase in Continental Europe, but decrease in some parts of Northern and Southern Europe by 2100 (Dankers and Feyen, 2008; Rojas et al., 2012). In contrast, studies for individual catchments indicate increases in extreme discharges, to varying degrees, in Finland (Veijalainen et al., 2010), Denmark (Thodsen, 2007), Ireland (Wang et al., 2006; Steele-Dunne et al., 2008; Bastola et al., 2011), the Rhine basin (Görgen et al., 2010; te Linde et al., 2010a), Meuse basin (Leander et al., 2008; Ward et al., 2011), the Danube basin (Dankers et al., 2007), and France (Quintana-Segui et al., 2011; Chauveau et al., 2013). Although snowmelt floods may decrease, increased autumn and winter rainfall could lead to higher peak discharges in Northern Europe (Lawrence and Hisdal, 2011). Declines in low flows are projected for the UK (Christierson et al., 2012), Turkey (Fujihara et al., 2008), France (Chauveau et al., 2013), and rivers fed by Alpine glaciers (Huss, 2011).

The analysis of trends in droughts is made complex by the different categories or definitions of drought (meteorological, agricultural, and hydrological) and the lack of long-term observational data (SREX Box 3-3). Southern Europe shows trends toward more intense and longer meteorological droughts, but they are still inconsistent (Sousa et al., 2011). Drought trends in all other sub-regions are not statistically significant (SREX Section 3.5.1). Regional and global climate simulations project (*medium confidence*) an increase in duration and intensity of droughts in Central and Southern Europe and the Mediterranean up until the UK for different definitions of drought (Gao and Giorgi, 2008; Feyen and Dankers, 2009; Vidal and Wade, 2009; Koutroulis et al., 2010; Tsanis et al., 2011; Chapter 21). Even in regions where summer precipitation is expected to increase, soil moisture and hydrological droughts may become more severe as a result of increasing evapotranspiration (Wong et al., 2011). Projected changes in the length of meteorological dry spells show that the increase is large in Southern Europe (Figure 23-2d).

## 23.3. Implications of Climate Change for Production Systems and Physical Infrastructure

### 23.3.1. Settlements

#### 23.3.1.1. Coastal Flooding

As the risk of extreme sea level events increases with climate change (Section 23.2.3; Chapter 5), coastal flood risk will remain a key challenge for several European cities, port facilities, and other infrastructure (Hallegatte et al., 2008, 2011; Nicholls et al., 2008). With no adaptation, coastal flooding in the 2080s is projected to affect an additional 775,000 and 5.5 million people per year in the EU27 (B2 and A2 scenarios, respectively; Ciscar et al., 2011). The Atlantic, Northern, and Southern European regions are projected to be most affected. Direct costs from sea level rise in the EU27 without adaptation could reach €17 billion per year by 2100 (Hinkel et al., 2010), with indirect costs also estimated for land-locked countries (Bosello et al., 2012). Countries with high absolute damage costs include Netherlands, Germany, France, Belgium, Denmark, Spain, and Italy (Hinkel et al., 2010). Upgrading coastal defenses would substantially reduce impacts and damage costs (Hinkel et al., 2010). However, the amount of assets and populations that need to be protected by coastal defenses is increasing; thus, the magnitude of losses when floods do occur will also increase in the future (Hallegatte et al., 2013).

An increase in future flood losses due to climate change have been estimated for Copenhagen (Hallegatte et al., 2011), UK coast (Mokrech et al., 2008; Purvis et al., 2008; Dawson et al., 2011), the North Sea coast (Gaslikova et al., 2011), cities including Amsterdam and Rotterdam (Hanson et al., 2011), and the Netherlands (Aerts et al., 2008). A 1 m sea level rise in Turkey could affect 3 million additional people and put US$12 billion capital value at risk, with around US$20 billion adaptation costs (10% of GNP; Karaca and Nicholls, 2008). In Poland, up to 240,000 people would be affected by increasing flood risk on the Baltic coast (Pruszak and Zawadzka, 2008). The increasing cost of insurance and unwillingness of investors to place assets in affected areas is a potential growth impediment to coastal and island economies (Day et al., 2008).

#### 23.3.1.2. River and Pluvial Flooding

Recent major flood events in Europe include the 2007 floods in the UK (Table 23-1; Chatterton et al., 2010) and the 2013 floods in Germany. The observed increase in river flood events and damages in Europe is well documented (see Section 18.4.2.1); however, the main cause is increased exposure of persons and property in flood risk areas (Barredo, 2009). Since AR4, new studies provide a wider range of estimates of future economic losses from river flooding attributable to climate change, depending on the modeling approach and climate scenario (Bubeck et al., 2011). Studies now also quantify risk under changes in population and economic growth, generally indicating this contribution to be about equal or larger than climate change per se (Feyen et al., 2009; Maaskant et al., 2009; Bouwer et al., 2010; Rojas et al., 2013; te Linde et al., 2011). Some regions may see increasing risks, but others may see decreases or little to no change (ABI, 2009; Feyen et al., 2009, 2012; Lugeri et al., 2010; Mechler et al., 2010; Bubeck et al., 2011; Lung et al., 2012). In the EU15, river flooding could affect 250,000 to 400,000

**Table 23-1 |** Impacts of climate extremes in the last decade in Europe.[a]

| Year | Region | Meteorological characteristics | Production systems and physical infrastructure, settlements | Agriculture, fisheries, forestry, bioenergy | Health and social welfare | Environmental quality and biological conservation | Mega-fire |
|---|---|---|---|---|---|---|---|
| 2003 | Western and central Europe | Hottest summer in at least 500 years (Luterbacher et al., 2004) | Damage to road and rail transport systems<br><br>Reduced/interrupted operation of nuclear power plants (mostly in France)<br><br>High transport prices on the Rhine due to low water levels | Grain harvest losses of 20% (Ciais et al., 2005) | 35,000 deaths in August in central and western Europe (Robine et al., 2008) | Decline in water quality (Daufresne et al., 2007)<br><br>High outdoor pollution levels (EEA, 2012) | Yes |
| 2004/ 2005 | Iberian Peninsula | Hydrological drought | | Grain harvest losses of 40% (EEA, 2010c) | | | |
| 2007 | Southern Europe | Hottest summer on record in Greece since 1891 (Founda and Giannakopoulos, 2009) | 1710 buildings burned down or rendered uninhabitable in Greece (JRC, 2008) | ~575,500 hectares burnt area (JRC, 2008) | 6 deaths in Portugal, 80 deaths in Greece (JRC, 2008) | Several protected conservation sites (Natura, 2000) were destroyed (JRC, 2008). | Yes, Greece |
| 2007 | England and Wales | May–July wettest since records began in 1766 | Estimated total losses £4 billion (£3 billion insured losses) (Chatterton et al., 2010)<br><br>Failure of pumping station led to 20,000 people without water for 2 weeks. | 78 farms flooded. Impacts on agriculture £50 million (Chatterton et al., 2010) | 13 deaths and 48,000 flooded homes (Pitt, 2008). Damage costs for health effects, including loss of access to education, £287 million (Chatterton et al., 2010) | | |
| 2010 | Western Russia | Hottest summer since 1500 (Barriopedro et al., 2011) | | Fire damage to forests (Shvidenko et al., 2011)<br><br>Reduction in crop yields (Barriopedro et al., 2011; Coumou and Rahmstorf, 2012) | Estimated 10,000 excess deaths due to heat wave in Moscow in July and August (Revich and Shaposhnikov, 2012) | High outdoor pollution levels in Moscow (Bondur, 2011; Revich and Shaposhnikov, 2012) | Yes |
| 2011 | France | Hottest and driest spring in France since 1880 | Reduction in snow cover for skiing | 8% decline in wheat yield (AGRESTE, 2011) | | | |

[a]Extreme events derived from Coumou and Rahmstorf (2012).

additional people by the 2080s (SRES A2 and B2 scenarios, respectively) more than doubling annual average damages, with Central and Northern Europe and the UK most affected (Ciscar, 2009; Ciscar et al., 2011). When economic growth is included, economic flood losses in Europe could increase 17-fold under the A1B climate scenario (Rojas et al., 2013).

Few studies have estimated future damages from inundation in response to an increase in intense rainfall (Hoes, 2006; Willems et al., 2012). Processes that influence flash flood risk include increasing exposure from urban expansion, and forest fires that lead to erosion and increased surface runoff (Lasda et al., 2010). Some studies have costed adaptation measures but these may only partly offset anticipated impacts (Zhou et al., 2012).

#### 23.3.1.3. Windstorms

Several studies project an overall increase in storm hazard in northwest Europe (Section 23.2.2.3) and in economic and insured losses (Section 17.7), but natural variations in frequencies are large. There is no evidence that the observed increase in European storm losses is due to anthropogenic climate change (Barredo, 2010). There is a lack of information for other storm types, such as tornadoes and thunderstorms.

#### 23.3.1.4. Mass Movements and Avalanches

In the European Alps, the frequency of rock avalanches and large rock slides has apparently increased over the period 1900–2007 (Fischer et al., 2012). The frequency of landslides may also have increased in some locations (Lopez Saez et al., 2013). Mass movements are projected to become more frequent with climate change (Huggel et al., 2010; Stoffel and Huggel, 2012), although several studies indicate a more complex or stabilizing response of mass movements to climate change (Dixon and Brook, 2007; Jomelli et al., 2007, 2009; Huggel et al., 2012; Melchiorre and Frattini, 2012). Some land use practices have led to conditions favorable to increased landslide risk, despite climate trends that would result in a decrease of landslide frequency, as reported in Calabria (Polemio and Petrucci, 2010) and in the Apennines (Wasowski et al., 2010). Snow avalanche frequency changes in Europe are dominated by climate variability; studies based on avalanche observations (Eckert et al., 2010) or favorable meteorological conditions (Castebrunet et al., 2012; Teich et al., 2012) show contrasting variations, depending on the region, elevation, season, and orientation.

### 23.3.2. Built Environment

Built infrastructure in Europe is vulnerable to extreme weather events, including overheating of buildings (houses, hospitals, schools) during hot weather (Crump et al., 2009; DCLG, 2012). Buildings that were originally designed for certain thermal conditions will need to function in warmer climates in the future (WHO, 2008). Climate change in Europe is expected to increase cooling energy demand (Dolinar et al., 2010; see also Section 23.3.4), with implications for mitigation and adaptation policies (Section 23.8.1). A range of adaptive strategies for buildings are available, including effective thermal mass and solar shading (Three Regions Climate Change Group, 2008). Climate change may also increase the frequency and intensity of drought-induced soil subsidence and associated damage to dwellings (Corti et al., 2009).

With respect to the outdoor built environment, there is limited evidence regarding the potential for differential rates of radiatively forced climate change in urban compared to rural areas (McCarthy et al., 2010). Climate change may exacerbate London's nocturnal urban heat island (UHI) (Wilby, 2008); however, the response of different cities may vary. For example, a study of Paris (Lemonsu et al., 2013) indicated a future reduction in strong urban heat island events when increased soil dryness was taken into effect. Modification of the built environment, via enhanced urban greening, for example, can reduce temperatures in urban areas, with co-benefits for health and well-being (Sections 23.7.4, 23.8.1).



### 23.3.3. Transport

Systematic and detailed knowledge on climate change impacts on transport in Europe remains limited (Koetse and Rietveld, 2009).

On road transport, in line with AR4, more frequent but less severe collisions due to reduced speed are expected in case of increased precipitation (Kilpeläinen and Summala, 2007; Brijs et al., 2008). However, lower traffic speed may cause welfare losses due to additional time spent driving (Sabir et al., 2010). Severe snow and ice-related accidents will also decrease, but the effect of fewer frost days on total accidents is unclear (Andersson and Chapman, 2011a,b). Severe accidents caused by extreme weather are projected to decrease by 63 to 70% in 2040–2070 compared to 2007 as a result of modified climate and expected developments in vehicle technology and emergency systems (Nokkala et al., 2012).

For rail, consistent with AR4, increased buckling in summer, as occurred in 2003 in the UK, is expected to increase the average annual cost of heat-related delays in some regions, while the opposite is expected for ice and snow-related delays (Lindgren et al., 2009; Dobney et al., 2010; Palin et al., 2013). Effects from extreme precipitation, as well as the net overall regional impact of climate change remain unclear. Efficient adaptation comprises proper maintenance of track and track bed.

Regarding inland waterways, the case of Rhine shows that, for 1°C to 2°C increases by 2050, more frequent high water levels are expected in winter, while after 2050 days with low water levels in summer will also increase (te Linde, 2007; Hurkmans et al., 2010; Jonkeren et al., 2011; te Linde et al., 2011). Low water levels will reduce the load factor of inland ships and consequently increase transport prices, as in the Rhine and Moselle in 2003 (Jonkeren et al., 2007; Jonkeren, 2009). Adaptation includes modal shifts, increased navigational hours per day under low water levels, and infrastructure modifications (e.g., canalization of river parts) (Jonkeren et al., 2011; Krekt et al., 2011).

For long range ocean routes, the economic attractiveness of the Northwest Passage and the Northern Sea Route depends also on passage fees, bunker prices, and cost of alternative sea routes (Verny and Grigentin, 2009; Liu and Kronbak, 2010; Lasserre and Pelletier, 2011).

Regarding air transport, for Heathrow airport (UK), future temperature and wind changes were estimated to cause a small net annual increase but much larger seasonal changes on the occurrence of delays (Pejovic et al., 2009).

### 23.3.4. Energy Production, Transmission, and Use

On wind energy, no significant changes are expected before 2050, at least in Northern Europe (Pryor and Barthelmie, 2010; Pryor and Schoof, 2010; Seljom et al., 2011; Barstad et al., 2012; Hueging et al., 2013). After 2050, in line with AR4, the wind energy potential in Northern, Continental, and most of Atlantic Europe may increase during winter and decrease in summer (Rockel and Woth, 2007; Harrison et al., 2008; Nolan et al., 2012; Hueging et al., 2013). For Southern Europe, a decrease in both seasons is expected, except for the Aegean Sea and Adriatic coast, where a significant increase during summer is possible (Bloom et al., 2008; Najac et al., 2011; Pašičko et al., 2012; Hueging et al., 2013).

For hydropower, electricity production in Scandinavia is expected to increase by 5 to 14% during 2071–2100 compared to historic or present levels (Haddeland et al., 2011; Golombek et al., 2012); for 2021–2050, increases by 1 to 20% were estimated (Haddeland et al., 2011; Seljom et al., 2011; Hamududu and Killingtveit, 2012). In Continental and part of Alpine Europe, reductions in electricity production by 6 to 36% were estimated (Schaefli et al., 2007; Stanzel and Nachtnebel, 2010; Paiva et al., 2011; Pašičko et al., 2012; Hendrickx and Sauquet, 2013). For Southern Europe, production is expected to decrease by 5 to 15% in 2050 compared to 2005 (Hamududu and Killingtveit, 2012; Bangash et al., 2013). Adaptation consists of improved water management, including pump storage if appropriate (Schaefli et al., 2007; García-Ruiz et al., 2011).

Biofuel production is discussed in Section 23.4.5. There are few studies of impacts on solar energy production. Crook et al. (2011) estimated an increase of the energy output from photovoltaic panels and especially from concentrated solar power plants in most of Europe under the A1B scenario.

On thermal power, in line with AR4, van Vliet et al. (2012) estimated a 6 to 19% decrease of the summer average usable capacity of power plants by 2031–2060 compared to 1971–2000, while smaller decreases have been also estimated (Förster and Lilliestam, 2010; Linnerud et al., 2011). Closed-cooling circuits are efficient adaptation choices for new plants (Koch and Vögele, 2009). In power transmission, increasing lightning and decreasing snow-sleet and blizzard faults for 2050–2080 were estimated for the UK (McColl et al., 2012).

By considering both heating and cooling, under a +3.7°C scenario by 2100 a decrease of total annual energy demand in Europe as a whole during 2000–2100 was estimated (Isaac and van Vuuren, 2009). Seasonal changes will be prominent, especially for electricity (see Figure 23-3), with summer peaks arising also in countries with moderate summer temperatures (Hekkenberg et al., 2009). Heating degree days are expected to decrease by 11 to 20% between 2000 and 2050 due solely to climate change (Isaac and van Vuuren, 2009). For cooling, very large percentage increases up to 2050 are estimated by the same authors for most of Europe as the current penetration of cooling devices is low; then, increases by 74 to 118% in 2100 (depending on the region) from 2050 are expected under the combined effect of climatic and non-climatic drivers. In Southern Europe, cooling degree days by 2060 will increase, while heating degree days will decrease but with substantial spatial variations (Giannakopoulos et al., 2009). Consequently, net annual electricity generation cost will increase in most of the Mediterranean and decrease in the rest of Europe (Mirasgedis

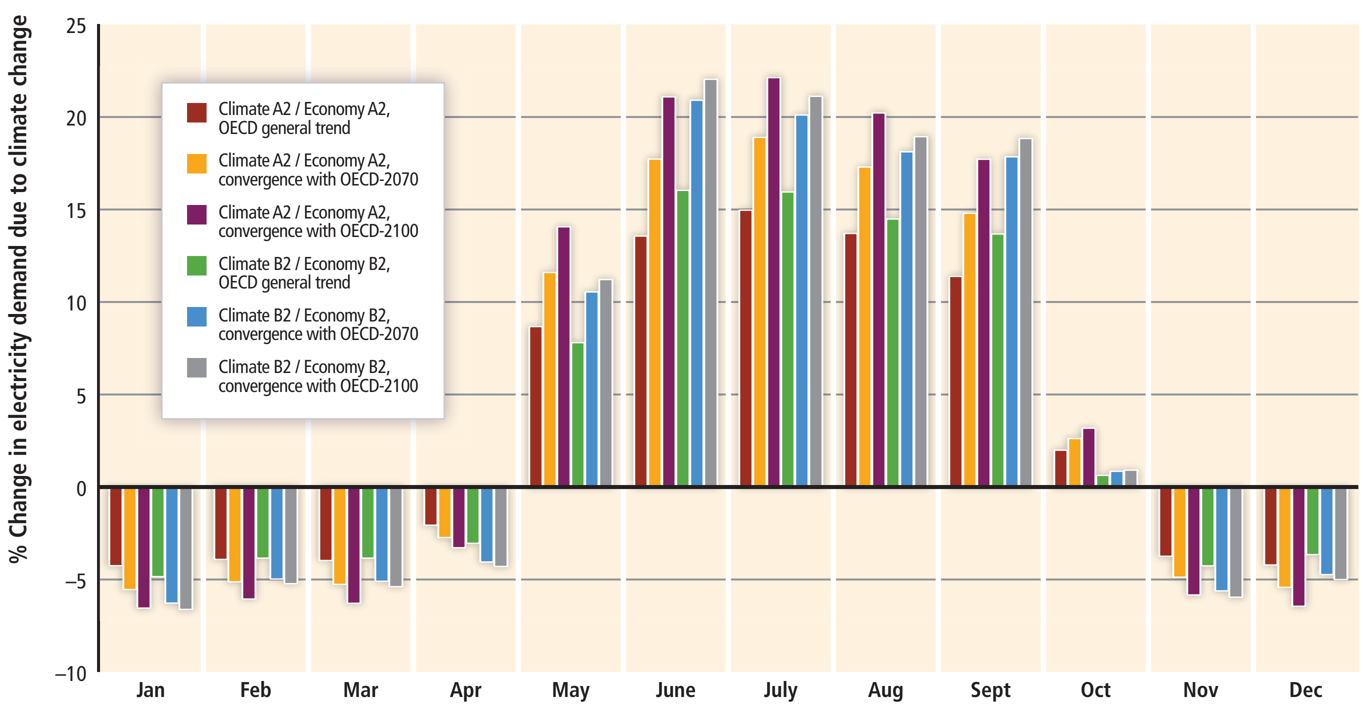


**Figure 23-3 |** Percentage change in electricity demand in Greece attributable to climate change, under a range of climate scenarios and economic assumptions. Source: Mirasgedis et al., 2007.

et al., 2007; Eskeland and Mideksa, 2010; Pilli-Sihlova et al., 2010; Zachariadis, 2010).

Future building stock changes and retrofit rates are critical for impact assessment and adaptation (Olonscheck et al., 2011). Energy-efficient buildings and cooling systems, and demand-side management, are effective adaptation options (Artmann et al., 2008; Jenkins et al., 2008; Day et al., 2009; Breesch and Janssens, 2010; Chow and Levermore, 2010).

### 23.3.5. Industry and Manufacturing

Research on the potential effects of climate change in industry is limited. Modifications in future consumption of food and beverage products have been estimated on the basis of current sensitivity to seasonal temperature (Mirasgedis et al., 2013). Higher temperatures may favor the growth of food-borne pathogens or contaminants (Jacxsens et al., 2010; Popov Janevska et al., 2010; see also Section 23.5.1). The quality of some products, such as wine (Section 23.4.1; Box 23-2), is also likely to be affected. In other sectors, the cumulative cost of direct climate change impacts in the Greek mining sector for 2021–2050 has been estimated at €0.245 billion, in 2010 prices (Damigos, 2012). Adaptation to buildings or work practices are likely to be needed to maintain labor productivity during hot weather (Kjellstrom et al., 2009; see also Section 11.6.2.2).

### 23.3.6. Tourism

In line with AR4, the climate for general tourist activities especially after 2070 is expected to improve significantly during summer and less during autumn and spring in northern Continental Europe, Finland, southern Scandinavia, and southern England (Amelung et al., 2007; Nicholls and Amelung, 2008; Amelung and Moreno, 2012). For the Mediterranean, climatic conditions for light outdoor tourist activities are expected to deteriorate in summer mainly after 2050, but improve during spring and autumn (Amelung et al., 2007; Amelung and Moreno, 2009; Hein et al., 2009; Perch-Nielsen et al., 2010; Giannakopoulos et al., 2011). Others concluded that before 2030 (or even 2060) this region as a whole will not become too hot for beach or urban tourism (Moreno and Amelung, 2009; Rutty and Scott, 2010), while surveys showed that beach tourists are deterred mostly by rain (De Freitas et al., 2008; Moreno, 2010).

Thus, from 2050, domestic tourism and tourist arrivals at locations in Northern and parts of Continental Europe may be enhanced at the expense of southern locations (Hamilton and Tol, 2007; Hein et al., 2009; Amelung and Moreno, 2012; Bujosa and Roselló, 2012). The age of tourists, the climate in their home country, and local economic and environmental conditions (e.g., water stress, tourist development) are also critical (Hamilton and Tol, 2007; Lyons et al., 2009; Moreno and Amelung, 2009; Rico-Amoros et al., 2009; Eugenio-Martin and Campos-Soria, 2010; Perch-Nielsen et al., 2010).

Tourism in mountainous areas may benefit from improved climatic conditions in summer (Endler et al., 2010; Perch-Nielsen et al., 2010; Endler and Matzarakis, 2011; Serquet and Rebetez, 2011). However, in agreement with AR4, natural snow reliability and thus ski season length will be adversely affected, especially where artificial snowmaking is limited (Moen and Fredman, 2007; OECD, 2007; Steiger, 2011). Low-lying areas will be the most vulnerable (Uhlmann et al., 2009; Endler et al., 2010; Endler and Matzarakis, 2011; Serquet and Rebetez, 2011; Steiger, 2011). Tourist response to marginal snow conditions remains largely unknown, while changes in weather extremes may also be critical (Tervo, 2008). Up to 2050, demographic changes (e.g., population declines in source countries, aging populations) may have a higher impact than climate change (Steiger, 2012). Artificial snowmaking has physical and economic limitations, especially in small sized and low-altitude ski stations (Steiger and Mayer, 2008; Sauter et al., 2010; Steiger, 2010, 2011), and increases water and energy consumption. Shifts to higher altitudes, operational/ technical measures, and year-round tourist activities may not fully compensate for adverse impacts.



### 23.3.7. Insurance and Banking

Insurance and banking face problems related to accurate pricing of risks, shortage of capital after large loss events, and by an increasing burden of losses that can affect markets and insurability, within but also outside the European region (CEA, 2007; Botzen et al., 2010a,b; see also Section 10.7). However, risk transfer, including insurance, also holds potential for adaptation by providing incentives to reduce losses (Botzen and van den Bergh, 2008; CEA, 2009; Herweijer et al., 2009).

Banking is potentially affected through physical impacts on assets and investments, as well as through regulation and/or mitigation actions by changing demands regarding sustainability of investments and lending portfolios. Few banks have adopted climate strategies that also address adaptation (Cogan, 2008; Furrer et al., 2009).

Windstorm losses are well covered in Europe by building and motor policies, and thus create a large exposure to the insurance sector. Flood losses in the UK in 2000, 2007, and 2009 have put the insurance market under further pressure, with increasing need for the government to reduce risk (Ward et al., 2008; Lamond et al., 2009). Other risks of concern to the European insurance industry is building subsidence related to drought (Corti et al., 2009), and hail damage to buildings and agriculture (Kunz et al., 2009; Botzen et al., 2010b; GDV, 2011).

The financial sector can adapt by adjusting premiums, restricting or reducing coverage, spreading risk further, and importantly incentivizing risk reduction (Crichton, 2006, 2007; Clemo, 2008; Botzen et al., 2010a; Surminski and Philp, 2010; Wamsler and Lawson, 2011). Public attitudes in Scotland and the Netherlands would support insurance of private property and public infrastructure damages in the case of increasing flood risk (Botzen et al., 2009; Glenk and Fisher, 2010). Government intervention is, however, often needed to provide compensation and back-stopping in the event of major losses (Aakre and Rübbelke, 2010; Aakre et al., 2010). Hochrainer et al. (2010) analyzed the performance of the European Union Solidarity Fund that supports European governments in large events, and argue there is a need to increase its focus on risk reduction. Current insurance approaches present in Europe are likely to remain, as they are tailored to local situations and preferences (Schwarze et al., 2011).

## 23.4. Implications of Climate Change for Agriculture, Fisheries, Forestry, and Bioenergy Production

### 23.4.1. Plant (Food) Production

In AR4, Alcamo et al. (2007) reported that crop suitability is likely to change throughout Europe. During the 2003 and 2010 summer heat waves, grain-harvest losses reached 20 and 25-30% in affected regions of Europe and Russia, respectively (Ciais et al., 2005; Barriopedro et al., 2011; see also Table 23-1). Cereals production fell on average by 40% in the Iberian Peninsula during the intense 2004/2005 drought (EEA, 2010a). Climate-induced variability in wheat production has increased in recent decades in Southern and Central Europe (Ladanyi, 2008; Brisson et al., 2010; Hawkins et al., 2013), but no consistent reduction has been recorded in the northernmost areas of Europe (Peltonen-Sainio et al., 2010). Country-scale rainfed cereals yields are below agro-climatic potentials (Supit et al., 2010), and wheat yield increases have leveled off in several countries over 1961–2009 (Olesen et al., 2011). High temperatures and droughts during grain filling have contributed to the lack of yield increase of winter wheat in France despite improvements in crop breeding (Brisson et al., 2010; Kristensen et al., 2011). In contrast, in eastern Scotland, warming has favored an increase in potato yields since 1960 (Gregory and Marshall, 2012). In northeast Spain, grape yield was reduced by an increased water deficit in the reproductive stage since the 1960s (Camps and Ramos, 2012).

Insight into the potential effect of climate change on crops requires the combination of a wide range of emission scenarios, Global Climate Models (GCMs), and impact studies (Trnka et al., 2007; Soussana et al., 2010). In the EU27, a 2.5°C regional temperature increase in the 2080s under the B2 scenario could lead to small changes (on average +3%) in crop yields, whereas a 5.4°C regional warming under the A2 scenario could reduce mean yields by 10% according to a study based on regional climate models (Ciscar et al., 2011). An initial benefit from the increasing $CO_2$ concentration for rainfed crop yields would contrast by the end of the century with yield declines in most European sub-regions, although wheat yield could increase under the A2 scenario (three GCMs, B1, A2 scenarios; Supit et al., 2012). Disease-limited yields of rainfed wheat and maize in the 2030s does not show consistent trends across two GCMs (Donatelli et al., 2012). For a global temperature increase of 5°C, agroclimatic indices show an increasing frequency of extremely unfavorable years in European cropping areas (Trnka et al., 2011). Under the A2 and B2 scenarios, crop production shortfalls, defined as years with production below 50% of its average climate normal production would double by 2020 and triple by 2070 as compared to a current frequency of 1 to 3 years per decade in the currently most productive southern European regions of Russia (Alcamo et al., 2007).

The regional distribution of climate change impacts on agricultural production is likely to vary widely (Donatelli et al., 2012; Iglesias et al., 2012; see also Figure 23-4). Southern Europe would experience the largest yield losses (–25% by 2080 under a 5.4°C warming; Ciscar et al., 2011), with increased risks of rainfed summer crop failure (Ferrara et al., 2010; Bindi and Olesen, 2011; Ruiz-Ramos et al., 2011). Warmer and drier conditions by 2050 (Trnka et al., 2010, 2011) would cause moderate declines in crop yields in Central Europe regions (Ciscar et al., 2011). In Western Europe, increased heat stress around flowering could cause considerable yield losses in wheat (Semenov, 2009). For Northern Europe, there is diverging evidence concerning future impacts. Positive yield changes combined with the expansion of climatically suitable areas could lead to crop production increases (between 2.5°C and 5.4°C regional warming) (Bindi and Olesen, 2011). However, increased climatic variability would limit winter crops expansion (Peltonen-Sainio et al., 2010) and cause at high latitudes high risk of marked cereal yield loss (Rötter et al., 2011). Spring crops from tropical origin like maize for silage could become cultivated in Finland by the end of the century (Peltonen-Sainio et al., 2009). Cereal yield reduction from ozone (Fuhrer, 2009) could reach 6 and 10 % in 2030 for the European Union with the B1 and A2 scenarios, respectively (Avnery et al., 2011a,b). Because of limited land availability and soil fertility outside of Chernozem (black earth) areas, the shift of agriculture to the boreal forest zone would not compensate for crop losses owing to increasing aridity in South European regions of Russia with the best soils (Dronin and Kirilenko, 2011).

With generally warmer and drier conditions, deep rooted weeds (Gilgen et al., 2010) and weeds with contrasting physiology, such as $C_4$ species, could pose a more serious threat (Bradley et al., 2010) to crops than shallow rooted $C_3$ weeds (Stratonovitch, 2012). Arthropod-borne diseases (viruses and phytoplasmas), winter infection root and stem diseases (phoma stem canker of oilseed rape and eyespot of wheat; Butterworth et al., 2010; West et al., 2012), *Fusarium* blight (Madgwick et al., 2011), grapevine moth (Caffarra et al., 2012), and a black rot fungus in fruit trees (Weber, 2009) could create increasing damages in Europe under climate change. However, other pathogens such as cereal stem rots (e.g., *Puccinia striiformis*; Luck et al., 2011) and grapevine powdery mildew (Caffarra et al., 2012) could be limited by increasing temperatures. Increased damages from plant pathogens and insect pests are projected by 2050 in Nordic countries, which have hitherto been protected by cold winters and geographic isolation (Hakala et al., 2011; Roos et al., 2011). Some pests, such as the European corn borer (Trnka et al., 2007), could also extend their climate niche in Central Europe. Pests and disease management will be affected with regard to timing, preference, and efficacy of chemical and biological measures of control (Kersebaum et al., 2008).

Autonomous adaptation by farmers, through the advancement of sowing and harvesting dates and the use of longer cycle varieties (Howden et al., 2007; Moriondo et al., 2010a, 2011; Olesen et al., 2011) could result in a general improvement of European wheat yields in the 2030s compared to the 2000s (Donatelli et al., 2012; see also Figure 23-4). However, farmer sowing dates seem to advance slower than crop phenology (Menzel et al., 2006; Siebert and Ewert, 2012), possibly because earlier sowing is often prevented by lack of soil workability and frost-induced soil crumbling (Oort et al., 2012). Simulation studies that anticipate on earlier sowing in Europe may thus be overly optimistic. Further adaptation options include changes in crop species, fertilization, irrigation, drainage, land allocation, and farming system (Bindi and Olesen, 2011). At the high range of the projected temperature changes, only plant breeding aimed at increasing yield potential jointly with drought resistance and adjusted agronomic practices may reduce risks of yield shortfall (Olesen et al., 2011; Rötter et al., 2011; Ventrella et al., 2012). Crop breeding is, however, challenged by temperature and rainfall variability, since (1) breeding has not yet succeeded in altering crop plant development responses to short-term changes in temperature (Parent and Tardieu, 2012), and (2) distinct crop drought tolerance traits are required for mild and severe water deficit scenarios (Tardieu, 2012). Adaptation to increased climatic variability may require an increased use of between and within species genetic diversity in farming systems (Smith and Olesen, 2010) and the development of insurance products against weather-related yield variations (Musshoff et al., 2011). Adaptive capacity and long-term economic viability of farming systems may vary given farm structural change induced by climate change (Moriondo et al., 2010b; Mandryk et al., 2012). In Southern Europe, the regional welfare



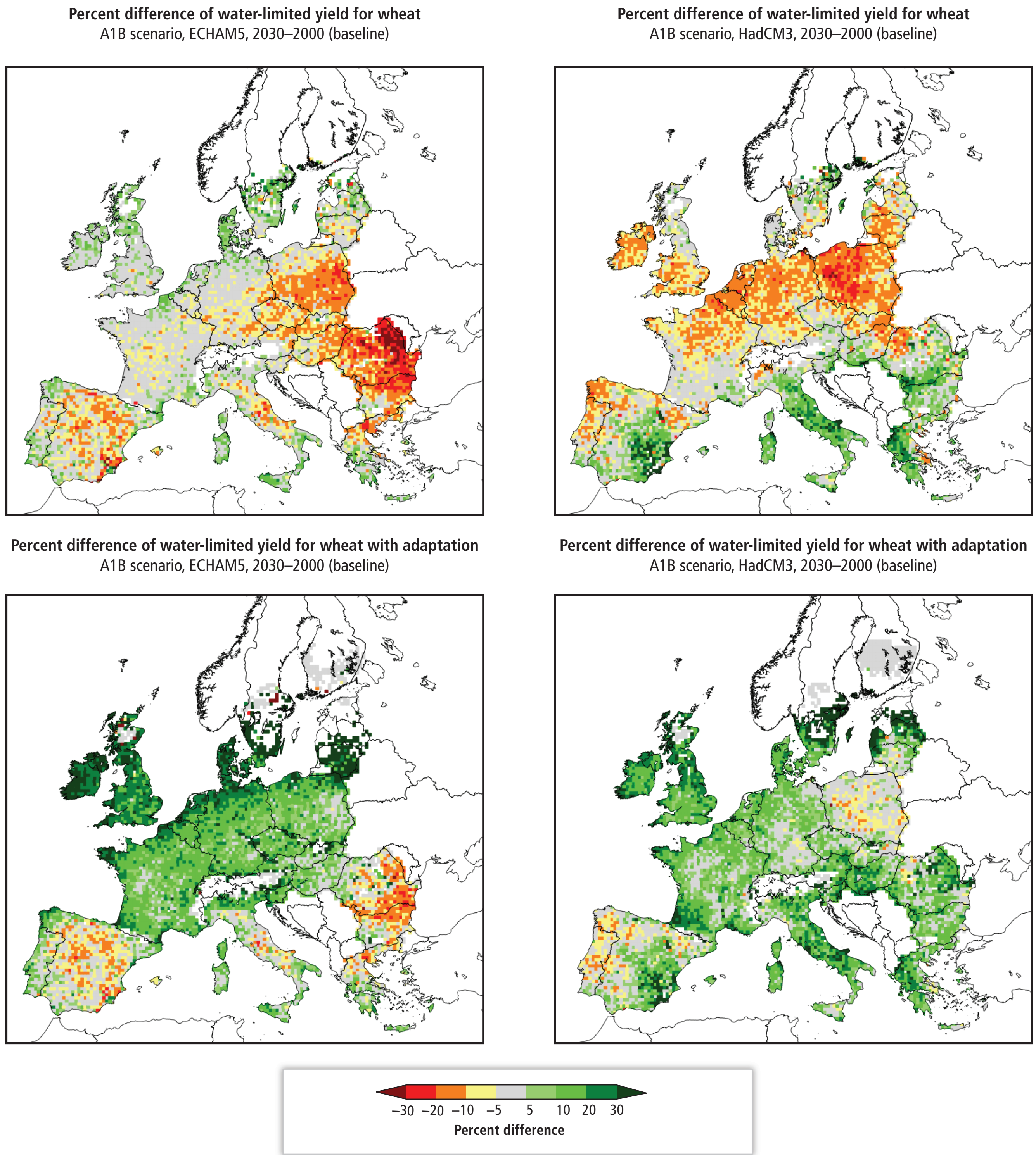


**Figure 23-4 |** Percentage change in simulated water-limited yield for winter wheat in 2030 with respect to the 2000 baseline for the A1B scenario using European Centre for Medium Range Weather Forecasts and Hamburg 5 (ECHAM5; left column) and Hadley Centre Coupled Model version 3 (HadCM3; right) General Circulation Models (GCMs). Upper maps do not take adaptation into account. Bottom maps include adaptation. Analysis developed at the Joint Research Centre of the European Commission. Source: Donatelli et al., 2012.

loss caused by changes in the agriculture sector under a high warming scenario (+5.4°C) was estimated at 1% of gross domestic product (GDP). Northern Europe was the single sub-region with welfare gains (+0.7%) from agriculture in this scenario (Ciscar et al., 2011).

### 23.4.2. Livestock Production

Livestock production is adversely affected by heat (Tubiello et al., 2007; see also Section 7.2.1.3). With intensive systems, heat stress reduced dairy production and growth performance of large finishing pigs at daily mean air temperatures above 18°C and 21°C, respectively (André et al., 2011; Renaudeau et al., 2011). High temperature and air humidity during breeding increased cattle mortality risk by 60% in Italy (Crescio et al., 2010). Adaptation requires changes in diets and in farm buildings (Renaudeau et al., 2012) as well as targeted genetic improvement programs (Hoffmann, 2010).

With grass-based livestock systems, model simulations (A1B scenario, ensemble of downscaled GCMs) show by the end of the 21st century increases in potential dairy production in Ireland and France, with, however, higher risks of summer-autumn production failures in Central Europe and at French sites (Trnka et al., 2009; Graux et al., 2012). Climate conditions projected for the 2070s in central France (A2 scenario) reduced significantly grassland production in a 4-year experiment under elevated $CO_2$ (Cantarel et al., 2013). At the same site, a single experimental summer drought altered production during the next 2 years (Zwicke et al., 2013).

Resilience of grassland vegetation structure was observed to prolonged experimental heating and water manipulation (Grime et al., 2008). However, weed pressure from tap-rooted forbs was increased after severe experimental summer droughts (Gilgen et al., 2010). Mediterranean populations could be used to breed more resilient and better adapted forage plant material for livestock production (Poirier et al., 2012).

Climate change has affected animal health in Europe (*high confidence*). The spread of bluetongue virus in sheep across Europe has been partly attributed to climate change (Arzt et al., 2010; Guis et al., 2012) through increased seasonal activity of the *Culicoides* vector (Wilson and Mellor, 2009). The distribution of this vector is unlikely to expand but its abundance could increase in Southern Europe (Acevedo et al., 2010). Ticks, the primary arthropod vectors of zoonotic diseases in Europe (e.g., Lyme disease and tick-borne encephalitis), have changed distributions towards higher altitudes and latitudes with climate change (Randolph and Rogers, 2010; van Dijk et al., 2010; Petney et al., 2012; see also Section 23.5). Exposure to fly strike could increase in a warmer climate but adaptation in husbandry practices would limit impacts on livestock (Wall and Ellse, 2011). The overall risk of incursion of Crimean-Congo hemorrhagic fever virus in livestock through infected ticks introduced by migratory bird species would not be increased by climate change (Gale et al., 2012). The probability of introduction and large-scale spread of Rift Valley fever in Europe is also very low (Chevalier et al., 2010). Epidemiological surveillance and increased coordinated regional monitoring and control programs have the potential to reduce the incidence of vector-borne animal diseases (Wilson and Mellor, 2009; Chevalier et al., 2010).

### 23.4.3. Water Resources and Agriculture

Future projected trends confirm the widening of water resource differences between Northern and Southern Europe reported in AR4 (Alcamo et al., 2007). In Southern Europe, soil water content will decline, saturation conditions and drainage will be increasingly rare and restricted to periods in winter and spring, and snow accumulation and melting will change, especially in the mid-mountain areas (García-Ruiz et al., 2011). Across most of Northern and Continental Europe, an increase in flood hazards (Falloon and Betts, 2010; see also Section 23.3.1) could increase damages to crops and plant growth, complicate soil workability, and increase yield variability (Olesen et al., 2011). Groundwater recharge and/or water table level would be significantly reduced by the end of the 21st century under A2 scenario for river basins located in southern Italy, Spain, northern France, and Belgium (Ducharne et al., 2010; Goderniaux et al., 2011; Guardiola-Albert and Jackson, 2011; Senatore et al., 2011). However, nonsignificant impacts were found for aquifers in Switzerland and in England (Jackson et al., 2011; Stoll et al., 2011). Less precipitation in summer and higher rainfall during winter could increase nitrate leaching (Kersebaum et al., 2008) with negative impacts on water quality (Bindi and Olesen, 2011). Even with reduced nitrogen fertilizer application, groundwater nitrate concentrations would increase by the end of the century in the Seine river basin (Ducharne et al., 2007). More robust water management, pricing, and recycling policies to secure adequate future water supply and prevent tensions among users could be required in Southern Europe (García-Ruiz et al., 2011).

Reduced suitability for rainfed agricultural production (Henriques et al., 2008; Daccache and Lamaddalena, 2010; Trnka et al., 2011; Daccache et al., 2012) will increase water demand for crop irrigation (Savé et al., 2012). However, increased irrigation may not be a viable option, especially in the Mediterranean area, because of projected declines in total runoff and groundwater resources (Olesen et al., 2011). In a number of catchments water resources are already over-licensed and/or over-abstracted (Daccache et al., 2012) and their reliability is threatened by climate change-induced decline in groundwater recharge and to a lesser extent by the increase in potential demand for irrigation (Ducharne et al., 2010; Majone et al., 2012). To match this demand, irrigation system costs could increase by 20 to 27% in southern Italy (Daccache and Lamaddalena, 2010) and new irrigation infrastructures would be required in some regions (van der Velde et al., 2010). However, since the economic benefits are expected to be small, the adoption of irrigation would require changes in institutional and market conditions (Finger et al., 2011). Moreover, since aquatic and terrestrial ecosystems are affected by agricultural water use (Kløve et al., 2011), irrigation demand restrictions are projected in environmentally focussed future regional scenarios (Henriques et al., 2008). Earlier sowing dates, increased soil organic matter content, low-energy systems, deficit irrigation, and improved water use efficiency of irrigation systems and crops can be used as adaptation pathways (Gonzalez-Camacho et al., 2008; Lee et al., 2008; Daccache and Lamaddalena, 2010; Schutze and Schmitz, 2010), especially in Southern and southeastern regions of Europe (Trnka et al., 2009; Falloon and Betts, 2010). Improved water management in upstream agricultural areas could mitigate adverse impacts downstream (Kløve et al., 2011), and groundwater recharge could be targeted in areas with poor water-holding soils (Wessolek and Asseng, 2006).

### 23.4.4. Forestry

Observed and future responses of forests to climate change include changes in growth rates, phenology, composition of animal and plant communities, increased fire and storm damage, and increased insect and pathogen damage. Tree mortality and forest decline due to severe drought events were observed in forest populations in Southern Europe (Bigler et al., 2006; Raftoyannis et al., 2008; Affolter et al., 2010), including Italy (Giuggiola et al., 2010; Bertini et al., 2011), Cyprus (ECHOES Country Report: Cyprus, 2009), and Greece (Raftoyannis et al., 2008), as well as in Belgium (Kint et al., 2012), Switzerland (Rigling et al., 2013), and the pre-Alps in France (Rouault et al., 2006; Allen et al., 2010; Charru et al., 2010). Declines have also been observed in wet forests not normally considered at risk of drought (Choat et al., 2012). An increase in forest productivity has been observed in the Russian Federation (Sirotenko and Abashina, 2008).

Future projections show that, in Northern and Atlantic Europe, increasing atmospheric $CO_2$ and higher temperatures are expected to increase forest growth and wood production, at least in the short to medium term (Lindner et al., 2010). On the other hand, in Southern and Eastern Europe, increasing drought and disturbance risks will cause adverse effects and productivity is expected to decline (Sirotenko and Abashina, 2008; Lavalle et al., 2009; Lindner et al., 2010; Hlásny et al., 2011; Keenan et al., 2011; Silva et al., 2012). By 2100, climate change is expected to reduce the economic value of European forest land depending on interest rate and climate scenario, which equates to potential damages of several hundred billion euros (Hanewinkel et al., 2013).

In Southern Europe, fire frequency and wildfire extent significantly increased after the 1970s compared with previous decades (Pausas and Fernández-Muñoz, 2012) as a result of fuel accumulation (Koutsias et al., 2012), climate change (Lavalle et al., 2009), and extreme weather events (Camia and Amatulli, 2009; Hoinka et al., 2009; Carvalho et al., 2011; Koutsias et al., 2012; Salis et al., 2013), especially in the Mediterranean basin (Fernandes et al., 2010; Marques et al., 2011; Koutsias et al., 2012; Pausas and Fernández-Muñoz, 2012). The most severe events in France, Greece, Italy, Portugal, Spain, and Turkey in 2010 were associated with strong winds during a hot dry period (EEA, 2010c). However, for the Mediterranean region as a whole, the total burned area has decreased since 1985 and the number of wildfires has decreased from 2000 to 2009, with large interannual variability (Marques et al., 2011; San-Miguel-Ayanz et al., 2012; Turco et al., 2013). Megafires, triggered by extreme climate events, had caused record maxima of burnt areas in some Mediterranean countries during the last decades (San-Miguel-Ayanz et al., 2013).

Future wildfire risk is projected to increase in Southern Europe (Lindner et al., 2010; Carvalho et al., 2011; Dury et al., 2011; Vilén and Fernandes,

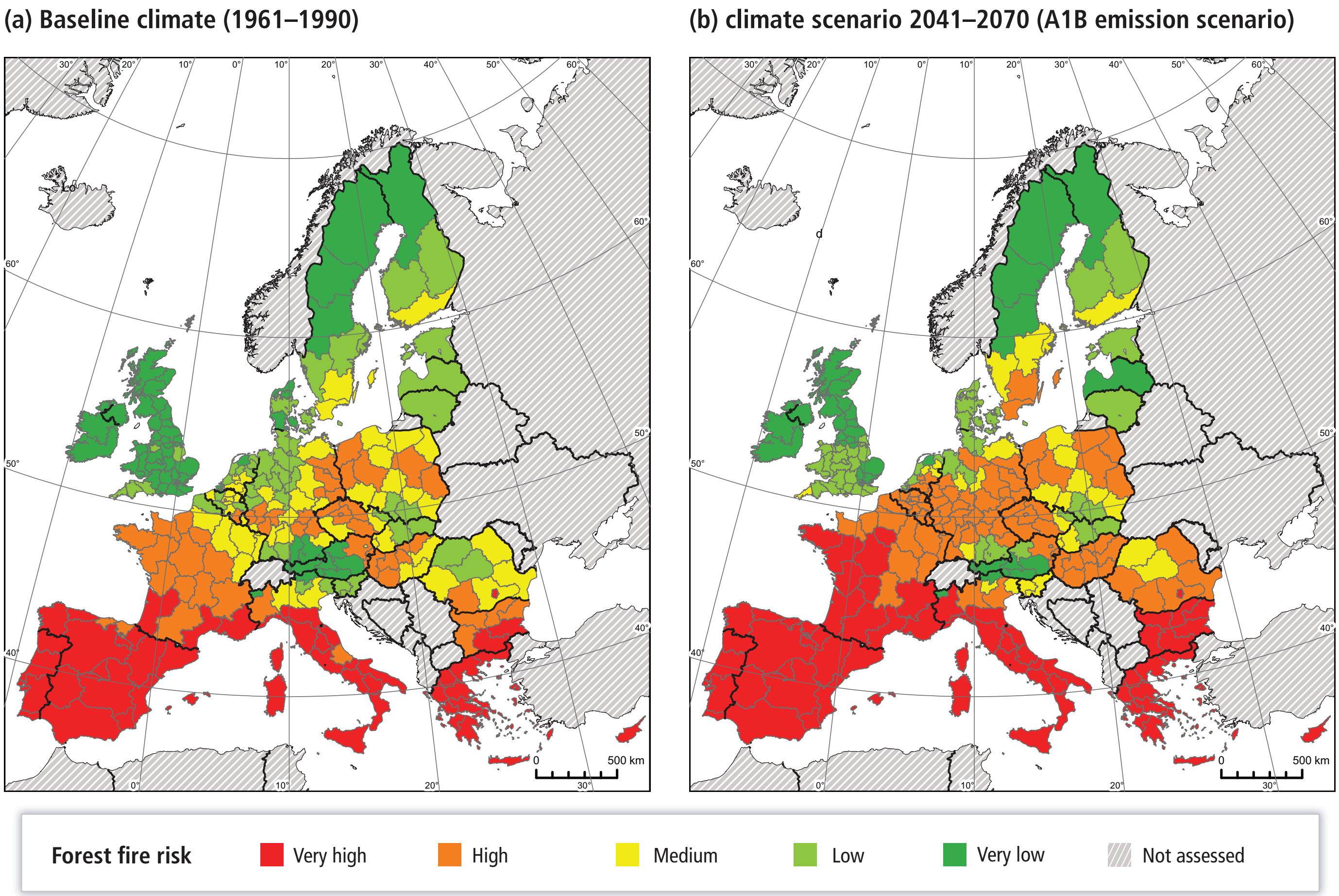


**Figure 23-5 |** Forest fire risk in Europe for two time periods: baseline (left) and 2041–2070 (right), based on high-resolution regional climate models and the Special Report on Emission Scenarios (SRES) A1B emission scenario. Forest fire risk indicator is based on climate and non-climate factors (e.g., fuel availability, fire ignition potential). Source: Lung et al., 2013.

2011), with an increase in the occurrence of high fire danger days (Arca et al., 2012; Lung et al., 2012) and in fire season length (Pellizzaro et al., 2010). The annual burned area is projected to increase by a factor of 3 to 5 in Southern Europe compared to the present under the A2 scenario by 2100 (Dury et al., 2011). In Northern Europe, fires are projected to become less frequent due to increased humidity (Rosan and Hammarlund, 2007). Overall, the projected increase in wildfires is likely to lead to a significant increase in greenhouse gas (GHG) emissions due to biomass burning (Pausas et al., 2008; Vilén and Fernandes, 2011; Chiriacò et al., 2013), even if often difficult to quantify (Chiriacò et al., 2013).

Wind storm damage to forests in Europe has recently increased (Usbeck et al., 2010). Boreal forests will become more vulnerable to autumn/early spring storm damage due to expected decrease in period of frozen soil (Gardiner et al., 2010). Increased storm losses by 8 to 19% under A1B and B2 scenarios, respectively, is projected in western Germany for 2060–2100 compared to 1960–2000, with the highest impacts in the mountainous regions (Pinto et al., 2010; Klaus et al., 2011).

An increase in the incidence of diseases has been observed in many European forests (Marcais and Desprez-Loustau, 2007; FAO, 2008b). In Continental Europe, some species of fungi benefit from milder winters and others spread during drought periods from south to north (Drenkhan et al., 2006; Hanso and Drenkhan, 2007). Projected increased late summer warming events will favor diffusion of bark beetle in Scandinavia, in lowland parts of Central Europe, and Austria (Jönsson et al., 2009, 2011; Seidl et al., 2009).

Possible response approaches to the impacts of climate change on forestry include short- and long-term strategies that focus on enhancing ecosystem resistance and resilience and responding to potential limits to carbon accumulation (Millar et al., 2007; Nabuurs et al., 2013). Fragmented small-scale forest ownership can constrain adaptive capacity (Lindner et al., 2010). Landscape planning and fuel load management may reduce the risk of wildfires but may be constrained by the higher flammability owing to warmer and drier conditions (Moreira et al., 2011). Strategies to reduce forest mortality include preference of species better adapted to relatively warm environmental conditions (Resco de Dios et al., 2007). The selection of tolerant or resistant families and clones may also reduce the risk of damage by pests and diseases in pure stands (Jactel et al., 2009).

### 23.4.5. Bioenergy Production

The potential distribution of temperate oilseeds (e.g., oilseed rape, sunflower), starch crops (e.g., potatoes), cereals (e.g., barley), and solid biofuel crops (e.g., sorghum, *Miscanthus*) is projected to increase in Northern Europe by the 2080s, as a result of increasing temperatures, and to decrease in Southern Europe due to increased drought frequency

## Box 23-1 | Assessment of Climate Change Impacts on Ecosystem Services by Sub-region

Ecosystems provide a number of vital provisioning, regulating, and cultural services for people and society that flow from the stock of natural capital (Stoate et al., 2009; Harrison et al., 2010). Provisioning services such as food from agro-ecosystems or timber from forests derive from intensively managed ecosystems; regulating services underpin the functioning of the climate and hydrological systems; and cultural services such as tourism, recreation, and aesthetic value are vital for societal well-being (see Section 23.5.4). The table summarizes the potential impacts of climate change on ecosystem services in Europe by sub-region based on an assessment of the published literature (2004–2013). The direction of change (increasing, decreasing, or neutral) is provided, as well as the number of studies/papers on which the assessment was based (in parentheses). Empty cells indicate the absence of appropriate literature. Unless otherwise stated, impacts assume no adaptation and are assessed for the mid-century (2050s). A decrease in natural hazard regulation (e.g., for wildfires) implies an increased risk of the hazard occurring. Biodiversity is included here as a service (for completeness), although it is debated whether biodiversity should be considered as a service or as part of the natural capital from which services flow. What is agreed, however, is that biodiversity losses within an ecosystem will have deleterious effects on service provision (Mouillot et al., 2013).

The provision of ecosystem services in Southern Europe is projected to decline across all service categories in response to climate change (*high confidence*). Other European sub-regions are projected to have both losses and gains in the provision of ecosystem services (*high confidence*). The Northern sub-region will have increases in provisioning services arising from climate change (*high confidence*). Except for the Southern sub-region, the effects of climate change on regulating services are balanced with respect to gains and losses (*high confidence*). There are fewer studies for cultural services, although these indicate a balance in service provision for the Alpine and Atlantic regions, with decreases in service provision for the Continental, Northern, and Southern sub-regions (*low confidence*).

Continued next page →

## Box 23-1 (continued)

| | | | Southern | Atlantic | Continental | Alpine | Northern |
|---|---|---|---|---|---|---|---|
| Provisioning services | Food production | | ↓ (1) | ↓ (1) | ↓ (1) | No (1)<br>↓ (4) | ↑ (1)<br>↓ (1) |
| | Livestock production | | | | | No (1)<br>↓ (1) | |
| | Fiber production | | | | | ↓ (1) | |
| | Bioenergy production | | ↓ (1) | | | ↑ (1) | ↑ (1) |
| | Fish production | | No (1)<br>↓ (2) | No (1)<br>↓ (1) | ↓ (1) | | No (1)<br>↓ (1) |
| | Timber production | | ↓ (2) | ↑ (2)<br>No (3) | ↑ (1)<br>No (2)<br>↓ (1) | ↑ (5)<br>No (2)<br>↓ (5) | ↑ (6)<br>No (1) |
| | Non-wood forest products | | ↓ (1) | | | | ↑ (1)<br>No (1) |
| | Sum of effects on provisioning services | | No (1)<br>↓ (7) | ↑ (2)<br>No (4)<br>↓ (2) | ↑ (1)<br>No (2)<br>↓ (3) | ↑ (6)<br>No (4)<br>↓ (11) | ↑ (9)<br>No (3)<br>↓ (2) |
| Regulating services | Climate regulation (carbon sequestration) | General/forests | ↑ (3)<br>↓ (1) | ↑ (4)<br>No (1) | ↑ (3)<br>No (1) | ↑ (4)<br>No (1)<br>↓ (3) | ↑ (4)<br>No (1)<br>↓ (1) |
| | | Wetland | No (1)<br>↓ (1) | No (1)<br>↓ (1) | ↓ (1) | | No (1)<br>↓ (1) |
| | | Soil carbon stocks | No (1)<br>↓ (1) | No (1)<br>↓ (2) | No (1)<br>↓ (1) | No (1)<br>↓ (2) | ↓ (3) |
| | Pest control | | ↓ (1) | | ↑ (1) | ↑ (1) | ↑ (1) |
| | Natural hazard regulation[a] | Forest fires/wildfires | ↓ (1) | ↓ (1) | ↓ (2) | | |
| | | Erosion, avalanche, landslide | | | | ↑ (2)<br>↓ (1) | |
| | | Flooding | | | | ↓ (1) | |
| | | Drought | No (1)<br>↓ (1) | | ↓ (1) | | |
| | Water quality regulation | | | ↓ (1) | | | ↓ (1) |
| | Biodiversity | | ↑ (1)<br>↓ (8) | ↑ (2)<br>No (1)<br>↓ (4) | ↑ (2)<br>↓ (4) | ↑ (2)<br>↓ (4) | ↑ (3)<br>↓ (2) |
| | Sum of effects on regulating services | | ↑ (4)<br>No (3)<br>↓ (14) | ↑ (6)<br>No (4)<br>↓ (9) | ↑ (6)<br>No (2)<br>↓ (9) | ↑ (9)<br>No (2)<br>↓ (11) | ↑ (8)<br>No (2)<br>↓ (8) |
| Cultural services | Recreation (fishing, nature enjoyment) | | ↑ (1) | ↓ (1) | | | ↑ (1)<br>↓ (2) |
| | Tourism (skiing) | | | | | ↑ (1) | ↑ (1) |
| | Aesthetic/heritage (landscape character, cultural landscapes) | | ↓ (1) | ↓ (1) | No (1)<br>↓ (1) | ↑ (1) | |
| | Sum of effects on cultural services | | ↓ (2) | ↑ (1)<br>↓ (1) | No (1)<br>↓ (1) | ↑ (1)<br>↓ (1) | ↑ (1)<br>↓ (3) |

↓ = Climate change impacts are decreasing ecosystem service

↑ = Climate change impacts are increasing ecosystem service

No = Neutral effect

(1) = Numbers in brackets refer to the number of studies supporting the change (increasing, decreasing, neutral) in ecosystem service.

[a]A decline in ecosystem services implies an increased risk of the specified natural hazard.

Entries for biodiversity are those that were found during the literature search for climate change impacts on ecosystem services. A wider discussion of the impacts of climate change on biodiversity can be found in Sections 4.3.4 and 23.6.

References: Wessel et al. (2004); Schroter et al. (2005); Fuhrer et al. (2006); Koca et al. (2006); Gret-Regamy et al. (2008); Hemery (2008); Metzger et al. (2008); Palahi et al. (2008); Bolte et al. (2009); Garcia-Fayos and Bochet (2009); Johnson et al. (2009); Albertson et al. (2010); Canu et al. (2010); Clark et al. (2010a); Lindner et al. (2010); Lorz et al. (2010); Milad et al. (2011); Okruszko et al. (2011); Seidl et al. (2011); Briner et al. (2012); Civantos et al. (2012); Rusch (2012); Bastian (2013); Forsius et al. (2013); Gret-Regamy et al. (2013); Seidl and Lexer (2013).

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(Tuck et al., 2006). Mediterranean oil and solid biofuel crops, currently restricted to Southern Europe, are likely to extend further north (Tuck et al., 2006). The physiological responses of bioenergy crops, in particular $C_3$ Salicaceae trees, to rising atmospheric $CO_2$ concentration may increase drought tolerance because of improved plant water use; consequently yields in temperate environments may remain high in future climate scenarios (Oliver et al., 2009).

A future increase in the northward extension of the area for short rotation coppice (SRC) cultivation leading to GHG neutrality is expected (Liberloo et al., 2010). However, the northward expansion of SRC would erode the European terrestrial carbon sink due to intensive management and high turnover of SRC compared to conventional forest where usually harvesting is less than annual growth (Liberloo et al., 2010).

### 23.4.6. Fisheries and Aquaculture

In AR4, Easterling et al. (2007) reported that the recruitment and production of marine fisheries in the North Atlantic are *likely* to increase. In European seas, warming causes a displacement to the north and/or in depth of fish populations (Daufresne et al., 2009; see also Chapter 6; Section 23.6.4), which has a direct impact on fisheries (Tasker, 2008; Cheung et al., 2010, 2013). For instance, in British waters, the lesser sandeel (*Ammodytes marinus*), which is a key link in the food web, shows declining recruitments since 2002 and is projected to further decline in the future with a warming climate (Heath et al., 2012). In the Baltic Sea, although some new species would be expected to immigrate because of an expected increase in sea temperature, only a few of these would be able to successfully colonize the Baltic because of its low salinity (Mackenzie et al., 2007). In response to climate change and intensive fishing, widespread reductions in fish body size (Daufresne et al., 2009) and in the mean size of zooplankton (Beaugrand and Reid, 2012) have been observed over time and these trends further affect the sustainability of fisheries (Pitois and Fox, 2006; Beaugrand and Kirby, 2010; see also Chapter 6). Aquaculture can be affected as the areal extent of some habitats that are suitable for aquaculture can be reduced by sea level rise. Observed higher water temperatures have adversely affected both wild and farmed freshwater salmon production in the southern part of the distribution areas (Jonsson and Jonsson, 2009). In addition, ocean acidification may disrupt the early developmental stages of shellfish (Callaway et al., 2012).

Numerous studies confirm the amplification through fishing of the effects of climate change on population dynamics and consequently on fisheries (Planque et al., 2010). The decline of the North Sea cod during the 1980–2000 period resulted from the combined effects of overfishing and of an ecosystem regime shift due to climate change (Beaugrand and Kirby, 2010). Over the next decade, this stock was not restored from its previous collapse (Mieszkowska et al., 2009; ICES, 2010). In the North and Celtic Seas, the steep decline in boreal species (Henderson, 2007) was compensated for by the arrival of southern (Lusitanian) species (ter Hofstede et al., 2010; Engelhard et al., 2011; Lenoir et al., 2011).

Climate change may reinforce parasitic diseases and impose severe risks for aquatic animal health (see Chapter 6). As water temperatures increase, a number of endemic diseases of both wild and farmed salmonid populations are *likely* to become more prevalent and threats associated with exotic pathogens may rise (Marcos-Lopez et al., 2010). In the Iberian Atlantic, the permitted harvesting period for the mussel aquaculture industry was reduced because of harmful algal blooms resulting from changes in phytoplankton communities linked to a weakening of the Iberian upwelling (Perez et al., 2010). With freshwater systems, summer heat waves boost the development of harmful cyanobacterial blooms (Johnk et al., 2008). For oysters in France, toxic algae may be linked to both climate warming and direct anthropogenic stressors (Buestel et al., 2009).

Fishery management thresholds will have to be reassessed as the ecological basis on which existing thresholds have been established changes, and new thresholds will have to be developed for immigrant species (Mackenzie et al., 2007; Beaugrand and Reid, 2012). These changes may lead to loss of productivity, but also the opening of new fishing opportunities, depending on the interactions between climate impacts, fishing grounds, and fleet types. They will also affect fishing regulations, the price of fish products, and operating costs, which in turn will affect the economic performance of the fleets (Cheung et al., 2012). Climate change impacts on fisheries profits range from negative for sardine fishery in the Iberian Atlantic fishing grounds (Garza-Gil et al., 2010; Perez et al., 2010) to nonsignificant for the Bay of Biscay (Le Floc'h et al., 2008) and positive on the Portuguese coast, since most of the immigrant fish species are marketable (Vinagre et al., 2011). Human social fishing systems dealing with high variability upwelling systems with rapidly reproducing fish species may have greater capacities to adjust to the additional stress of climate change than human social fishing systems focused on longer-lived and generally less variable species (Perry et al., 2010, 2011). Climate change adaptation is being considered for integration in European maritime and fisheries operational programs (EC, 2013c).

## 23.5. Implications of Climate Change for Health and Social Welfare

### 23.5.1. Human Population Health

Climate change is likely to have a range of health effects in Europe. Studies since AR4 have confirmed the effects of heat on mortality and morbidity in European populations and particularly in older people and those with chronic disease (Kovats and Hajat, 2008; Åström et al., 2011; Corobov et al., 2012, 2013). With respect to sub-regional vulnerability, populations in Southern Europe appear to be most sensitive to hot weather (Michelozzi et al., 2009; D'Ippoliti et al., 2010; Baccini et al., 2011), and also will experience the highest heat wave exposures (Figure 23-2). However, populations in Continental (Hertel et al., 2009) and Northern Europe (Rocklöv and Forsberg, 2010; Armstrong et al., 2011; Varakina et al., 2011) are also vulnerable to heat wave events. Adaptation measures to reduce heat health effects include heat wave plans (Bittner et al., 2013) which have been shown to reduce heat-related mortality in Italy (Schifano et al., 2012), but evidence of effectiveness is still very limited (Hajat et al., 2010; Lowe et al., 2011). There is little information about how future changes in housing and infrastructure (Section 23.3.2) would reduce the regional or local future burden of heat-related mortality or morbidity. Climate change is likely to increase future heat-related mortality (Baccini et al., 2011; Ballester et al., 2011; Huang et al., 2011) and morbidity (Åström et al., 2013), although most published risk assessments do not include consideration of adaptation (Huang et al., 2011). For most countries in Europe, the current burden of cold-related mortality (Analitis et al., 2008) is greater than the burden of heat mortality. Climate change is likely to reduce future cold-related mortality (Ballester et al., 2011; HPA, 2012; see also Section 11.4.1).

Mortality and morbidity associated with flooding is becoming better understood, although the surveillance of health effects of disasters remains inadequate (WHO, 2013). Additional flood mortality due to sea level rise has been estimated in the Netherlands (Maaskant et al., 2009) and in the UK for river flooding (Hames and Vardoulakis, 2012), but estimates of future mortality due to flooding are highly uncertain. There remains limited evidence regarding the long-term mental health impacts of flood events (Paranjothy et al., 2011; WHO, 2013).

Evidence about future risks from climate change with respect to infectious diseases is still limited (Semenza and Menne, 2009; Randolph and Rogers, 2010; Semenza et al., 2012). There have been developments in mapping the current and potential future distribution of important disease vector species in Europe. The Asian tiger mosquito *Aedes albopictus* (a vector of dengue and Chikungunya; Queyriaux et al., 2008) is currently present in Southern Europe (ECDC, 2009) and may extend eastward and northward under climate change (Fisher et al., 2011; Roiz et al., 2011; Caminade et al., 2012). The risk of introduction of dengue remains very low because it would depend on the introduction and expansion of the *Aedes aegypti* together with the absence of effective vector control measures (ECDC, 2012).

Climate change is unlikely to affect the distribution of visceral and cutaneous leishmaniasis (currently present in the Mediterranean region) in the near term (Ready, 2010). However, in the long term (15 to 20 years), there is potential for climate change to facilitate the expansion of either vectors or current parasites northwards (Ready, 2010). The risk of introduction of exotic *Leishmania* species was considered very low due to the low competence of current vectors (Fischer, D. et al., 2010). The effect of climate change on the risk of imported or locally transmitted (autochthonous) malaria in Europe has been assessed in Spain (Sainz-Elipe et al., 2010), France (Linard et al., 2009), and the UK (Lindsay et al., 2010). Disease re-emergence would depend on many factors, including the introduction of a large population of infectious people or mosquitoes, high levels of people-vector contact, resulting from significant changes in land use, as well as climate change (see Chapter 11).

Since AR4, there has been more evidence on implications of climate change on food safety at all stages from production to consumption (FAO, 2008a; Jacxsens et al., 2010; Popov Janevska et al., 2010). The sensitivity of salmonellosis to ambient temperature has declined in recent years (Lake et al., 2009) and the overall incidence of salmonellosis is declining in most European countries (Semenza et al., 2012). Climate change may also have effects on food consumption patterns. Weather affects pre- and post-harvest mycotoxin production but the implications of climate change are unclear. Cold regions may become liable to temperate-zone problems concerning contamination with ochratoxin A, patulin, and *Fusarium* toxins (Paterson and Lima, 2010). Control of the environment of storage facilities may avoid post-harvest problems but at additional cost (Paterson and Lima, 2010).

Other potential consequences concern marine biotoxins in seafood following production of phycotoxins by harmful algal blooms and the presence of pathogenic bacteria in foods following more frequent extreme weather conditions (Miraglia et al., 2009). There is little evidence that climate change will affect human exposures to contaminants in the soil or water (e.g., persistent organic pollutants). Risk modeling is often developed for single-exposure agents (e.g., a pesticide) with known routes of exposure. These are difficult to scale up to the population level. The multiple mechanisms by which climate may affect transmission or contamination routes also make this very complex (Boxall et al., 2009).

Adaptation in the health sector has so far been largely limited to the development of heat health warning systems, with many research gaps regarding effective adaptation options (HPA, 2012). A survey of national infectious disease experts in Europe identified several institutional changes that needed to be addressed to improve future responses to climate change risks: ongoing surveillance programs, collaboration with veterinary sector and management of animal disease outbreaks, national monitoring and control of climate-sensitive infectious diseases, health services during an infectious disease outbreak, and diagnostic support during an epidemic (Semenza et al., 2012).



### 23.5.2. Critical Infrastructure

Critical national infrastructure is defined as assets (physical or electronic) that are vital to the continued delivery and integrity of essential services on which a country relies, the loss or compromise of which would lead to severe economic or social consequences or to loss of life. Extreme weather events, such as floods, heat waves, and wild fires are known to damage critical infrastructure. The UK floods in 2007 led to significant damage to power and water utilities, and to communications and transport infrastructure (Chatterton et al., 2010; see also Table 23-1). Forest fires can affect transport infrastructure, as well as the destruction of buildings. Major storms in Sweden and Finland have led to loss of trees, with damage to the power distribution network, leading to electricity blackouts lasting weeks, as well as the paralysis of services such as rail transport and other public services that depend on grid electricity.

Health system infrastructure (hospitals, clinics) is vulnerable to extreme events, particularly flooding (Radovic et al., 2012). The heat waves of 2003 and 2006 had adverse effects on patients and staff in hospitals from overheating of buildings. Evidence from France and Italy indicate that death rates among in-patients increased significantly during heat wave events (Ferron et al., 2006; Stafoggia et al., 2008). Further, higher temperatures have had serious implications for the delivery of health care, as well drug storage and transport (Carmichael et al., 2013).

### 23.5.3. Social Impacts

There is little evidence regarding the implications of climate change for employment and/or livelihoods in Europe. However, the evidence so far (as reviewed in this chapter) indicates that there are likely to be changes to some industries (e.g., tourism, agriculture) that may lead to changes in employment opportunities by sub-region and by sector.

Current damages from weather-related disasters (floods and storms) are significant (Section 23.3.1). Disasters have long lasting effects on the affected populations (Schnitzler et al., 2007). Households are often displaced while their homes are repaired (Whittle et al., 2010). Little research has been carried out on the impact of extreme weather events such as heat waves and flooding on temporary or permanent displacement in Europe. Coastal erosion associated with sea level rise, storm surges, and coastal flooding will require coastal retreat in some of Europe's low-lying areas (Philippart et al., 2011). Managed retreat is also an adaptation option in some coastal areas. Concerns have been raised about equality of access to adaptation within coastal populations at risk from climate change. For example, a study in the UK found that vulnerability to climate change in coastal communities is likely to be increased by social deprivation (Zsamboky et al., 2011).



In the European region, the indigenous populations present in the Arctic are considered vulnerable to climate change impacts on livelihoods and food sources (ACIA, 2005; see also Sections 12.3, 28.2.4). Research has focused on indigenous knowledge, impacts on traditional food sources, and community responses/adaptation (Mustonen and Mustonen, 2011a,b). However, these communities are also experiencing rapid social, economic, and other non-climate-related environmental changes (such as oil and gas exploration; see Section 28.2.4). There is evidence that climate change has altered the seasonal behavior of pastoralist populations, such as the Nenets reindeer herders in northern Russia (Amstislavski et al., 2013). However, socioeconomic factors may be more important than climate change for the future sustainability of reindeer husbandry (Rees et al., 2008; see also Section 28.2.3.5).

### 23.5.4. Cultural Heritage and Landscapes

Climate change will affect culturally valued buildings (Storm et al., 2008) through extreme events and chronic damage to materials (Brimblecombe et al., 2006; Brimblecombe and Grossi, 2010; Brimblecombe, 2010a, 2010b; Grossi et al., 2011; Sabbioni et al., 2012). Cultural heritage is a non-renewable resource and impacts from environmental changes are assessed over long time scales (Brimblecombe and Grossi, 2008, 2009, 2010; Grossi et al., 2008; Bonazza et al., 2009a,b). Climate change may also affect indoor environments where cultural heritage is preserved (Lankester and Brimblecombe, 2010) as well as visitor behavior at heritage sites (Grossi et al., 2010). There is also evidence to suggest that climate change and sea level rise will affect maritime heritage in the form of shipwrecks and other submerged archaeology (Björdal, 2012).

Surface recession on marble and compact limestone will be affected by climate change (Bonazza et al., 2009a). Marble monuments in Southern Europe will continue to experience high levels of thermal stress (Bonazza et al., 2009b) but warming is likely to reduce frost damage across Europe, except in Northern and Alpine Europe and permafrost areas (Iceland) (Grossi et al., 2007; Sabbioni et al., 2008). Damage to porous materials due to salt crystallization may increase all over Europe (Benavente et al., 2008; Grossi et al., 2011). In Northern and Eastern Europe, wood

### Box 23-2 | Implications of Climate Change for European Wine and Vineyards

Wine production in Europe accounts for more than 60% of the global total (Goode, 2012) and makes an important contribution to cultural identity. Apart from impacts on grapevine yield, higher temperatures are also expected to affect wine quality in some regions and grape varieties by changing the ratio between sugar and acids (Duchêne et al., 2010; Bock et al., 2011; Santos et al., 2011). In Western and Central Europe, projected future changes could benefit wine quality, but might also demarcate new potential areas for viticulture (Malheiro et al., 2010). Adaptation measures are already occurring in some vineyards (e.g., vine management, technological measures, production control, and to a smaller extent relocation; Battaglini et al., 2009; Holland and Smit, 2010; Malheiro et al., 2010; Duarte Alonso and O'Neill, 2011; Moriondo et al., 2011; Santos et al., 2011).Vineyards may be displaced geographically beyond their traditional boundaries ("terroir" linked to soil, climate, and traditions; Metzger and Rounsevell, 2011) and, in principle, wine producers could adapt to this problem by growing grape varieties that are more suited to warmer climates. Such technical solutions, however, do not account for the unique characteristics of wine production cultures and consumer perceptions of wine quality that strongly affect the prices paid for the best wines (White et al., 2009; Metzger and Rounsevell, 2011). It would become very difficult, for example, to produce fine wines from the cool-climate Pinot Noir grape within its traditional "terroir" of Burgundy under many future climate scenarios, but consumers may not be willing to pay current day prices for red wines produced from other grape varieties (Metzger and Rounsevell, 2011). An additional barrier to adaptation is that wine is usually produced within rigid, regionally specific, regulatory frameworks that often prescribe, among other things, what grapes can be grown where, for example, the French AOC (Appellation d'Origine Controlee) or the Italian DOC (Denominazione di Origine Controllata) and DOCG (Denominazione di Origine Controllata e Garantita) designations. Suggestions have been made to replace these rigid concepts of regional identity with a geographically flexible "terroir" that ties a historical or constructed sense of culture to the wine maker and not to the region (White et al., 2009).

structures will need additional protection against rainwater and high winds (Sabbioni et al., 2012). AR4 concluded that current flood defenses would not protect Venice from climate change. Venice now has a flood forecasting system, and is introducing the MOSE (MOdulo Sperimentale Elettromeccanico) system of flood barriers (Keskitalo, 2010). Recent evidence suggests, however, that climate change may lead to a decrease in the frequency of extreme storm surges in this area (Troccoli et al., 2012a).

Europe has many unique rural landscapes, which reflect the cultural heritage that has evolved from centuries of human intervention, for example, the cork oak based Montado in Portugal, the Garrigue of southern France, Alpine meadows, grouse moors in the UK, machair in Scotland, peatlands in Ireland, the polders of Belgium and the Netherlands, and vineyards. Many, if not all, of these cultural landscapes are sensitive to climate change and even small changes in the climate could have significant impacts (Gifford et al., 2011). Alpine meadows, for example, are culturally important within Europe, but although there is analysis of the economics (tourism, farming) and functionality (water runoff, flooding, and carbon sequestration) of these landscapes there is very little understanding of how climate change will affect the cultural aspects on which local communities depend. Because of their societal value, cultural landscapes are often protected and managed through rural development and environmental policies. The peat-rich uplands of Northern Europe, for example, have begun to consider landscape management as a means of adapting to the effects of climate change (e.g., the moors for the future partnership in the Peak District National Park, UK). For a discussion of the cultural implications of climate change for vineyards, see Box 23-2.

## 23.6. Implications of Climate Change for the Protection of Environmental Quality and Biological Conservation

Terrestrial and freshwater ecosystems provide a number of vital services for people and society, such as biodiversity, food, fiber, water resources, carbon sequestration, and recreation (Box 23-1).

### 23.6.1. Air Quality

Climate change will have complex and local effects on pollution chemistry, transport, emissions, and deposition. Outdoor air pollutants have adverse effects on human health, biodiversity, crop yields, and cultural heritage. The main outcomes of concern are both the average (background) levels and peak events for tropospheric ozone, particulates, sulfur oxides ($SO_x$), and nitrogen oxides ($NO_x$). Future pollutant concentrations in Europe have been assessed using atmospheric chemistry models, principally for ozone (Forkel and Knoche, 2006, 2007). Reviews have concluded that GCM/Chemical Transport Model (CTM) studies find that climate change per se (assuming no change in future emissions or other factors) is likely to increase summer tropospheric ozone levels (range 1 to 10 ppb) by 2050s in polluted areas (i.e., where concentrations of precursor nitrogen oxides are higher) (AQEG, 2007; Jacob and Winner, 2009; see also Section 21.3.3.6). The effect of future climate change alone on future concentrations of particulates, nitrogen oxides, and volatile organic compounds (VOCs) is much more uncertain. Higher temperatures also affect natural VOC emissions, which are ozone precursors (Hartikainen et al., 2012). One study has projected an increase in fire-related air pollution (ozone and particulate matter with aerodynamic diameter <10 µm ($PM_{10}$)) in Southern Europe (Carvalho et al., 2011).

Overall, the model studies are inconsistent regarding future projections of background level and exceedances. Recent evidence has shown adverse impacts on agriculture from even low concentrations of ozone; however, there is more consistent evidence now regarding the threshold for health (mortality) impacts of ozone. Therefore, it is unclear whether increases in background levels below health-related thresholds would be associated with an increased burden of ill health.

Some studies have attributed an observed increase in European ozone levels to observed warming (Meleux et al., 2007), which appears to be driven by the increase in extreme heat events (Solberg et al., 2008). High ozone levels were observed during the major heat waves in Europe in multiple countries (Table 23-1). Wildfire events have had an impact on local and regional air quality (Hodzic et al., 2007; Liu et al., 2009; Miranda et al., 2009), with implications for human health (Analitis et al., 2012; Table 23-1).

### 23.6.2. Soil Quality and Land Degradation

The current cost of soil erosion, organic matter decline, salinization, landslides, and contamination is estimated to be €38 billion annually for the EU (JRC and EEA, 2010), in the form of damage to infrastructures, treatment of water contaminated through the soil, disposal of sediments, depreciation of land, and costs related to the ecosystem functions of soil (JRC and EEA, 2010). Projections show significant reductions in summer soil moisture in the Mediterranean region, and increases in the northeastern part of Europe (Calanca et al., 2006). Climate change impacts on erosion shows diverging evidence under the A2 scenario. In Tuscany, even with a decline in precipitation volume until 2070, in some months higher erosion rates would occur because of higher rainfall erosivity (Marker et al., 2008). For two Danish river catchments, assuming a steady-state land use, suspended sediment transport would increase by 17 to 27% by 2071–2100 (Thodsen, 2007; Thodsen et al., 2008). In Upper Austria, with the regional climate model HadRM3H, a small reduction in average soil losses is projected for croplands in all tillage systems, however, with high uncertainty (Scholz et al., 2008). In Northern Ireland, erosion decreases are generally projected with downscaled GCMs for a case study hillslope (Mullan et al., 2012).

Adaptive land use management can reduce the impact of climate change through soil conservation methods such as zero tillage and conversion of arable land to grasslands (Klik and Eitzinger, 2010). In central Europe, compared to conventional tillage, conservation tillage systems reduced modeled soil erosion rates under future climate scenarios by between 49 and 87% (Scholz et al., 2008). Preserving upland vegetation reduced both erosion and loss of soil carbon and favored the delivery of a high-quality water resource (McHugh, 2007; House et al., 2011). Maintaining soil water retention capacity, for example, through adaptation measures (Post et al., 2008), contributes to reduce risks of flooding as soil organic matter absorbs up to 20 times its weight in water.

### 23.6.3. Water Quality

Climate change may affect water quality in several ways, with implications for food production and forestry (Section 23.4), ecosystem functioning (Box 23-1), human and animal health, and compliance with environmental quality standards, including those of the Water Framework Directive. Shallower waters will witness a more rapid temperature increase than deeper waters, since heat is absorbed mainly in the upper water layers and turbulent mixing is truncated by shallow depth. In parallel, a decrease in saturating oxygen concentrations occurs. Since AR4, there is further evidence of adverse effects caused by extreme weather events: reductions in dissolved oxygen, algal blooms (Mooij et al., 2007; Ulén and Weyhenmeyer, 2007) during hot weather, and contamination of surface and coastal waters with sewage and/or chemicals (pesticides) after rainfall (Boxall et al., 2009). A reduction in rainfall may lead to low flows that increase concentrations of biological and chemical contaminants. Reduced drainage can also enhance sedimentation in drainage systems and hence enhance particle-bound phosphorous retention and reduce phosphorous load to downstream higher order streams (Hellmann and Vermaat, 2012).

Variability in changes in rainfall and runoff, as well as water temperature increases, will lead to differences in water quality impacts by sub-region. Climate change is projected to increase nutrient loadings: In Northern Europe this is caused by increased surface runoff, and in Southern Europe by increased evapotranspiration and increased concentrations due to reduced volumes of receiving lakes (Jeppesen et al., 2011). Local studies generally confirm this pattern. Increased nutrient loads are foreseen in Danish watersheds (Andersen et al., 2006), and in France (Delpla et al., 2011) and the UK (Whitehead et al., 2009; Howden et al., 2010; Macleod et al., 2012; see also Section 4.3.3.3). In larger rivers, such as the Meuse, increased summer temperature and drought can lead to more favorable conditions for algal blooms and reduced dilution capacity of effluent from industry and sewage works (van Vliet and Zwolsman, 2008).

### 23.6.4. Terrestrial and Freshwater Ecosystems

Current and projected future climate changes, including $CO_2$ increase, are determining negative effects of habitat loss on species density and diversity (Rickebusch et al., 2008; Mantyka-pringle et al., 2012). Projected habitat loss is greater for species at higher elevations (Castellari, 2009; Engler et al., 2011; Dullinger et al., 2012) and suitable habitats for Europe's breeding birds are projected to shift nearly 550 km northeast by the end of the 21st century (Huntley et al., 2007). Aquatic habitats and habitat connectivity in river networks may become increasingly fragmented (Fronzek et al., 2006, 2010, 2011; Elzinga et al., 2007; Della Bella et al., 2008; Harrison et al., 2008; Blaustein et al., 2010; Gallego-Sala et al., 2010; Gómez-Rodríguez et al., 2010; Hartel et al., 2011; Morán-López et al., 2012). Despite some local successes and increasing responses, the rate of biodiversity loss does not appear to be slowing (Butchart et al., 2010). The effectiveness of Natura 2000 areas to respond to climate change has been questioned (Araújo et al., 2011). However, when considering connectivity related to the spatial properties of the network, the Natura 2000 network appears rather robust (Mazaris et al., 2013). Several studies now highlight the importance of taking into account climate change projections in the selection of conservation areas (Araújo et al., 2011; Ellwanger et al., 2011; Filz et al., 2013; Virkkala et al., 2013).

Observed changes in plant communities in European mountainous regions show a shift of species ranges to higher altitudes resulting in species richness increase in boreal-temperate mountain regions and decrease in Mediterranean mountain regions (Gottfried et al., 2012; Pauli et al., 2012). In Southern Europe, a great reduction in phylogenetic diversity of plant, bird, and mammal assemblages will occur, and gains are expected in regions of high latitude or altitude for 2020, 2050, and 2080. However, losses will not be offset by gains and a trend toward homogenization across the continent will be observed (Alkemade et al., 2011; Thuiller et al., 2011). Large range contractions due to climate change are projected for several populations of *Pinus cembra* and *Pinus Sylvestris* (Casalegno et al., 2010; Giuggiola et al., 2010) while for the dominant Mediterranean tree species, holm oak, a substantial range expansion is projected under the A1B emissions scenario (Cheaib et al., 2012). The human impacts on distribution of tree species landscape may make them more vulnerable to climate change (del Barrio et al., 2006; Hemery et al., 2010).

Observed climate changes are altering breeding seasons, timing of spring migration, breeding habitats, latitudinal distribution, and migratory behavior of birds (Jonzén et al., 2006; Lemoine et al., 2007a,b; Rubolini et al., 2007a,b; Feehan et al., 2009). A northward shift in bird community composition has been observed (Devictor et al., 2008). Common species of European birds with the lowest thermal maxima have showed the sharpest declines between 1980 and 2005 (Jiguet et al., 2010).

Projections for 120 native terrestrial non-volant European mammals suggest that 5 to 9% are at risk of extinction, assuming no migration, during the 21st century due to climate change, while 70 to 78% may be severely threatened under A1 and B2 climatic scenarios (Levinsky et al., 2007). Those populations not showing a phenological response to climate change may decline (Moller et al., 2008), such as amphibian and reptile species (Araújo et al., 2006), or experience ecological mismatches (Saino et al., 2011). Climate change can affect trophic interactions, as co-occurring species may not react in a similar manner. Novel emergent ecosystems composed of new species assemblages arising from differential rates of range shifts of species can occur (Keith et al., 2009; Montoya and Raffaelli, 2010; Schweiger et al., 2012).

Since invasive alien species rarely change their original climatic niches (Petitpierre et al., 2012), climate change can exacerbate the threat posed by invasive species to biodiversity in Europe (West et al., 2012), amplifying the effects of introduction of the exotic material such as alien bioenergy crops (EEA, 2012), pest and diseases (Aragòn and Lobo, 2012), tropical planktonic species (Cellamare et al., 2010), and tropical vascular plants (Skeffington and Hall, 2011; Taylor et al., 2012).

### 23.6.5. Coastal and Marine Ecosystems

Climate change will affect Europe's coastal and marine ecosystems by altering the biodiversity, functional dynamics, and ecosystem services of coastal wetlands, dunes, inter-tidal and subtidal habitats, offshore shelves, seamounts, and currents (Halpern et al., 2008) through changes in eutrophication, invasive species, species range shifts, changes in fish stocks, and habitat loss (EEA, 2010d; Doney et al., 2011). The relative magnitude of these changes will vary temporally and spatially, requiring a range of adaptation strategies that target different policy measures, audiences, and instruments (Airoldi and Bec, 2007; Philippart et al., 2011).

Europe's northern seas are experiencing greater increases in sea surface temperatures (SSTs) than the southern seas, with the Baltic, North, and Black Seas warming at two to four times the mean global rate (Belkin, 2009; Philippart et al., 2011). In the Baltic, decreased sea ice will expose coastal areas to more storms, changing the coastal geomorphology (HELCOM, 2007; BACC Author Team, 2008). Warming SSTs will influence biodiversity and drive changes in depth and latitudinal range for intertidal and subtidal marine communities, particularly in the North and Celtic Seas (Sorte et al., 2010; Hawkins et al., 2011; Wethey et al., 2011).

Warming is affecting food chains and changing phenological rates (Durant et al., 2007). For example, changes in the timing and location of phytoplankton and zooplankton are affecting North Sea cod larvae (Beaugrand et al., 2010; Beaugrand and Kirby, 2010). Temperature changes have affected the distribution of fisheries in all seas over the past 30 years (Beaugrand and Kirby, 2010; Hermant et al., 2010). Warmer waters also increase the rate of the establishment and spread of invasive species, further altering trophic dynamics and the productivity of coastal marine ecosystems (Molnar et al., 2008; Rahel and Olden, 2008). Changes in the semi-enclosed seas could be indicative of future conditions in other coastal-marine ecosystems (Lejeusne et al., 2009). In the Mediterranean, invasive species have arrived in recent years at the rate of one introduction every 4 weeks (Streftaris et al., 2005). While in this case the distribution of endemic species remained stable, most non-native species have spread northward by an average of 300 km since the 1980s, resulting in an area of spatial overlap with invasive species replacing natives by nearly 25% in 20 years.

Dune systems will be lost in some places due to coastal erosion from combined storm surge and sea level rise, requiring restoration (Day et al., 2008; Magnan et al., 2009; Ciscar et al., 2011). In the North Sea, the Iberian coast, and Bay of Biscay, a combination of coastal erosion, infrastructure development, and sea defenses may lead to narrower coastal zones ("coastal squeeze") (EEA, 2010d; OSPAR, 2010; Jackson and McIlvenny, 2011).



## 23.7. Cross-Sectoral Adaptation Decision Making and Risk Management

Studies on impacts and adaptation in Europe generally consider single sectors or outcomes, as described in the previous sections of this chapter. For adaptation decision making, more comprehensive approaches are required. Considerable progress has been made to advance planning and development of adaptation measures, including economic analyses (Section 23.7.6; see Box 23-3), and the development of climate services (WMO, 2011; Medri et al., 2012). At the international level, the European

### Box 23-3 | National and Local Adaptation Strategies

The increasing number of national (EEA, 2013) and local (Heidrich et al., 2013) adaptation strategies in Europe has led to research on their evaluation and implementation (Biesbroek et al., 2010). Many adaptation strategies were found to be agendas for further research, awareness raising, and/or coordination and communication for implementation (e.g., Pfenniger et al., 2010; Dumollard and Leseur, 2011). Actual implementation often was limited to disaster risk reduction, environmental protection, spatial planning (Section 23.7.4), and coastal zone and water resources management. The implementation of planned adaptation at the national level was attributed to political will and good financial and information capacity (Westerhoff et al., 2011). Analysis of seven national adaptation strategies (Denmark, Finland, France, Germany, Netherlands, Spain, UK) found that although there is a high political commitment to adaptation planning and implementation, evaluation of the strategies and actual implementation is yet to be defined (Swart et al., 2009b; Biesbroek et al., 2010; Westerhoff et al., 2011). One of the earliest national adaptation strategies (Finland) has been evaluated, in order to compare identified adaptation measures with those launched in different sectors. It has found that although good progress has been made on research and identification of options, few measures have been implemented except in the water resources sector (Ministry of Agriculture and Forestry, 2009).

At the local government level, adaptation plans are being developed in several cities (EEA, 2013), including London (GLA, 2010), Madrid, Manchester, Copenhagen, Helsinki, and Rotterdam. Adaptation in general is a low priority for many European cities, and many plans do not have adaptation priority as the main focus (Carter, 2011). Many studies are covering sectors sensitive to climate variability, as well as sectors that are currently under pressure from socioeconomic development. A recent assessment found a lack of cross-sector impact and adaptation linkages as an important weakness in the city plans (Hunt and Watkiss, 2011). Flexibility in adaptation decision making needs to be maintained (Hallegatte et al., 2008; Biesbroek et al., 2010).

Union has started adaptation planning, through information sharing (Climate-ADAPT platform) and legislation (EC, 2013b). National and local governments are also beginning to monitor progress on adaptation, including the development of a range of indicators (UK-ASC, 2011).

### 23.7.1. Coastal Zone Management

Coastal zone management and coastal protection plans that integrate adaptation concerns are now being implemented. Underlying scientific studies increasingly assess effectiveness and costs of specific options (Hilpert et al., 2007; Kabat et al., 2009; Dawson et al., 2011; see also Section 23.7.6). Early response measures are needed for floods and coastal erosion, to ensure that climate change considerations are incorporated into marine strategies, with mechanisms for regular update (OSPAR, 2010; UNEP, 2010).



In the Dutch plan for flood protection, adaptation to increasing river runoff and sea level rise plays a prominent role (Delta Committee, 2008). It also includes synergies with nature conservation and freshwater storage (Kabat et al., 2009), and links to urban renovation (cost estimates are included in Section 23.7.6). Though that plan mostly relies on large-scale measures, new approaches such as small-scale containment of flood risks through compartmentalization are also studied (Klijn et al., 2009). The UK government has developed extensive adaptation plans (TE2100) to adjust and improve flood defenses for the protection of London from future storm surges and flooding (EA, 2009). An elaborate analysis has provided insight in the pathways for different adaptation options and decision-points that will depend on the eventual sea level rise (Box 5-1).

### 23.7.2. Integrated Water Resource Management

Water resources management in Europe has experienced a general shift from "hard" to "soft" measures that allow more flexible responses to environmental change (Pahl-Wostl, 2007). Integrated water resource management explicitly includes the consideration of environmental and social impacts (Wiering and Arts, 2006). Climate change has been incorporated into water resources planning in England and Wales (Arnell, 2011; Charlton and Arnell, 2011; Wade et al., 2013) and in the Netherlands (de Graaff et al., 2009). The robustness of adaptation strategies for water management in Europe has been tested in England (Dessai and Hulme, 2007) and Denmark (Haasnoot et al., 2012; Refsgaard et al., 2013). Other studies have emphasized the search for robust pathways, for instance, in the Netherlands (Kwadijk et al., 2010; Haasnoot et al., 2012).

Public participation has also increased in decision making, for example, river basin management planning (Huntjens et al., 2010), flood defense plans (e.g., TE2100), and drought contingency plans (Iglesias et al., 2007). Guidance has been developed on the inclusion of adaptation in water management (UNECE, 2009) and river basin management plans (EC, 2009b). Adaptation in the water sector could also be achieved through the EU Water Framework and Flood Directives (Quevauviller, 2011), but a study of decision makers, including local basin managers, identified several important barriers to this (Brouwer et al., 2013). Water allocation between upstream and downstream countries is challenging in regions exposed to prolonged droughts such as the Euphrates-Tigris river basin, where Turkey plans to more than double water abstraction by 2023 (EEA, 2010a).

### 23.7.3. Disaster Risk Reduction and Risk Management

A series of approaches to disaster risk management are employed in Europe, in response to national and European policy developments to assess and reduce natural hazard risks. New developments since the AR4 include assessment and protection efforts in accordance with the EU Floods Directive (European Parliament and EU Council, 2007), the mapping of flood risks, and improvement of civil protection response and early warning systems (Ciavola et al., 2011). Most national policies address hazard assessment and do not include analyses of possible impacts (de Moel et al., 2009). The effectiveness of flood protection (Bouwer et al., 2010) and also non-structural or household level measures to reduce losses from river flooding has been assessed (Botzen et al., 2010a; Dawson et al., 2011). Some studies show that current plans may be insufficient to cope with increasing risks from climate change, as shown, for instance, for the Rhine River basin (te Linde et al., 2010a,b).

Other options that are being explored are the reduction of consequences, response measures, and increasing social capital (Kuhlicke et al., 2011), as well as options for insuring and transferring losses (Section 23.3.7). The Netherlands carried out a large-scale analysis and simulation exercise to study the possible emergency and evacuation response for a worst-case flood event (ten Brinke et al., 2010). Increasing attention is also being paid in Europe to non-government actions that can reduce possible impacts from extreme events. Terpstra and Gutteling (2008) found through a survey that individual citizens are willing to assume some responsibility for managing flood risk, and they are willing to contribute to preparations in order to reduce impacts. Survey evidence is available for Germany and the Netherlands that, under certain conditions, individuals can be encouraged to adopt loss prevention measures (Thieken et al., 2006; Botzen et al., 2009). Small businesses can reduce risks when informed about possibilities immediately after an event (Wedawatta and Ingirige, 2012).

### 23.7.4. Land Use Planning

Spatial planning policies can build resilience to the impacts of climate change (Bulkeley, 2010). However, the integration of adaptation into spatial planning is often limited to a general level of policy formulation that can sometimes lack concrete instruments and measures for implementation in practice (Mickwitz et al., 2009; Swart et al., 2009a). There is evidence to suggest the widespread failure of planning policy to account for future climate change (Branquart et al., 2008). Furthermore, a lack of institutional frameworks to support adaptation is, potentially, a major barrier to the governance of adaptation through spatial planning (ESPACE, 2007; Chapter 16). Climate change adaptation is often treated as a water management or flooding issue, which omits other important aspects of the contribution of land use planning to adaptation (Wilson, 2006; Mickwitz et al., 2009; Van Nieuwaal et al., 2009). For example, in the UK, houses were still being built in flood risk areas (2001–2011) because of competing needs to increase the housing stock (ARUP, 2011).

City governance is also dominated by the issues of climate mitigation and energy consumption rather than adapting to climate change (Bulkeley, 2010; Heidrich et al., 2013). Some cities, for example, Rotterdam, have started to create climate adaptation plans and this process tends to be driven by the strong political leadership of mayors (Sanchez-Rodriguez, 2009). The Helsinki Metropolitan Area's Climate Change Adaptation Strategy (HSY, 2010) is a regional approach focusing on the built environment in the cities of Helsinki, Espoo, Vantaa, and Kauniainen, and their surroundings. It includes approaches for dealing with increasing heat waves, more droughts, milder winters, increasing (winter) precipitation, heavy rainfall events, river floods, storm surges, drainage water floods, and sea level rise.

Green infrastructure provides both climate adaptation and mitigation benefits as well as offering a range of other benefits to urban areas, including health improvements, amenity value, inward investment, and the reduction of noise and outdoor air pollution. Green infrastructure is an attractive climate adaptation option since it also contributes to the sustainable development of urban areas (Gill et al., 2007; James et al., 2009). Urban green space and green roofs can moderate temperature and decrease surface rainwater runoff (Gill et al., 2007). Despite the benefits of urban green space, conflict can occur between the use of land for green space and building developments (Hamin and Gurran, 2009).

European policies for biodiversity (e.g., the European Biodiversity Strategy (EC, 2011)) look to spatial planning to help protect and safeguard internationally and nationally designated sites, networks, and species, as well as locally valued sites in urban and non-urban areas, and to create new opportunities for biodiversity through the development process (Wilson, 2008). Conservation planning in response to climate change impacts on species aims to involve several strategies to better manage isolated habitats, increase colonization capacity of new climate zones, and optimize conservation networks to establish climate refugia (Vos et al., 2008).

### 23.7.5. Rural Development

Rural development is one of the key policy areas for Europe, yet there is little or no discussion about the role of climate change in affecting future rural development. The EU White Paper on adapting to climate change (EC, 2009a) encourages member states to embed climate change adaptation into the three strands of rural development aimed at improving competitiveness, the environment, and the quality of life in rural areas. It appears however that little progress has been made in achieving these objectives.

For example, the EUs Leader program was designed to help rural actors improve the long-term potential of their local areas by encouraging the implementation of sustainable development strategies. Many Leader projects address climate change adaptation, but only as a secondary or in many cases a non-intentional by-product of the primary rural development goals. The World Bank's community adaptation project has seen a preponderance of proposals from rural areas in Eastern Europe and Central Asia (Heltberg et al., 2012), suggesting that adaptation-based development needs in Eastern Europe are currently not being met by policy.

### 23.7.6. Economic Assessments of Adaptation

Compared to studies assessed in AR4 (WGII AR4 Section 17.2.3), cost estimates for Europe are increasingly derived from bottom-up and sector-specific studies, aimed at costing response measures (Watkiss and Hunt, 2010), in addition to the economy-wide assessments (Aaheim et al., 2012). The evidence base, however, is still fragmented and incomplete. The coverage of adaptation costs and benefit estimates is dominated by structural (physical) protection measures, where effectiveness and cost components can be more easily identified. For energy, agriculture, and infrastructure, there is medium coverage of cost and benefit categories. There is a lack of information regarding adaptation costs in the health and social care sector. Table 23-2 summarizes some of the more comprehensive cost estimates for Europe for sectors at regional and

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**Table 23-2 |** Selected published cost estimates for planned adaptation in European countries.

| Region | Cost estimate | Time period | Sectors/outcomes | Reference |
|---|---|---|---|---|
| Europe | €2.6–3.5 billion $yr^{-1}$ | In 2100 | Coastal adaptation costs | Hinkel et al. (2010) |
| | €1.7 billion $yr^{-1}$ | By 2020s | Protection from river flood risk for EU27 | Rojas et al. (2013) |
| | €3.4 billion $yr^{-1}$ | By 2050s | | |
| | €7.9 billion $yr^{-1}$ | By 2080s | | |
| Netherlands | €1.2–1.6 billion $yr^{-1}$ | Up to 2050 | Protection from coastal and river flooding | Delta Committee (2008) |
| | €0.9–1.5 billion $yr^{-1}$ | 2050–2100 | | |
| Sweden | Total of up to €2.4 billion | 2010–2100 | Investments in structural adaptation, information campaigns, and research | Swedish Commission on Climate and Vulnerability (2007) |
| Italy | €0.4–2 billion | By 2080s | Coastal protection | Bosello et al. (2012) |
| | Up to €44 billion | By 2080s | Hydrogeological protection | Medri et al. (2013) |
| Greece | €0.4–3.3 billion | Up to 2100 | Coastal protection | Bank of Greece (2011) |
| United Kingdom | €1.8 billion | Until 2035 | Maintain and improve Thames flood protection | EA (2011) |
| | €2.2 billion | 2035–2050 | Renew and improve Thames flood protection | |
| | €7–8 billion | At 2100 | New Thames barrier for London | |

national levels. It is stressed that the costing studies use a range of methods and metrics and relate to different time periods and sectors, which renders robust comparison difficult. As an example, there are large differences between the cost estimates for coastal and river protection in the Netherlands and other parts of Europe (Table 23-2), which is due to the objectives for adaptation and the large differences in the level of acceptable risk. For example, Rojas et al. (2013) assess a 1-in-100 year level of protection for Europe, while the Netherlands has set standards up to 1-in-4000 and 10,000-year level return periods. More detailed treatment of the economics of adaptation is provided in Chapter 17.

### 23.7.7. Barriers and Limits to Adaptation

Implementation of adaptation options presents a range of opportunities, constraints, and limits. Constrains (barriers) to implementation are financial, technical, and political (see discussion in Chapter 16). Some impacts will be unavoidable due to physical, technological, social, economic, or political limits. Examples of limits in the European context are described by sector in Table 23-3. For example, the contraints on building or extending flood defenses would include pressure for land, conservation needs, and amenity value of coastal areas (Section 5.5.6).

Toward the end of the century, it is likely that adaptation limits will be reached earlier under higher rates of warming. Opportunities and co-benefits of adaptation are also discussed in Section 23.8.

## 23.8. Co-Benefits and Unintended Consequences of Adaptation and Mitigation

Scientific evidence for decision making is more useful if impacts are considered in the context of impacts on other sectors and in relation to adaptation, mitigation, and other important policy goals. The benefits of adaptation and mitigation policies can be felt in the near term and in the local population, although benefits relating to GHG emissions reduction may not be apparent until the longer term. The benefits of adaptation measures are often assessed using conventional economic analyses, some of which include non-market costs and benefits (externalities) (Watkiss and Hunt, 2010). This section describes policies, strategies, and measures where there is good evidence regarding mitigation/adaptation costs and benefits. Few studies have quantified directly the trade-offs/synergies for a given policy.

### 23.8.1. Production and Infrastructure

Mitigation policies (decarbonization strategies) are likely to have important implications for dwellings across Europe. The unintended consequences of mitigation in the housing sector include changes to household energy prices and adverse effects from decreased ventilation in dwellings (Jenkins et al., 2008; Jenkins, 2009; Davies and Oreszczyn, 2012; Mavrogianni et al., 2012). The location, type, and dominant energy use of the building will determine its overall energy gain or loss to maintain comfort levels. Adaptation measures such as the use of cooling devices will probably increase a building's energy consumption if no other mitigation measures are applied. The potential for cooling dwellings without increased energy consumption, and with health benefits is large (Wilkinson et al., 2009).

When looking at the broader context of urban infrastructures, despite existing efforts to include both adaptation and mitigation into sustainable development strategies at the city level (e.g., Hague, Rotterdam, Hamburg, Madrid, London, Manchester), priority on adaptation still remains low (Carter, 2011). There is potential to develop strategies that can address both mitigation and adaptation solutions, as well as have health and environmental benefits (Milner et al., 2012). In energy supply, the adverse effect of climate change on water resources in some coastal regions in Southern Europe may further enhance the development of

**Table 23-3 |** Limits to adaptation to climate change.

| Area/location | System | Adaptation measures | Limits to adaptation measure(s) | References |
|---|---|---|---|---|
| Low-altitude/small-size ski resorts | Ski tourism | Artificial snowmaking | Climatic, technological, and environmental constraints; economic viability; social acceptability of charging for previously free skiing; social acceptability of alternatives for winter sport/leisure | Steiger and Mayer (2008); Unbehaun et al. (2008); Steiger (2010, 2011); Landauer et al. (2012) |
| Thermal power plants/cooling through river intake and discharge | Once-through cooling systems | Closed-circuit cooling | High investment cost for retrofitting existing plants | Koch and Vögele (2009); van Vliet et al. (2012); Hoffman et al. (2013) |
| Rivers used for freight transport | Inland transport | Reduced load factor of inland ships | Increased transport prices (Rhine and Moselle market) | Jonkeren et al. (2007); Jonkeren (2009) |
| | | Use of smaller ships | Existing barges below optimal size (Rhine) | Demirel (2011) |
| Agriculture, northern and continental Europe | Arable crops | Changing sowing date as agricultural adaptation | Other constraints (e.g., frost) limit farmer behavior. | Oort (2012) |
| | | Irrigation | Groundwater availability; competition with other users | Olesen et al. (2011) |
| Agriculture, viticulture | High-value crops | Change distribution | Legislation on cultivar and geographical region | Box 23-1 |
| Conservation; cultural landscapes | Alpine meadow | Extend habitat | No technological adaptation option | Engler et al. (2011); Dullinger et al. (2012) |
| Conservation of species richness | Movement of species | Extend habitat | Landscape barriers and absence of climate projections in selection of conservation areas | Butchart et al. (2010); Araújo et al. (2011); Filz et al. (2012); Virkkala et al. (2013) |
| Forests | Movement of species and productivity reduction | Introduce new species | Not socially acceptable; legal barriers to non-native species | Casalegno et al. (2007); Giuggiola et al. (2010); Hemery et al. (2010); García-López and Alluéa (2011) |

desalination plants as an adaptation measure, possibly increasing energy consumption and thus GHG emissions. Coastal flood defense measures may alter vector habits and have implications for local vector-borne disease transmission (Medlock and Vaux, 2013).

In tourism, adaptation and mitigation may be antagonistic, as in the case of artificial snowmaking in European ski resorts, which requires significant amounts of energy and water (OECD, 2007; Rixen et al., 2011), and the case of desalination for potable water production, which also requires energy. However, depending on the location and size of the resort, implications are expected to differ and thus need to be investigated on a case-by-case basis. A similar relationship between adaptation and mitigation may hold for tourist settlements in Southern Europe, where expected temperature increases during the summer may require increased cooling to maintain tourist comfort and thus increase GHG emissions and operating costs. Furthermore, a change of tourist flows as a result of tourists adapting to climate change may affect transport emissions, while mitigation in transport could also lead to a change in transport prices and thus possibly affect tourist flows.

### 23.8.2. Agriculture, Forestry, and Bioenergy

Agriculture and forestry face two challenges under climate change, both to reduce emissions and to adapt to a changing and more variable climate (Lavalle et al., 2009; Smith and Olesen, 2010). The agriculture sector contributes about 10% of the total anthropogenic GHG emissions in the EU27 (EEA, 2010b). Estimates of European $CO_2$, methane, and $NO_x$ fluxes between 2000 and 2005 suggest that methane emissions from livestock and $NO_x$ emissions from agriculture are fully compensated for by the $CO_2$ sink provided by forests and by grassland soils (Schulze et al., 2010). However, projections following a baseline scenario suggest a significant decline (–25 to –40%) of the forest carbon sink of the EU until 2030 compared to 2010. Using wood for bioenergy results initially in a carbon debt due to reduced storage in forests, which affects the net GHG balance depending on the energy type that is replaced and the time span considered (McKechnie et al., 2011). Including additional bioenergy targets of EU member states has an effect on the development of the European forest carbon sink (and on the carbon stock), which is not accounted for in the EU emission reduction target (Bottcher et al., 2012).

In arable production systems, adapting to climate change by increasing the resilience of crop yields to heat and to rainfall variability would have positive impacts on mitigation by reducing soil erosion, as well as soil organic carbon and nitrogen losses. Improving soil water holding capacity through the addition of crop residues and manure to arable soils, or by adding diversity to the crop rotations, may contribute both to adaptation and to mitigation (Smith and Olesen, 2010). There are also synergies and trade-offs between mitigation and adaptation options for soil tillage, irrigation, and livestock breeding (Smith and Olesen, 2010). Reduced tillage (and no-till) may contribute to both adaptation and mitigation as it tends to reduce soil erosion and runoff (Soane et al., 2012) and fossil-fuel use (Khaledian et al., 2010), while increasing in some situations soil organic carbon stock (Powlson et al., 2011). However, increased $N_2O$ emission may negate the mitigation effect of reduced tillage (Powlson et al., 2011). Irrigation may enhance soil carbon sequestration in arable systems (Rosenzweig and Tubiello, 2007; Rosenzweig et al., 2008), but increased irrigation under climate change would increase energy use and may reduce water availability for hydropower (reduced mitigation potential) (Wreford et al., 2010). In intensive livestock systems, warmer conditions in the coming decades might trigger the implementation of enhanced cooling and ventilation in farm buildings (Rosenzweig and Tubiello, 2007), thereby increasing energy use and associated GHG emissions. In grass-based livestock systems, adaptation by adjusting the mean annual animal stocking density to the herbage growth potential (Graux et al., 2012) is *likely* to create a positive feedback on GHG emissions per unit area (Soussana and Luscher, 2007; Soussana et al., 2010).



Land management options may also create synergies and trade-offs between mitigation and adaptation. Careful adaptation of forestry and soil management practices will be required to preserve a continental ecosystem carbon sink in Europe (Schulze et al., 2010) despite the vulnerability of this sink to climatic extremes (Ciais et al., 2005) and first signs of carbon sink saturation in European forest biomass (Nabuurs et al., 2013). In areas that are vulnerable to extreme events (e.g., fires, storms, droughts) or with high water demand, the development of bioenergy production from energy crops and from agricultural residues (Fischer, G. et al., 2010; De Wit et al., 2011) could further increase demands on adaptation (Wreford et al., 2010). Conversely, increased demands on mitigation could be induced by the potential expansion of agriculture at high latitudes, which may release large amounts of carbon and nitrogen from organic soils (Rosenzweig and Tubiello, 2007).

### 23.8.3. Social and Health Impacts

Significant research has been undertaken since AR4 on the health co-benefits of mitigation policies (see Chapter 11 and WGIII AR5 Chapters 7, 8, 9). Several assessments have quantified benefits in terms of lives saved by reducing particulate air pollution. Policies that improve health from changes in transport and energy can be said to have a general benefit to population health and resilience (Haines et al., 2009a,b).

Changes to housing and energy policies also have indirect implications for human health. Research on the benefits of various housing options (including retrofitting) has been intensively addressed in the context of low-energy, healthy, and sustainable housing (see WGIII AR5 Chapters 9, 12).

### 23.8.4. Environmental Quality and Biological Conservation

There are several conservation management approaches that can address mitigation, adaptation, and biodiversity objectives (Lal et al., 2011). Some infrastructure adaptation strategies—such as desalinization, sea defenses, and flood control infrastructure—may have negative effects on both mitigation and biodiversity. However, approaches, such as forest conservation and urban green space (Section 23.7.4) have multiple benefits and potentially significant effects. There has been relatively little research about the impacts of future land use demand for bioenergy production, food production, and urbanization on nature conservation.

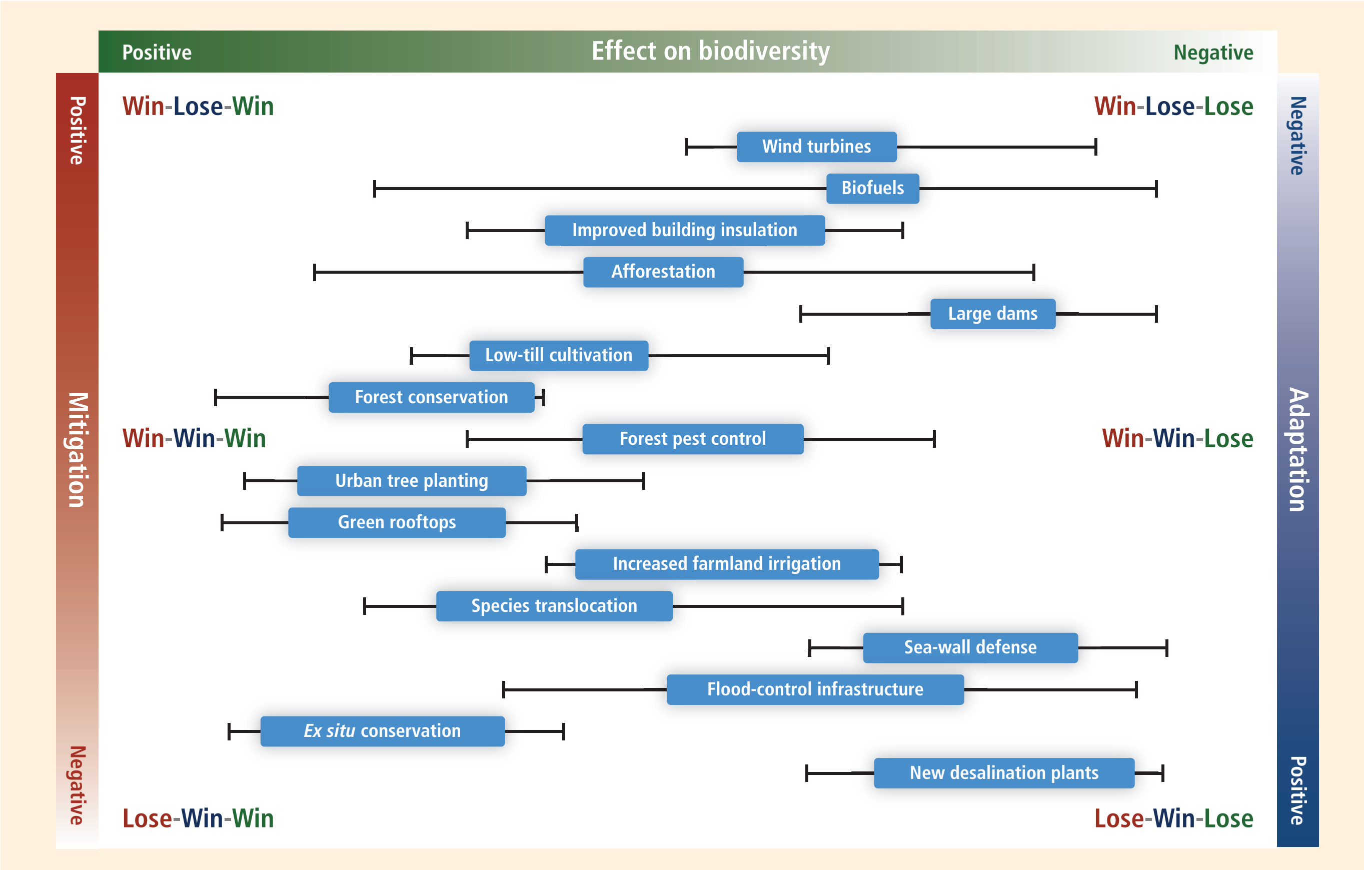



**Figure 23-6** | Adaptation and mitigation options and their effects on biodiversity. The horizontal axis ranges from positive effects on biodiversity (lefthand side) to negative effects (righthand side). Each mitigation/adaptation option is located on the biodiversity effect axis (solid bars), including an estimate of the uncertainties associated with the assessment (error bars). The various options are given vertically with mitigation at the top and adaptation at the bottom. Options located toward the center of the vertical axis have benefits for both mitigation and adaptation. Thus, options located at the center left of the figure have benefits for mitigation, adaptation, and biodiversity and hence are labeled as win-win-win. Other combinations of benefits and dis-benefits are labeled accordingly, for example, win-lose-win, lose-win-lose, etc. Based on Paterson et al., 2008.

Figure 23-6 (Paterson et al., 2008) summarizes the evidence regarding mitigation and adaptation options on biodiversity assessed from the literature. The figure shows that the options that come closest to being win-win-win are green rooftops, urban tree planting, forest conservation, and low-till cultivation. Other options with clear benefits are afforestation, forest pest control, increased farmland irrigation, and species translocation.

## 23.9. Synthesis of Key Findings

### 23.9.1. Key Vulnerabilities

Climate change will have adverse impacts in nearly all sectors and across all sub-regions. Table 23-4 describes the range of impacts projected in 2050 on infrastructure, settlements, environmental quality, and the health and welfare of the European population. The projected impacts of climate change on ecosystem services (including food production) are described in Box 23-1. A key finding is that all sub-regions are vulnerable to some impacts from climate change but these impacts differ significantly in type between the sub-regions. Impacts in neighboring regions (inter-regional) may also redistribute economic activities across the European landscape. The sectors most likely to be affected by climate change, and therefore with implications for economic activity and population movement (changes in employment opportunities), include tourism (Section 23.3.6), agriculture (Section 23.4.1), and forestry (Section 23.4.4).

The majority of published assessments are based on climate projections in the range of 1°C to 4°C global mean temperature per century. Under these scenarios, regions in Europe may experience higher rates of warming (in the range 1°C to 4°C per century), due to climate variability (Jacob et al., 2013). Limited evidence exists on the potential impacts in Europe under very high rates of warming (>4°C above preindustrial levels) but these would lead to a large increase in coastal flood risk as well as impacts on global cereal yields and other effects on the global economy (Section 19.5.1).

Many key vulnerabilities are already well known since the AR4, but some new vulnerabilities are emerging based on the evidence reviewed in this report. The policy/governance context in Europe is extremely important in determining (reducing or exacerbating) key vulnerabilities since Europe is a highly regulated region. Further, vulnerability will be strongly affected by changes in the non-climate drivers of change (e.g., economic, social protection measures, governance, technological drivers).

**Table 23-4 |** Assessment of climate change impacts by sub-region by 2050, assuming a medium emissions scenario and no planned adaptation. Impacts assume economic development, including land use change. Impacts are assessed for the whole sub-region, although differences in impact within sub-regions are estimated for some impacts.

| | | Southern | Atlantic | Continental | Alpine | Northern | Sections |
|---|---|---|---|---|---|---|---|
| Energy | Wind energy production | ↗ green + → black + ↘ red [a] | ↗ green + → black + ↘ red | → black | → black | ↗ green + → black | 23.3.4 |
| | Hydropower generation | ↘ red | ↘ red | ↘ red | ↗ green + ↘ red [b] | ↗ green + → black | |
| | Thermal power production | → black + ↘ red | → black + ↘ red | → black + ↘ red | → black + ↘ red | → black | 23.3.4, 8.2.3.2 |
| | Energy consumption (net annual change) | ↗ red | ↘ green | ↘ green | ↘ green | ↘ green | 23.3.4, 23.8.1 |
| Transport | Road accidents[c] | ↘ green | → black + ↘ green | → black + ↘ green | → black + ↘ green | → black + ↘ green | 23.3.3 |
| | Rail delays (weather-related) | ? | ↗ red + ↘ green [d] | ? | ? | ↗ red | 23.3.3, 8.3.3.6 |
| | Load factor of inland ships | ? | → black + ↘ red | → black + ↘ red | ? | ? | 23.3.3 |
| | Transport time and cost in ocean routes | ? | ? | ↘ green | ? | ↘ green | 23.3.3, 18.3.3.3.5 |
| Settlements | River flood damages | → black | ↗ red + ↘ green | ↗ red + ↘ green | → black | → black | 23.3.1 |
| | Coastal flood damages | ↗ red + → black | ↗ red + → black | ↗ red + → black | N/A | ↗ red + → black | |
| Tourism | Length of ski season | ? | ? | ↘ red | → black + ↘ red | ↘ red | 23.3.6, 3.5.7 |
| Human health | Heat wave mortality and morbidity[e] | ↗ red | ↗ red | ↗ red | → black | ↗ red | 23.5.1 |
| | Food-borne disease[e] | ↗ red | ↗ red | ↗ red | → black | ↗ red | |
| Social and cultural impacts | Social costs of floods | ↗ red + → black | ↗ red + ↘ green | ↗ red + ↘ green | → black | ↗ red + → black | 23.5.3 |
| | Damage to cultural buildings | ↗ red + ↘ green | ↗ red | ↗ red | ↗ red | ↗ red | 23.5.4 |
| | Loss of cultural landscapes | ? | ↗ red | ↗ red | ↗ red | ↗ red | |
| Environmental quality | Air quality (ozone background levels) | ↗ red + ↘ green | ↗ red + ↘ green | ↗ red + ↘ green | ? | ↗ red + ↘ green | 23.6.1 |
| | Air quality (particulates) | ↗ red + ↘ green | ↗ red + ↘ green | ↗ red + ↘ green | ? | ↗ red + ↘ green | |
| | Water quality | ↘ red | ↘ red | → black | → black | → black | 23.6.3 |

Increasing ↗
No change →
Decreasing ↘

A range from no change to increasing ↗ + →
A range from no change to decreasing → + ↘
A range from increasing to decreasing ↗ + ↘

Green arrows mean a "beneficial change"
Red arrows means a "harmful change"
? means no relevant literature found

[a]Simulations have been performed, but mostly for the period after 2070.
[b]The increasing trend is for Norway.
[c]The decreasing trends refers mainly to the number of severe accidents.
[d]Impacts have been studied and quantified for UK only. The increasing trend stands for summer delays and the decreasing trends for winter delays.
[e]Impacts shown with respect to future world without climate change.

Extreme events affect multiple sectors and have the potential to cause systemic impacts from secondary effects (Chapter 19). Past events indicate the vulnerability of transport, energy, agriculture, water resources, and health systems. Resilience to very extreme events varies by sector, and by country (Pitt, 2008; Ludwig et al., 2011; Ulbrich et al., 2012). Extreme events (heat waves and droughts) have had significant impacts on populations as well as multiple economic sectors (Table 23-1), and resilience to future heat waves has been addressed only within some sectors. However, there is surprisingly little evidence regarding the impacts of major extreme events (e.g., Russian heat wave of 2010) and on responses implemented post-event to increase resilience. Future vulnerability will also be strongly affected by cross-sectoral (indirect) interactions, for example, flooding-ecosystems, agriculture-species, agriculture-cultural landscapes, and so on.

Climate change is likely to have significant impacts on future water availability, and the increased risks of water restrictions in Southern, Central, and Atlantic sub-regions. Studies indicate a significant reduction in water availability from river abstraction and from groundwater resources, combined to increased demands from a range of sectors (irrigation, energy and industry, domestic use) and to reduced water drainage and runoff (as a result of increased evaporative demand) (Ludwig et al., 2011).

Climate change will affect rural landscapes by modifying relative land values, and hence competition, between different land uses (Smith et al., 2010). This will occur directly, for example, through changes in the productivity of crops and trees (Section 23.4), and indirectly through climate change impacts on the global supply of land-based commodities and their movement through international trade (Section 23.9.2).

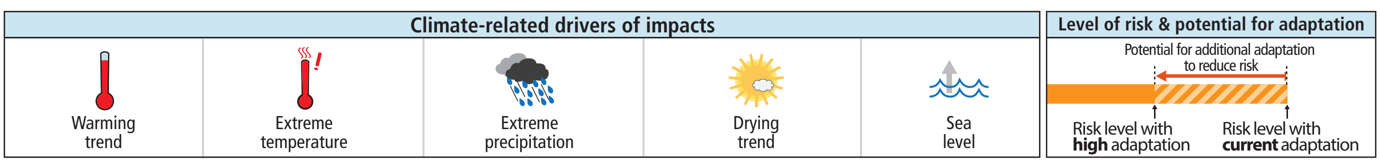
Climate change will have a range of impacts in different European sub-regions. The adaptive capacity of populations is likely to vary significantly within Europe. Adaptive capacity indicators have been developed based on future changes in socioeconomic indicators and projections (Metzger et al., 2008; Lung et al., 2012; Acosta et al., 2013). These studies concluded that the Nordic countries have higher adaptive capacity than most of the Southern European countries, with countries around the Mediterranean having a lower capacity than the countries around the Baltic Sea region. Some regions or areas are particularly vulnerable to climate change:

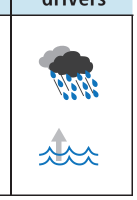
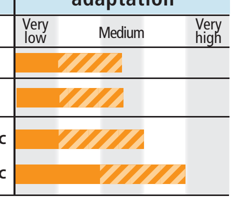
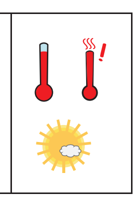
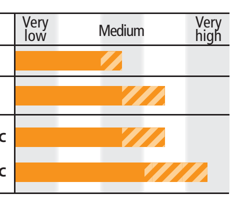
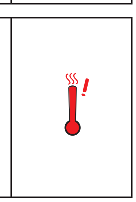
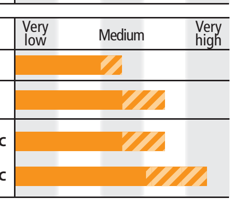
- Populations and infrastructure in coastal regions are likely to be adversely affected by sea level rise, particularly after mid-century (Sections 23.3.1, 23.5.3).
- Urban areas are also vulnerable to weather extremes owing to high density of people and built infrastructure (Sections 23.3, 23.5.1).
- Owing to high impact of climate change on natural hazard, and water and snow resources, and the lack of migration possibilities for plant species, mountain regions concentrate vulnerabilities in infrastructure for transport and energy sectors, as well as for tourism, agriculture, and biodiversity.
- The Mediterranean region will suffer multiple stresses and systemic failures due to climate changes. Changes in species composition, increase of alien species, habitat losses, and degradation both in land and sea together with agricultural and forests production losses due to increasing heat waves and droughts exacerbated also by the competition for water will increase vulnerability (Ulbrich et al., 2012).

The following risks have emerged from observations of climate sensitivity and observed adaptation:

- There is new evidence to suggest that arable crop yields and production may be more vulnerable as a result of increasing climate

**Table 23-5 |** Key risks from climate change in Europe and the potential for reducing risk through mitigation and adaptation. Risk levels are presented in three timeframes: the present, near-term (2030–2040), and longer term (2080–2100). For each timeframe, risk levels are estimated for a continuation of current adaptation and for a hypothetical highly adapted state. For a given key risk, change in risk level through time and across magnitudes of climate change is illustrated, but because the assessment considers potential impacts on different physical, biological, and human systems, risk levels should not necessarily be used to evaluate relative risk across key risks, sectors, or regions. Key risks were identified based on assessment of the literature and expert judgment.




| Key risk | Adaptation issues & prospects | Climatic drivers | Timeframe | Risk & potential for adaptation |
|---|---|---|---|---|
| Increased economic losses and people affected by flooding in river basins and coasts, driven by increasing urbanization, increasing sea levels, coastal erosion, and peak river discharges (*high confidence*)<br>[23.2-3, 23.7] | Adaptation can prevent most of the projected damages (*high confidence*).<br>• Significant experience in hard flood-protection technologies and increasing experience with restoring wetlands<br>• High costs for increasing flood protection<br>• Potential barriers to implementation: demand for land in Europe and environmental and landscape concerns |  | Present<br>Near term (2030–2040)<br>Long term (2080-2100) 2°C / 4°C |  |
| Increased water restrictions. Significant reduction in water availability from river abstraction and from groundwater resources, combined with increased water demand (e.g., for irrigation, energy and industry, domestic use) and with reduced water drainage and runoff as a result of increased evaporative demand, particularly in southern Europe (*high confidence*)<br>[23.4, 23.7] | • Proven adaptation potential from adoption of more water-efficient technologies and of water-saving strategies (e.g., for irrigation, crop species, land cover, industries, domestic use)<br>• Implementation of best practices and governance instruments in river basin management plans and integrated water management |  | Present<br>Near term (2030–2040)<br>Long-term (2080–2100) 2°C / 4°C |  |
| Increased economic losses and people affected by extreme heat events: impacts on health and well-being, labor productivity, crop production, air quality, and increasing risk of wildfires in southern Europe and in Russian boreal region (*medium confidence*)<br>[23.3-7, Table 23-1] | • Implementation of warning systems<br>• Adaptation of dwellings and workplaces and of transport and energy infrastructure<br>• Reductions in emissions to improve air quality<br>• Improved wildfire management<br>• Development of insurance products against weather-related yield variations |  | Present<br>Near term (2030-2040)<br>Long term (2080–2100) 2°C / 4°C |  |

variability. This will limit the potential poleward expansion of agricultural production. Limits to genetic progress to adapt are increasingly reported.

- New evidence has emerged regarding implications during summer on inland waterways (decreased access) and long-range ocean transport (increased access).
- Terrestrial and freshwater species are vulnerable from climate change shifts in habitats. There is new evidence that species cannot populate new habitat due to habitat fragmentation (urbanization). Observed migration rates are less than that assumed in modeling studies. There are legal barriers to introducing new species (e.g., forest species in France). New evidence reveals that phenological mismatch will cause additional adverse effects on some species.
- A positive (and emerging) effect that may reduce vulnerability is that many European governments (and individual cities) have become aware of the need to adapt to climate change and so are developing and/or implementing adaptation strategies and measures.

Additional risks have emerged from the assessed literature:

- Increased summer energy demand, especially in Southern Europe, requires additional power generation capacity (underutilized during the rest of the year), entailing higher supply costs.
- Housing will be affected, with increased overheating under no adaptation and damage from subsidence and flooding. Passive cooling measures alone are unlikely to be sufficient to address adaptation in all regions and types of buildings. Retrofitting current housing stock will be expensive.
- The vulnerability of cultural heritage, including monuments/buildings and cultural landscapes, is an emerging concern. Some cultural landscapes will disappear. Grape production is highly sensitive to climate, but production (of grape varieties) is strongly culturally dependent and adaptation is potentially limited by the regulatory context.
- There is strong evidence that climate change will increase the distribution and seasonal activity of pests and diseases, and limited evidence that such effects are already occurring. Increased threats to plant and animal health are noted. Public policies are in place to reduce pesticide use in agriculture use and antibiotics in livestock, and this will increase vulnerability to the impact of climate change on agriculture and livestock production.
- Lack of institutional frameworks is a major barrier to adaptation governance, in particular, the systematic failure in land use planning policy to account for climate change.

### 23.9.2. Climate Change Impacts Outside Europe and Inter-regional Implications

With increasing globalization, the impacts of climate change outside the European region are likely to have implications for countries within the region. For example, the Mediterranean region (Southern Europe and non-European Mediterranean countries) has been considered highly vulnerable to climate change (Navarra, 2013).

Eastern European countries have, in general, lower adaptive capacity than Western or Northern European countries. The high volume of international travel increases Europe's vulnerability to invasive species, including the vectors of human and animal infectious diseases. The transport of animals and animal products has facilitated the spread of animal diseases (Conraths and Mettenleiter, 2011). Important "exotic" vectors that have become established in Europe include the vector *Aedes albopictus* (Becker, 2009; see also Section 23.5.1).

Another inter-regional implication concerns the changes in the location of commercial fish stocks shared between countries. Such changes may render existing international agreements regarding the sharing of yield from these stocks obsolete, giving rise to international disputes (Arnason, 2012). For instance, the North Sea mackerel stock has recently been extending westwards beyond the EU jurisdiction into the Exclusive Economic Zones of Iceland and the Faroe Islands, which unilaterally claimed quota for mackerel. Territorial disagreements of this type could increase in the future with climate change.

Although several studies have proposed a role for climate change in increasing migration pressures in low- and middle-income countries in the future, there is little robust information regarding the respective roles of climate change, environmental resource depletion, and weather disasters in future inter-continental population movements. The effect of climate change on external migration flows into Europe is highly uncertain (see Section 12.4.1 for a more complete discussion). Modeling future migration patterns is complex, and so far no robust approaches have been developed.

### 23.9.3. Effects of Observed Climate Change in Europe

Table 23-6 summarizes the evidence with respect to key indicators in Europe for the detection of a trend and the attribution of that trend to observed changes in climate factors. The attribution of local warming to anthropogenic climate change is less certain (see Chapter 18 for a full discussion).

Further and better quality evidence since 2007 supports the conclusion of AR4 (Alcamo et al., 2007) that climate change is affecting land, freshwater, and marine ecosystems in Europe. Observed warming has caused advancement in the life cycles of many animal groups, including frogs spawning, birds nesting, and the arrival of migrant birds and butterflies (see Chapter 4 and review by Feehan et al., 2009). There is further evidence that observed climate change is already affecting agricultural, forest, and fisheries productivity (see Section 23.4).

The frequency of river flood events, and annual flood and windstorm damages, in Europe have increased over recent decades, but this increase is attributable mainly to increased exposure and the contribution of observed climate change is unclear (*high confidence*, based on *robust evidence*, *high agreement*; SREX Section 4.5.3; Barredo, 2010).

The observed increase in the frequency of hot days and hot nights (*high confidence*) is likely to have increased heat-related health effects in Europe (*medium confidence*), as well as a decrease in cold-related health effects (*medium confidence*; Christidis et al., 2010). Multiple impacts on health, welfare, and economic sectors were observed due to the major heat wave events of 2003 and 2010 in Europe (Table 23-1; see Chapter 18 for discussion on attribution of events).

**Table 23-6 |** Observed changes in key indicators in ecological and human systems attributable to climate factors.

| | Indicator | Change in indicator | Confidence in detection | Confidence in attribution to change in climate factors* | Key references | Section |
|---|---|---|---|---|---|---|
| Bio-physical systems | Glacier retreat | Fast mass loss of 30 Swiss glaciers since the 1980s | *High confidence* | *Medium confidence* | Huss (2010) | 18.3.1, WGI 10.5 |
| Infrastructure | Storm losses | Increase since 1970s | *High confidence* | No causal role for climate | Barredo (2010) | 23.3.7 |
| | Hail losses | Increase in parts of Germany | *Low confidence* | *Low confidence* | Kunz et al. (2009) | 23.3.7 |
| | Flood losses | Increasing general trend in economic losses in Europe since 1970s; none in Spain | *Medium confidence* | No causal role for climate | Barredo (2009); Barredo et al. (2012) | 23.3.1 |
| Agriculture, fisheries, forestry, and bioenergy production | $C_3$ crop yield | $CO_2$-induced positive contribution to yield since pre-industrial for $C_3$ crops | *High confidence* (*high agreement, robust evidence*) | *High confidence* (*high agreement, robust evidence*) | Amthor (2001); Long et al. (2006); McGrath and Lobell (2011) | 7.2.1 |
| | Wheat yield | Stagnation of wheat yields in some countries in recent decades | *High confidence* | *Medium confidence* | Brisson et al. (2010); Kristensen et al. (2011); Lobell et al. (2011) | 23.4.1 |
| | Phenology—leaf greening | Earlier greening, earlier leaf emergence and fruit set in temperate and boreal climate | *High confidence* (*high agreement, robust evidence*) | *High confidence* (*high agreement, robust evidence*) | Menzel et al. (2006) | 4.4.1.1 |
| | Phytoplankton productivity | Increased phytoplankton productivity in northeast Atlantic, decrease in warmer regions, due to warming trend and hydroclimatic variations | *High confidence* | *Medium confidence* | Beaugrand et al. (2002); Edwards and Richardson (2004) | 6.3 |
| | Ocean systems | Northward movement of species and increased species richness due to warming trend | *High confidence* | *Medium confidence* | Philippart et al. (2011) | 6.3 |
| Environmental quality and biodiversity | Biodiversity | Increased number of colonization events by alien plant species in Europe | *Medium confidence* (*high agreement, medium evidence*) | *Medium confidence* | Walther et al. (2009) | 4.2.4.6 |
| | Migratory birds | Decline over the period 1990–2000 of species that did not advance their spring migration | *Medium confidence* (*medium agreement, medium evidence*) | *Medium confidence* | Moller et al. (2008) | 4.4.1.1 |
| | Tree species | Upward shift in tree line in Europe | *Medium evidence* (*medium agreement, high evidence*) | *Medium confidence* | Gehrig-Fasel et al. (2007); Lenoir et al. (2008) | 18.3.2 |
| | Forest fires | Increase in burnt area | *High confidence* | *High confidence* (*high agreement, robust evidence*) | Pereira et al. (2005); Camia and Amatulli (2009); Hoinka et al. (2009); Carvalho et al. (2010); Koutsias et al. (2012); Salis et al. (2013) | 23.4.4 |

*The studies included in this table are those with good evidence of a detection of a long-term trend in the outcome of interest, and where there has been an assessment of the attribution of the trend to an observed change in climate factor. It is not possible to make an attribution to anthropogenic climate change at this scale; see Chapter 18 for a more complete discussion.

### 23.9.4. Key Knowledge Gaps and Research Needs

There is a clear mismatch between the volume of scientific work on climate change since the AR4 and the insights and understanding required for policy needs, as many categories of impacts are still under-studied. Some specific research needs have been identified:

- Little information is available on integrated and cross-sectoral climate change impacts in Europe, as the impact studies typically describe a single sector (see Sections 23.3-6). This also includes a lack of information on cross-sector vulnerabilities, and the indirect effects of climate change impacts and adaptation responses. This is a major barrier in developing successful evidence-based adaptation strategies that are cost-effective.
- Climate change impact models are difficult to validate (Sections 23.3-6); proper testing of the characteristics of baseline impact estimates against baseline information and data would improve their reliability, or the development of alternative methods where baseline data are not available.
- There is little knowledge on co-benefits and unintended consequences of adaptation options across a range of sectors (Sections 23.3-6).
- There is a need to better monitor and evaluate local and national adaptation and mitigation responses to climate change, in both public and private sectors (Section 23.7; Box 23-3). This includes policies and strategies—as well as the effectiveness of individual adaptation measures. Evaluation of adaptation strategies, over a range of time scales, would better support decision making. Although some means for reporting of national actions exist in Europe (e.g., EU Climate-ADAPT), there is no consistent method of monitoring or a mechanism for information exchange (Section 23.7).
- There are now more economic methods and tools available for the costing and valuation of specific adaptation options, in particular for flood defenses, water, energy, and agriculture sectors (Section 23.7.6). However, for other sectors—such as biodiversity, business and industry, and population health costs—cost estimates are still lacking or incomplete. The usefulness of this costing information in decision making needs to be evaluated and research can be undertaken to make economic evaluation more relevant to decision making.
- The need for local climate information to inform decision making also needs to be evaluated.

- Further research is needed on the effects of climate change on critical infrastructure, including transport, water and energy supplies, and health services (Section 23.5.2).
- Further research is needed on the role of governance in adaptation (local and national institutions) with respect to implementation of measures in the urban environment, including flood defenses, over-heating, and urban planning.
- The impacts from high end scenarios of climate change (>4°C global average warming, with higher temperature change in Europe) are not yet known. Such scenarios have only recently become available, and related impact studies still need to be undertaken for Europe.
- More study of the implications for rural development would inform policy in this area (Section 23.7.5). There is also a lack of information on the resilience of cultural landscapes and communities, and how to manage adaptation, particularly in low-technology (productively marginal) landscapes.
- More research is needed for the medium- and long-term monitoring of forest responses and adaptation to climate change and on the



Frequently Asked Questions

## FAQ 23.1 | Will I still be able to live on the coast in Europe?

Coastal areas affected by storm surges will face increased risk both because of the increasing frequency of storms and because of higher sea level. Most of this increase in risk will occur after the middle of this century. Models of the coast line suggest that populations in the northwestern region of Europe are most affected and many countries, including the Netherlands, Germany, France, Belgium, Denmark, Spain, and Italy, will need to strengthen their coastal defenses. Some countries have already raised their coastal defense standards. The combination of raised sea defenses and coastal erosion may lead to narrower coastal zones in the North Sea, the Iberian coast, and the Bay of Biscay. Adapting dwellings and commercial buildings to occasional flooding is another response to climate change. But though adapting buildings in coastal communities and upgrading coastal defenses can significantly reduce adverse impacts of sea level rise and storm surges, they cannot eliminate these risks, especially as sea levels will continue to rise over time. In some locations, "managed retreat" is likely to become a necessary response.

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Frequently Asked Questions

## FAQ 23.2 | Will climate change introduce new infectious diseases into Europe?

Many factors play a role in the introduction of infectious diseases into new areas. Factors that determine whether a disease changes distribution include: importation from international travel of people, vectors or hosts (insects, agricultural products), changes in vector or host susceptibility, drug resistance, and environmental changes, such as land use change or climate change. One area of concern that has gained attention is the potential for climate change to facilitate the spread of tropical diseases, such as malaria, into Europe. Malaria was once endemic in Europe. Even though its mosquito vectors are still present and international travel introduces fresh cases, malaria has not become established in Europe because infected people are quickly detected and treated. Maintaining good health surveillance and good health systems are therefore essential to prevent diseases from spreading. When an outbreak has occurred (i.e., the introduction of a new disease) determining the causes is often difficult. It is likely that a combination of factors will be important. A suitable climate is a necessary but not a sufficient factor for the introduction of new infectious diseases.

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Frequently Asked Questions

## FAQ 23.3 | Will Europe need to import more food because of climate change?

Europe is one of the world's largest and most productive suppliers of food, but also imports large amounts of some agricultural commodities. A reduction in crop yields, particularly wheat in Southern Europe, is expected under future climate scenarios. A shift in cultivation areas of high-value crops, such as grapes for wine, may also occur. Loss of food production may be compensated by increases in other European sub-regions. However, if the capacity of the European food production system to sustain climate shock events is exceeded, the region would require exceptional food importation.

predictive modeling of wildfire distribution to better address adaptation and planning policies. There is also a lack of information on the impact of climate changes and climate extremes on carbon sequestration potential of agricultural and forestry systems (Section 23.4.4).

- More research is needed on impacts of climate change on transport, especially on the vulnerability of road and rail infrastructure, and on the contribution of climatic and non-climatic parameters in the vulnerability of air transport (e.g., changes in air traffic volumes, airport capacities, air traffic demand, weather at the airports of origin, intermediate and final destination; Section 23.3.3).
- Improved monitoring of droughts is needed to support the management of crop production (Section 23.4). Remote sensing could be complemented by field experiments that assess the combined effects of elevated $CO_2$ and extreme heat and drought on crops and pastures.
- Research is needed on resilience of human populations to extreme events (factors that increase resilience), including responses to flood and heat wave risks. Research is also needed on how adaptation policies may increase or reduce social inequalities (Section 23.5).
- Improved risk models need to be developed for vector-borne disease (human and animal diseases) to support health planning and surveillance (Sections 23.4.2, 23.5.1).

A major barrier to research is lack of access to data, which is variable across regions and countries (especially with respect to socioeconomic data, climate data, forestry, and routine health data). There is a need for long-term monitoring of environmental and social indicators and to ensure open access to data for long-term and sustainable research programs. Cross-regional cooperation could also ensure compatibility and consistency of parameters across the European region.

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