Chapter 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 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, 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*] 23.4.5]. There is less evidence of impacts on social systems attributable to observed climate change, except in pastoralist populations [*low confidence*].

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, 23.4, 23.5, 23.6, 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*] [23.9.2, 23.5.], while some countries have improved their flood protection following major flood events [23.9.2, 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, labour productivity, and the built environment [Table 23-1, 23.3.2, 23.3.3, 23.3.4, 23.3.6, 23.4.1, 23.4.2, 23.4.3, 23.4.4, 23.5.1].

The provision of ecosystem services is projected to decline across all service categories in response to climate change in Southern Europe and Alpine sub-regions [*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*] [Table 23.4, 23.9.3], and may increase future intra-regional disparity [*low confidence*] [23.9.3]. 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] [Box 23-3].

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 due to 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*] [23.5]. Adaptation is further impeded because climate change affects multiple sectors [23.10]. The majority of published assessments are based on climate projections in the range 1-4 degrees global mean temperature per century. Limited evidence exists regarding the potential impacts in Europe under high rates of warming (>4 degrees 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 defences in some areas [23.3.1, 23.7.1, 23.8.3]. 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 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 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 between 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 which 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, 23.9.1].

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].

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 socio-economic damages from shifts in forest tree species range (from south-west to north-east) [*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 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] and the disease vectors and hosts [*medium confidence*] [23.4.3]. 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, 23.6.5], 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 level [23.7], including the prioritisation 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, 23.7.2, 23.7.3]. There is limited evidence of adaptation planning in rural development or land-use planning [23.7.4, 23.7.5].

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

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 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 [23.8.3] [*high confidence*].

23.1. Introduction

This chapter reviews the scientific evidence published since 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 Russia (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 the Polar Regions Chapter 28 and impacts in the Baltic and Mediterranean Seas are addressed in the Open Oceans Chapter 30. Impacts in Malta, Cyprus, and other island states in Europe are discussed in the Small Island Chapter 29.

The European region has been divided into 5 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 is not always possible, depending on the scientific information available.

[INSERT FIGURE 23-1 HERE
Figure 23-1: Sub-regional classification of the IPCC Europe region. Based on Metzger et al., 2005.]

23.1.1. Scope and Route Map of Chapter

The chapter is structured around key policy areas. Sections 23.3 to 23.6 summarise 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 synthesise 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 discussed 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 Russia 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].

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 the international, national and local levels although research on implementation of such policies is limited. Due to the vast range of policies, strategies and measures it is not possible to describe them extensively here. However, adaptation in related 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) catalogues adaptation actions reported by EU Member States (EC, 2013b). The EU Adaptation Strategy was adopted in 2013 (EC, 2013a). 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 (AR4 WG2 Chapter 12). The SREX confirmed increases in warm days, warm nights and decreases in cold days and cold nights since 1950 (*high confidence*, SREX-3.3.1). Extreme precipitation increased in part of the continent, mainly in winter over western-central Europe and European Russia (*medium confidence*, SREX-3.3.2). Dryness has increased mainly in Southern Europe (*medium confidence*, SREX-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 (AR4-12.4.1, SREX-3.3.2, SREX-3.5.1). Many climate-related hazard were projected to increase in frequency and intensity, but with significant variations within the region (AR4-12.4).

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 (AR4 WG2 12.6.1, SREX 9.2.1). National adaptation plans were developed and specific plans were incorporated in European and national policies (AR4 WG2 12.2.3, 12.5) but these were not yet evaluated (AR4 WG2 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 has 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 due to net immigration (Eurostat, 2011a), although population growth is slow (total and working age population) (Rees *et al.*, 2012). Ageing of the population is a significant trend in Europe, as in all high income populations. This will have both economic and social implications, with many regions experiencing a decline in the labour 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 fibre (Easterling *et al.*, 2007) and agriculture is the most important European land use by area (45% of the total area) (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 (ELME, 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 35% of the land area (Eurostat, 2009). The majority of forests now grow faster than in the early 20th century due to 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 CO_2 concentrations, nitrogen deposition, and the reduction of air pollution (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 (ELME, 2007). Peri-urbanisation 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: socio-economic development (Mooij de and Tang, 2003), land use change (Letourneau *et al.*, 2012; Verburg *et al.*, 2010)(Haines-Young *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 (Helming *et al.*, 2011)(Lennert and Robert, 2010). 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 Socio-economic Pathway scenarios (SSPs) (Kriegler *et al.*, 2010). Detailed country and regional scale socio-economic 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 socio-economic futures has also been developed for agricultural land use change (Hardacre *et al.*, 2012). 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 (AR5 WG2 Chapter 28). Since the 1980s, warming has been strongest over Scandinavia, especially in winter, whereas the Iberian Peninsula warmed mostly in summer (EEA, 2012; Haylock *et al.*, 2008). The decadal average temperature over land area for 2002-2011 is 1.3°C+/-0.11°C above the 1850-1899 average, based on HadCRUT3 (Brohan *et al.*, 2006), MLOST (Smith *et al.*, 2008) and GISS Temp (Hansen *et al.*, 2010). See AR5 WG1 Section 2.4 for a discussion of data and uncertainties and AR5 WG2 Chapter 21for 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 (AR5 WG1 Chapter 2.6, SREX-3)(EEA, 2012). The recent cold winters in Northern and Atlantic Europe reflect the high natural variability in the region (Peterson *et al.*, 2012)(AR5 WG1 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/decade) based on Haylock *et al.* (2008), and decreased in parts of Southern Europe (EEA, 2012). Winter snow cover extent has a high inter-annual variability and a non-significant 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* due to 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 (Albrecht *et al.*, 2011; EEA, 2012; Haigh *et al.*, 2010; Menendez and WoodWorth, 2010). 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

For Europe, sub-regional information from global (AR5 WG1 Chapter 14.8.6; AR5 WG1 Annex 1; AR5 WG2 Chapter 21 supplement) and regional high resolution climate model output (AR5 WG1 Chapter 14.8.6; WG2 Chapter 21, 23) provide more knowledge about the range of possible future climates under the SRES and RCP emission scenarios. Within the recognized limitations of climate projections (AR5 WG1 Chapter 9; WG2 Chapter 21), 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 (Kjellström *et al.*, 2011)(Goodess *et al.*, 2009). Even under an average global temperature increase limited to 2°C compared to pre-industrial times, the climate of Europe is simulated to depart significantly in the next decades from today's climate (Jacob and Podzun, 2010);(Van der Linden and Mitchell, 2009).

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 snow pack (although snow-rich winters will remain) towards the end of the 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 (Kreienkamp *et al.*, 2010; Ulbrich *et al.*, 2009) 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 CMIP3 global simulations (Dell'Aquila *et al.*, 2012).

For 2081-2100 compared to 1986-2005, projected global mean sea level rises (metres) are in the range 0.29-0.55 for RCP2.6, 0.36-0.63 for RCP4.5, 0.37-0.64 for RCP6.0 and 0.48-0.82 for RCP8.5 (*medium confidence*, AR5 WG3 Chapter 5). There is a *low confidenc*e on projected regional changes (Slangen *et al.*, 2012)(AR5 WG1 13.6). Low probability/high impact estimates of extreme mean sea-level rise projections derived from the A1FI SRES 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 (the 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) and AR5 WG2 Chapter 21 Supplement. 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 23-2 (upper panels) 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 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 23-2 (middle panels) shows projected seasonal changes of heavy precipitation events for 2071-2100 compared to 1971-2000 for RCP4.5 and RCP8.5.

[INSERT FIGURE 23-2 HERE
Figure 23-2: First row: 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. Second and third rows: Projected seasonal changes in heavy precipitation defined as the 95th percentile of daily precipitation (only days with precipitation > 1mm/day are considered) for the period 2071-2100 compared to 1971-2000 (in %) in the months December to January (DJF) and June to August (JJA). Fourth row: 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 1mm. Hatched areas indicate regions with robust (at least 66% of models agree in the sign of change) and/or statistical 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 EURO-CORDEX initiative. Adapted from Jacob et al. (2013).]

Projected changes of spatially averaged indices over the European sub-regions (Figure 23-1) are described in the supplemental information (Table SM23-2).

In winter, small increases in extreme wind speed are projected for Central and Northern Europe [*medium confidence*] (AR5 WG2 21.3.3.1.6; SREX Figure 3-8) (Beniston *et al.*, 2007; Haugen and Iversen, 2008; Rauthe *et al.*, 2010; Rockel and Woth, 2007; Schwierz *et al.*, 2010), connected to changes in storm tracks [*medium confidence*] (Pinto *et al.*, 2007a; Pinto *et al.*, 2007b)(Donat *et al.*, 2010)(Pinto *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*, AR5 WG1 13.7, SREX 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 6-8% 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 (Jordà *et al.*, 2012; Lionello *et al.*, 2012; Troccoli *et al.*, 2012b)(Planton *et al.*, 2011).

23.2.3. Observed and Projected Trends in the 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) (AR5 WG2 3.2.3). In general, few changes in flood trends can be attributed to climate change, partly due 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 two 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 30-50 years have been observed in parts of Germany (Petrow *et al.*, 2009)(Petrow *et al.*, 2007), 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).

Climate change is projected to affect the hydrology of river basins (SREX Chapter 3; AR5 WG2 Chapter 4). 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 (Chauveau *et al.*, 2013; Quintana-Segui *et al.*, 2011). 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 towards 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 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 (Feyen and Dankers, 2009; Gao and Giorgi, 2008; Vidal and Wade, 2009)(Koutroulis *et al*., 2010; Tsanis *et al*., 2011) (AR5 WG2 Chapter 21). Even in regions where summer precipitation is expected to increase, soil moisture and hydrological droughts may become more severe due to 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 23-2 fourth row).

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 [23.2.3, AR5 WG2 Chapter 5], coastal flood risk will remain a key challenge for several European cities, port facilities and other infrastructure (Nicholls *et al*., 2008)(Hallegatte *et al*., 2008)(Hallegatte *et al*., 2011). 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) (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 Euros 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 the Netherlands, Germany, France, Belgium, Denmark, Spain and Italy (Hinkel *et al*., 2010). Upgrading coastal defences would substantially reduce impacts and damage costs (Hinkel *et al*., 2010). However, the amount of assets and populations that need to protected by coastal defences is increasing, thus, the magnitude of losses when floods do occur will also increase in the futre (Hallegatte et al. 2013), entailing the need to prepare for very large flood disasters in the future.

An increase in future flood losses due to climate change have been estimated for Copenhagen (Hallegatte *et al*., 2011), the 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 1m sea-level rise in Turkey could affect 3 million additional people and put 12 billion USD capital value at risk, with around 20 billion USD 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 AR5 WG2 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 modelling 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; Rojas *et al.*, 2013)(Bouwer *et al.*, 2010)(Te Linde *et al.*, 2011). Some regions may see increasing risks, but others may see decreases or little to no change (Bubeck *et al.*, 2011)(ABI, 2009)(Feyen *et al.*, 2009)(Lugeri *et al.*, 2010)(Mechler *et al.*, 2010)(Feyen *et al.*, 2012)(Lung *et al.*, 2012). In the EU15, river flooding could affect 250,000-400,000 additional people by the 2080s (SRES A2 and B2 scenarios) and 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).

[INSERT Table 23-1 HERE
Table 23-1: Impacts of climate extremes in the last decade in Europe.]

23.3.1.3. Windstorms

Several studies project an overall increase storm hazard in northwest Europe [23.2.2.3] and in economic and insured losses [AR5 WG2 Chapter 17.7.3], 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 stabilising response of mass movements to climate change (Dixon and Brook, 2007; Huggel *et al.*, 2012; Jomelli *et al.*, 2007; Jomelli *et al.*, 2009; Melchiorre and Frattini, 2012). Some land-use practices have led to conditions favourable 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 favourable 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 (23.3.4) (Dolinar *et al.*, 2010), with implications for mitigation and adaptation policies (23.8.1). A range of adaptive strategies for buildings are available, including effective thermal mass and solar shading (ARUP, 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 wellbeing (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 (Brijs *et al.*, 2008)(Kilpeläinen and Summala, 2007). 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)(Andersson and Chapman, 2011b). Severe accidents caused by extreme weather are projected to decrease by 63-70% 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 (Dobney *et al.*, 2010; Lindgren *et al.*, 2009; 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 1-2 ºC 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 (Jonkeren *et al.*, 2011)(Te Linde *et al.*, 2011)(Te Linde, 2007)(Hurkmans *et al.*, 2010). 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, 2009)(Jonkeren *et al.*, 2007). Adaptation includes modal shifts, increase 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 in the 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 Schoof, 2010)(Pryor and Barthelmie, 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 (Harrison *et al.*, 2008; Hueging *et al.*, 2013)(Nolan *et al.*, 2012; Rockel and Woth, 2007). 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; Hueging *et al.*, 2013; Najac *et al.*, 2011; Pašičko *et al.*, 2012).

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

Killingtveit, 2012). Adaptation consists in 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 6-19% decrease of the summer average usable capacity of power plants by 2031–2060 compared to 1971-2000, while smaller decreases have been also estimated (Linnerud *et al.*, 2011)(Förster and Lilliestam, 2010). 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 ºC 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 11-20% 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 74-118% 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 (Eskeland and Mideksa, 2010)(Mirasgedis *et al.*, 2007)(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; Breesch and Janssens, 2010; Chow and Levermore, 2010; Day *et al.*, 2009; Jenkins *et al.*, 2008).

[INSERT FIGURE 23-3 HERE
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.]

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 favour the growth of food borne pathogens or contaminants (Jacxsens *et al.*, 2010; Popov Janevska *et al.*, 2010) (see also 23.5.1). The quality of some products, such as wine (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 Euros, in 2010 prices (Damigos, 2012). Adaptation to buildings or work practices are likely to be needed in order to maintain labour productivity during hot weather (Kjellstrom *et al.*, 2009)(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 and Moreno, 2012)(Amelung *et al.*, 2007)(Nicholls and Amelung, 2008). 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 and Moreno, 2009)(Hein *et al.*, 2009)(Perch-Nielsen *et al.*, 2010)(Amelung *et al.*, 2007)(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 (Amelung and Moreno, 2012; Bujosa and Roselló, 2012; Hamilton and Tol, 2007; Hein *et al.*, 2009). The age of tourists, the climate in their home country, local economic and environmental conditions (e.g. water stress, tourist development) are also critical (Hamilton and Tol, 2007)(Moreno and Amelung, 2009; Perch-Nielsen *et al.*, 2010)(Eugenio-Martin and Campos-Soria, 2010; Lyons *et al.*, 2009)(Rico-Amoros *et al.*, 2009).

Tourism in mountainous areas may benefit from improved climatic conditions in summer (Endler *et al.*, 2010; Endler and Matzarakis, 2011b; Perch-Nielsen *et al.*, 2010; 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 (OECD, 2007; Steiger, 2011)(Moen and Fredman, 2007). Low-lying areas will be the most vulnerable (Endler *et al.*, 2010; Endler and Matzarakis, 2011a; Serquet and Rebetez, 2011; Steiger, 2011; Uhlmann *et al.*, 2009). 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, ageing 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 (Sauter *et al.*, 2010; Steiger and Mayer, 2008; Steiger, 2010; Steiger, 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 (Botzen *et al.*, 2010a; Botzen *et al.*, 2010b; CEA, 2007)(AR5 WG2 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 (Furrer *et al.*, 2009)(Cogan, 2008).

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; GIA, 2011).

The financial sector can adapt through adjustment of premiums, restricting or reduction of coverage, further risk spreading, and importantly incentivising risk reduction (Botzen *et al.*, 2010a; Clemo, 2008)(Crichton, 2007)(Crichton, 2006)(Wamsler and Lawson, 2011)(Surminski and Philp, 2010). 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) analysed the performance of the EU 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 30% in affected regions of Europe and Russia, respectively (Barriopedro *et al.*, 2011; Ciais *et al.*, 2005) (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 (Brisson *et al.*, 2010)(Hawkins *et al.*, 2013)(Ladanyi, 2008), 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 levelled off in several countries over 1961-2009 (Olesen *et al.*, 2011). High temperatures and droughts during grain filling has 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 favoured an increase in potato yields since 1960 (Gregory and Marshall, 2012). In north-east 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 circulation models (GCM) 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 subregions, although wheat yield could increase under the A2 scenario (Supit *et al.*, 2012, three GCMs, B1, A2 scenarios). Disease-limited yields of rain fed 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 unfavourable 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 1-3 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 (Iglesias *et al.*, 2012) (Donatelli *et al.*, 2012) (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 rain fed summer crop failure (Bindi and Olesen, 2011)(Ferrara *et al.*, 2010)(Ruiz-Ramos *et al.*, 2011). Warmer and drier conditions by 2050 (Trnka *et al.*, 2010; Trnka *et al.*, 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 and 5.4°C regional warming) (Bindi and Olesen, 2011)(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; Avnery *et al.*, 2011b). 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 due to increasing aridity in South European regions of Russia with the best soils (Dronin and Kirilenko, 2011).

[INSERT FIGURE 23-4 HERE
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 ECHAM5 (left column) and HadCM3 (right) GCMs. Upper maps to do not take adaptation into account. Bottom maps include adaptation. Source: Donatelli et al., 2012.]

With generally warmer and drier conditions, deep rooted weeds (Gilgen *et al.*, 2010b) 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 like 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, like 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.*, 2011; Moriondo *et al.*, 2010; 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) (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 which 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: i) breeding has not yet succeeded in altering crop plant development responses to short-term changes in temperature (Parent and Tardieu, 2012) and ii) 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 (Mandryk *et al.*, 2012); (Moriondo *et al.*, 2010b). In Southern Europe, the regional welfare loss caused by changes in the agriculture sector under a high warming scenario (+5.4°C) was estimated at 1% of 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)(AR5 WG2 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 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 programmes (Hoffmann, 2010).

With grass based livestock systems, model simulations (A1B scenario, ensemble of downscaled GCMs) show by end of century increases in potential dairy production in Ireland and France, however with higher risks of summer-autumn production failures in Central Europe and at French sites (Graux *et al.*, 2012; Trnka *et al.*, 2009). Climate conditions projected for the 2070s in central France (A2 scenario) reduced significantly grassland production in a four years experiment under elevated CO_2 (Cantarel *et al.*, 2013). At the same site, a single experimental summer drought altered production during the next two 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*., 2010a). 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 (van Dijk *et al*., 2010)(Petney *et al*., 2012; Randolph and Rogers, 2010)(AR5 WG2 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 haemorrhagic 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 programmes have the potential to reduce the incidence of vector-borne animal diseases (Chevalier *et al*., 2010) (Wilson and Mellor, 2009).

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)(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 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, non-significant impacts were found for aquifers in Switzerland and in England (Stoll *et al*., 2011)(Jackson *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 N 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, in order 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 (Daccache and Lamaddalena, 2010; Daccache *et al*., 2012; Henriques *et al*., 2008; Trnka *et al*., 2011) 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 20-27% 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 (Daccache and Lamaddalena, 2010; Gonzalez-Camacho *et al*., 2008; Lee *et al*., 2008; Schutze and Schmitz, 2010) especially in

Southern and south-eastern 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 (Affolter *et al*., 2010; Bigler *et al*., 2006; Raftoyannis *et al*., 2008), including Italy (Bertini *et al*., 2011)(Giuggiola *et al*., 2010), Cyprus (ECHOES Country report, 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 (Allen *et al*., 2010; Charru *et al*., 2010; Rouault *et al*., 2006). 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 Russia (Sirotenko and Abashina, 2008).

Future projections show that in Northern and Atlantic Europe the increasing atmospheric CO_2 and higher temperatures are expected to increase forest growth and wood production, at least in the short-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 (Hlásny *et al*., 2011; Keenan *et al*., 2011; Lavalle *et al*., 2009; Lindner *et al*., 2010; Silva *et al*., 2012; Sirotenko and Abashina, 2008). 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) due to fuel accumulation (Koutsias *et al*., 2012), climate change (Lavalle *et al*., 2009) and extreme weather events (Camia and Amatulli, 2009; Carvalho *et al*., 2011; Hoinka *et al*., 2009; Koutsias *et al*., 2012; Salis *et al*., 2013) especially in the Mediterranean basin (Marques *et al*., 2011; Pausas and Fernández-Muñoz, 2012)(Fernandes *et al*., 2010; Koutsias *et al*., 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 inter-annual 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 last decades (San-Miguel-Ayanz *et al*., 2013).

Future wildfire risk is projected to increase in Southern Europe (Carvalho *et al*., 2011; Dury *et al*., 2011; Lindner *et al*., 2010; Vilén and Fernandes, 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 emissions due to biomass burning (Chiriacò *et al*., 2013; Pausas *et al*., 2008; Vilén and Fernandes, 2011), even if often difficult to quantify (Chiriacò *et al*., 2013).

[INSERT FIGURE 23-5 HERE
Figure 23-5: Changes in forest fire risk in Europe for two time periods: baseline (left) and 2041–2070 (right), based on high-resolution regional climate models and the SRES A1B emission scenario. Source: Lung 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 8-19% 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 (Klaus *et al.*, 2011; Pinto *et al.*, 2010).

An increase in the incidence of diseases has been observed in many European forests (FAO, 2008b; Marcais and Desprez-Loustau, 2007). 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 favour diffusion of bark beetle in Scandinavia, in lowland parts of central Europe and Austria (Jönsson *et al.*, 2011; Jönsson *et al.*, 2009)(Seidl *et al.*, 2009).

Possible response approaches to the impacts of climate change on forestry include short-term 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 due 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 *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, due to increasing temperatures, and to decrease in Southern Europe due to increased drought frequency) (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 C3 Salicaceae trees, to rising atmospheric CO_2 concentration may increase drought tolerance due to 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 greenhouse gas neutral 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) (AR5 WG2 Chapter 6, 23.6.4) which has a direct impact on fisheries (Cheung *et al.*, 2010; Cheung *et al.*, 2013; Tasker, 2008). 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 species 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 results 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 North Sea and Celtic Seas, the steep decline in boreal species (Henderson, 2007) was compensated for by the arrival of southern (Lusitanian) species (Engelhard *et al.*, 2011; Lenoir *et al.*, 2011; ter Hofstede *et al.*, 2010).

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 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 (Perez *et al.*, 2010)(Garza-Gil *et al.*, 2010), to non-significant 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.*, 2011; Perry *et al.*, 2010). Climate change adaptation is being considered for integration in European maritime and fisheries operational programs (European Commission, 2013).

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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 summarises 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 brackets). 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*].

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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. Further 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 (Corobov *et al*., 2012; Corobov *et al*., 2013; Kovats and Hajat, 2008; Åström *et al*., 2011). With respect to sub-regional vulnerability, populations in southern Europe appear to be most sensitive to hot weather (Baccini *et al*., 2011; D'Ippoliti *et al*., 2010; Michelozzi *et al*., 2009; Michelozzi *et al*., 2009), and also will experience the highest heat 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 (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)(AR5 WG2 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 (Randolph and Rogers, 2010; Semenza and Menne, 2009; 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 (Caminade *et al*., 2012; Fisher *et al*., 2011; Roiz *et al*., 2011). The risk of introduction of dengue remains very low because it would depend upon the introduction and expansion of the *Ae. 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 (15-20 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 *et al*., 2010a). 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 upon 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 is 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 sensitive of salmonellosis to 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 affects 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 ochratoxin *A, patulin* and *Fusarium* toxins (Paterson and Lima, 2010). A 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 modelling 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 climate may affect transmission or contamination routes also makes 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, but 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 the assets (physical or electronic) that are vital to the continued delivery and integrity of the essential services upon 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) (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 in 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 healthcare, 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 region and by sector.

Current damages from weather-related disasters (floods and storms) are significant (23.3.1). Disasters have long lasting effects of 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 are present in Arctic regions are considered vulnerable to climate change impacts on livelihoods and food sources (Arctic Climate Impact Assessment, 2005) [12.3.4, 28.2.4]. Research has focussed on indigenous knowledge, impacts on traditional food sources and community responses/adaptation (Mustonen and Mustonen, 2011a; Mustonen and Mustonen, 2011b). However, these communities are also experiencing rapid social, economic and other non-climate-related environmental changes (such as oil and gas exploration) [see 28.2.4]. There is evidence the climate change has altered the seasonal behaviour of pastoralist populations, such as the Nenets reindeer herders in northern Russia (Amstislavski *et al*., 2013). However, socio-economic factors may be more important than climate change for the future sustainability of Reindeer husbandry (Rees *et al*., 2008) [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; Brimblecombe, 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 timescales (Brimblecombe and Grossi, 2008)(Bonazza *et al*., 2009a; Bonazza *et al*., 2009b; Brimblecombe and Grossi, 2009; Brimblecombe and Grossi, 2010; Grossi *et al*., 2008). Climate change may also affect indoor environments where cultural heritage is preserved (Lankester and Brimblecombe, 2010) as well as visitor behaviour 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 crystallisation may increase all over Europe (Benavente *et al*., 2008; Grossi *et al*., 2011). In Northern and Eastern Europe, wood structures will need additional protection against rainwater and high winds (Sabbioni *et al*., 2012). AR4 concluded that current flood defences would not protect Venice from climate change. Venice now has a flood forecasting system, and is introducing the MOSE 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, e.g. 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 run-off, 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.

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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 (Bock *et al.*, 2011)(Santos *et al.*, 2011)(Duchêne *et al.*, 2010). 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; Duarte Alonso and O'Neill, 2011; Holland and Smit, 2010; Malheiro *et al.*, 2010; 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 (Metzger and Rounsevell, 2011)(White *et al.*, 2009). 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, amongst other things, what grapes can be grown where, e.g., the French AOC or the Italian DOC and DOCG 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).

_____ END BOX 23-2 HERE _____

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, fibre, 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, sulphur 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; Forkel and Knoche, 2007). Reviews have concluded that GCM/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 1–10 ppb) by 2050s in polluted areas (that is, where concentrations of precursor nitrogen oxides are higher) (AQEG, 2007; Jacob and Winner, 2009)[see also 21.4.1.3.2.]. The effect of future climate change alone on future concentrations of particulates, nitrogen oxides and volatile organic compounds is much more uncertain. Higher temperatures also affect natural emissions volatile organic compounds (VOCs) which are ozone precursors (Hartikainen *et al.*, 2012). One study has projected an increase in fire-related air pollution (O3 and PM10) in Southern Europe (Carvalho *et al.*, 2011).

Overall, the model studies are inconsistent regarding future projections of background level and exceedences. 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 in 2003, 2006 and 2010 (Solberg *et al*., 2008). Peak ozone events were observed during the major heat waves in Europe in multiple countries. Wildfire events have had an impact on local and regional on air quality (Hodzic *et al*., 2007; Liu *et al*., 2009; Miranda *et al*., 2009) which have 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, salinisation, landslides and contamination is estimated to be EUR 38 billion annually for the EU (JRC-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-EEA, 2010). Projections show significant reductions in summer soil moisture in the Mediterranean region, and increases in the north-eastern 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 month higher erosion rates would occur due to higher rainfall erosivity (Marker *et al*., 2008). For two Danish river catchments, assuming a steady-state land use, suspended sediment transport would increase by 17-27% by 2071-2100 (Thodsen *et al*., 2008; Thodsen, 2007). 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 like zero tillage and conversion of arable to grasslands (Klik and Eitzinger, 2010). In central Europe, compared to conventional tillage, conservation tillage systems reduced modelled 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 favoured the delivery of a high quality water resource (House *et al*., 2011); (McHugh, 2007). Maintaining soil water retention capacity, e.g. through adaptation measures (Post *et al*., 2008), contributes to reduce risks of flooding as soil organic matter absorbs up to twenty 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 (23.4.3), 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 which 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 run-off, 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; in Southern Europe this is caused 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), France (Delpla *et al*., 2011) and the UK (Howden *et al*., 2010; Macleod *et al*., 2012; Whitehead *et al*., 2009); AR5 WG2 Chapter

4.3.2.5). In larger rivers, such as the Meuse, increased summer temperature and drought can lead to more favourable 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 future climate changes including CO_2 increase are determining negative effects of habitat loss on species density and diversity (Mantyka-pringle *et al.*, 2012)(Rickebusch *et al.*, 2008). Projected habitat loss is greater for species at higher elevations (Engler *et al.*, 2011)(Castellari, 2009; 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 century (Huntley *et al.*, 2007). Aquatic habitats and habitat connectivity in river networks may become increasingly fragmented (Blaustein *et al.*, 2010; Della Bella *et al.*, 2008; Elzinga *et al.*, 2007; Gómez-Rodríguez *et al.*, 2010; Hartel *et al.*, 2011; Morán-López *et al.*, 2012)(Harrison *et al.*, 2008)(Clark *et al.*, 2010a)(Clark *et al.*, 2010; Fronzek *et al.*, 2006; Fronzek *et al.*, 2010; Fronzek *et al.*, 2011; Gallego-Sala *et al.*, 2010). 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 (Pauli *et al.*, 2012)(Gottfried *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 towards homogenization across the continent will be observed (Thuiller *et al.*, 2011)(Alkemade *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 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 behaviour of birds (Feehan *et al.*, 2009) (Jonzén *et al.*, 2006; Rubolini *et al.*, 2007a; Rubolini *et al.*, 2007b)(Lemoine *et al.*, 2007a; Lemoine *et al.*, 2007b). 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 5-9% are at risk of extinction, assuming no migration, during the 21st century due to climate change, while 70-78% 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 (Doney *et al.*, 2011)(EEA, 2010d). 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 (Philippart *et al.*, 2011)(Airoldi and Bec, 2007).

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 2-4 times the mean global rate (Philippart *et al.*, 2011)(Belkin, 2009). In the Baltic, decreased sea ice will expose coastal areas to more storms, changing the coastal geomorphology (BACC, 2008)(HELCOM, 2007). Warming SSTs will influence biodiversity and drive changes in depth and latitudinal range for intertidal and sub-tidal marine communities, particularly in the North and Celtic seas (Hawkins *et al.*, 2011)(Sorte *et al.*, 2010)(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 to 5 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)(Ciscar *et al.*, 2011)(Magnan *et al.*, 2009). In the North Sea, the Iberian coast, and Bay of Biscay, a combination of coastal erosion, infrastructure development and sea defences may lead to narrower coastal zones ("coastal squeeze") (EEA, 2010d)(Jackson and McIlvenny, 2011)(OSPAR, 2010).

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 the economic analyses (Section 23.7.6) (see Box 23-3), and the developed of climate services (Medri *et al.*, 2012; WMO, 2011). At the international level, the European Union has started adaptation planning, through information sharing (Climate-ADAPT platform) and legislation (EC, 2013a). National and local governments are also beginning to monitor progress on adaptation, including the development of a range of indicators (UK-ASC, 2011).

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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.*, 2010b). Many adaptation strategies were found to be agendas for further research, awareness raising and/or coordination and communication for implementation (e.g. (Dumollard and Leseur, 2011; Pfenniger *et al.*, 2010). Actual implementation often was limited to disaster risk reduction, environmental protection, spatial planning (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 that while there is a high political commitment to adaptation planning and implementation, evaluation of the strategies and actual implementation is yet to be defined (Biesbroek *et al*., 2010a; Swart *et al*., 2009b; 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 while 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*., 2010b).

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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) (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 updating (OSPAR, 2010; UNEP, 2010).

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

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 emphasised the search for robust pathways, for instance in the Netherlands (Haasnoot *et al*., 2012; Kwadijk *et al*., 2010). Public participation has also increased in decision making, e.g. river basin management planning (Huntjens *et al*., 2010), flood defence 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 Council, 2007), the mapping of flood risks, improve 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 has been assessed of flood protection (Bouwer *et al*., 2010) and also non-structural or household level measures to reduce losses from river flooding (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; Te Linde *et al*., 2010b).

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 (Mickwitz *et al*., 2009)(Wilson, 2006)(Van Nieuwaal *et al*., 2009). For example, in the UK, houses were still being built in flood risk areas (2001-2011) due to 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 in adapting to climate change (Bulkeley, 2010; Heidrich *et al*., 2013). Some cities, e.g. 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 run-off (Gill *et al*., 2007). Despite the benefits however 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 colonisation capacity of new climate zones and optimise 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 programme 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 (AR4 WG2 Chapter 17.2.3), costs 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, 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 summarises some of the more comprehensive cost estimates for Europe for sectors at regional and national level. 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), this 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 4,000 and 10,000 year level return periods. More detailed treatment of the economics of adaptation is provided in AR5 WG2 Chapter 17.

[INSERT TABLE 23-2 HERE
Table 23-2: Selected published cost estimates for planned adaptation in European countries.]

23.7.7. Barriers and Limits to Adaptation

The implementation of adaptation options presents a range of opportunities, constraints and limits. Constrains (barriers) to implementation are financial, technical and political (see discussion in AR5 WG2 16). Some impacts will be unavoidable due to limits (physical, technological, social, economic or political). Examples of limits in the European context are described by sector in Table 23-3. For example, the contraints on building or extending flood defences would include pressure for land, conservation needs, and amenity value of coastal areas (AR5 WG2 5.5.5).

Towards the end of the century, it is likely that adaptation limits are expected to be reached earlier under higher rates of warming. Opportunities and co-benefits of adaptation are also discussed in section 23.8 below.

[INSERT TABLE 23-3 HERE
Table 23-3: Limits to adaptation to climate change.]

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 greenhouse gas 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-markets costs and benefits (externalities)(Watkiss and Hunt, 2010). This section will describe 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 (decarbonisation 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 (Mavrogianni *et al*., 2012)(Davies and Oreszczyn, 2012)(Jenkins *et al*., 2008; Jenkins, 2009). 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 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 desalination plants as an adaptation measure, possibly increasing energy consumption and thus greenhouse gases emissions. Coastal flood defence 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 in order to maintain tourist comfort and thus increase greenhouse gas 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 (Smith and Olesen, 2010)(Lavalle *et al.*, 2009). The agriculture sector contributes to about 10% of the total anthropogenic greenhouse gas (GHG) emissions in the EU27 (EEA, 2010b). Estimates of European carbon dioxide, methane and nitrous oxide fluxes between 2000 and 2005 suggest that methane emissions from livestock and nitrous oxide emissions from agriculture are fully compensated for by the carbon dioxide 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 run-off (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 *et al.*, 2008)(Rosenzweig and Tubiello, 2007), but increased irrigation under climate change would increase energy use and may reduce water availability for hydro-power (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 (De Wit *et al.*, 2011) (Fischer *et al.*, 2010b) 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 WGIII chapters on Housing, Transport and Energy, and WGII chapter 11). Several assessment have quantified benefits in terms of lives saved by reducing particulate air pollution, and trying to coherent policy objectives for emissions reductions in local and global 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; Haines *et al.*, 2009b).

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

23.8.4. Environmental Quality and Biological Conservation

There are several conservation management approaches that can address both mitigation, adaptation and biodiversity objectives (Lal *et al.*, 2011). Some infrastructure adaptation strategies, such as desalinisation, sea defences and flood control infrastructure may have negative effects on both mitigation and biodiversity. However, approaches, such as forest conservation and urban green space (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 urbanisation on nature conservation.

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.

[INSERT FIGURE 23-6 HERE
Figure 23-6: Adaptation and mitigation options and their effects on biodiversity. The horizontal axis ranges from positive effects on biodiversity (left-hand side) to negative effects (right-hand 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 centre of the vertical axis have benefits for both mitigation and adaptation. Thus, options located at the centre left of the figure have benefits for mitigation, adaptation and biodiversity and hence are labelled as 'win-win-win'. Other combinations of benefits and dis-benefits are labelled accordingly, e.g. win-lose-win, lose-win-lose, etc. Based on Paterson et al., 2009.]

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 that these impacts differ significantly in type between the sub-regions. Impacts in neighbouring 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 (23.3.6), agriculture (23.4.1), and forestry (23.4.4).

[INSERT TABLE 23-4 HERE
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.]

The majority of published assessments are based on climate projections in the range 1-4 degrees global mean temperature per century. Under these scenarios, regions in Europe may experience higher rates of warming (in the range 4-6 degrees 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 degrees above pre-industrial levels) but these would lead to large increase in coastal flood risk as well as impacts on global cereal yields and other effects on the global economy (AR5 WG2 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 key vulnerabilities (either reducing or exacerbating vulnerability) 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).

Extreme events affect multiple sectors and have the potential to cause a 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 (Ludwig *et al.*, 2011; Pitt, 2008; Ulbrich *et al.*, 2012). Extreme events (heat waves and droughts) have had significant impacts on populations as well impacts on multiple economic sectors (Table 23-1), and resilience to future heat waves has only been addressed 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, e.g. 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 run-off (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, e.g. through changes in the productivity of crops and trees [23.4], and indirectly through climate change impacts on the global supply of land-based commodities and their movement through international trade [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 socio-economic indicators and projections (Lung *et al.*, 2012; Metzger *et al.*, 2008)(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 [23.3.1, 23.5.3].
- Urban areas are also vulnerable due to high density of people and built infrastructure from weather extremes [23.3, 23.5.1].
- High mountains. Due to high impact of climate change on natural hazard, water and snow resources and 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
- 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 the sub-region vulnerability (Ulbrich *et al.*, 2012).

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

- Arable crop yields. There is new evidence to suggest that crop yields and production may be more vulnerable as a result of increasing climate variability. This will limit the potential poleward expansion of agricultural production. Limits to genetic progress to adapt are increasingly reported.

- New evidence 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 modelling studies. There are legal barriers to introducing new species (e.g. forest species in France). New evidence 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, which will be under-utilised 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.
- An emerging concern is the vulnerability of cultural heritage, including monuments/buildings and cultural landscapes. 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.
- Good evidence that climate change will increase distribution and seasonal activity of pests and diseases. Limited evidence that such effects already occurring. Increased threats to plant and animal health. 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 particularly, the systematic failure in land use planning policy to account for climate change.

[INSERT TABLE 23-5 HERE
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.]

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 high 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) (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 of climate change to increase migration pressures in low and middle income countries in the future, there is little robust information regarding the role 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 chapter 12.4.1 for a more complete discussion). Modelling 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 summarises 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 (Europe chapter, 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 WGII 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 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 mainly due to increased exposure and the contribution of observed climate change is unclear (high confidence – based on robust evidence and high agreement)(SREX 4.5.3, (Barredo, 2010).

The observed increase in the frequency of hot days and hot nights (high confidence, WGI) is likely to have increased heat-related health effects in Europe (medium confidence), and 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 23-5) (see Chapter 18 for discussion on attribution of events).

[INSERT TABLE 23-6 HERE
Table 23-6: Observed changes in key indicators in ecological and human systems attributable to climate factors.]

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 understudied. 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 to 23.6]. 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 to 23.6]; 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 the co-benefits and unintended consequences of adaptation options across a range of sectors [section 23.3 to 23.6].
- 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 [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. While 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 [23.7].
- There are now more economic methods and tools available for the costing and valuation of specific adaptation options, in particular for flood defences, water, energy, and agriculture sectors [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 need 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, and water and energy supplies, health services) [23.5.2].
- Further research is needed on the role of governance in adaptation (including local and national institutions) with respect to implementation of measures in the urban environment, including flood defences, over-heating, and urban planning.
- The impacts for Europe from high end scenarios of climate change (above 4°C global average warming, with higher temperature change in Europe) are yet unknown. This is because such scenarios have only recently become available, and related impact studies still need to be undertaken for Europe.
- More study of the implications of climate change for rural development would inform policy in this area [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 predictive modelling 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 [23.4.4].
- More research on the 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) [23.3.3].
- Improved monitoring of droughts is needed to support the management of crop production [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 the resilience of human populations to extreme events (factors which increase resilience), including responses to flood and heat wave risks. Inequalities – and how adaptation policies may increase or reduce social inequalities [23.5].
- Development of improved risk models for vector borne disease (human and animal diseases) in order to support health planning and surveillance [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 socio-economic 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 programmes. Cross-regional cooperation could also ensure compatibility and consistency of parameters across the European region.

Frequently Asked Questions

FAQ 23.1: Will I still be able to live on the coast in Europe? [to remain at the end of the chapter]

Coastal areas affected by storm surges will face increased risk both because of the increasing frequency and 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 north western 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 defences. Some countries have already raised their coastal defence standards. The combination of raised sea defences and coastal erosion may lead to narrower coastal zones in the North Sea, the Iberian coast, and Bay of Biscay. Adapting dwellings and commercial buildings to occasional flooding is another response to climate change.

But while adapting buildings in coastal communities and upgrading coastal defences 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.

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

[to remain at the end of the chapter]

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 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.

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

[to remain at the end of the chapter]

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.

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Table 23-1: Impacts of climate extremes in the last decade in Europe.

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. Reduced/ interrupted operation of nuclear power plants (mostly in France). High transport prices in 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). High outdoor pollution levels (EEA 2012)	Yes
2004/ 2005	Iberian Peninsula - Portugal	Hydrological drought	-	Grain harvest losses of 40% (EEA, 2010c)	-	-	
2007	Southern Europe	Hottest summer on record in Greece since 1891 (Founda & Giannakopoulos 2009)	1710 buildings burned down or rendered uninhabitable in Greece (JRC, 2008)	Approx. 575,500 hectares burnt area (JRC, 2008)	Significant mortality impact: 6 deaths in Portugal, 80 deaths in Greece.	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). 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, incl. 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). Reduction in crop yields (Coumou and Rahmstorf, 2012)	Estimated 10,000 excess deaths due to heatwave 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)			

* Extreme events derived from Coumou and Rahmstorf, 2012.

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/a	In 2100	Coastal adaptation costs	Hinkel et al. 2010
Europe	€1.7 billion/a €3.4 billion/a €7.9 billion/a	By 2020s By 2050s By 2080s	Protection from river flood risk for EU27	Rojas et al., in press
Netherlands	€1.2–1.6 billion/a €0.9–1.5 billion/a	up to 2050 2050–2100	Protection from coastal and river flooding	Delta Committee, 2008
Sweden	total of up to €10 billion	2010-2100	Multi sector	Swedish Commission on Climate and Vulnerability, 2007
Italy	€0.4-2 billion Up to € 44 billion	By 2080s	Coastal protection Hydrogeological protection	Bosello et al. 2012, Medri et al. 2013.
Greece	€0.4-3.3 billion	Up to 2100	Coastal protection	Bank of Greece, 2011
UK	€1.8 billion €2.2 billion €7-8 billion	Until 2035 2035-2050 At 2100	Maintain and improve Thames flood protection Renew and improve Thames flood protection New Thames barrier for London	EA, 2011

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.	Landauer et al, 2012 ; Steiger, 2010; Steiger, 2011; Steiger and Mayer, 2008, Unbehaun et al., 2008
Thermal power plants/ cooling through river intake and discharge	Once-through cooling systems	Closed- circuit cooling	High investment cost for retrofitting existing plants	van Vliet et al., 2012, Koch and Vögele, 2009, 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, 2009, Jonkeren et al., 2007
		Use of smaller ships	Existing barges below optimal size (Rhine)	Demirel, 2011
Agriculture, Northern and Continental Europe.	Arable crops	Sowing date as agricultural adaptation	Other constraints (e.g. frost) limit farmer behaviour	Oort, 2012
Agriculture, Northern and Continental Europe.	Arable crops	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	Giuggiola *et al.*, 2010; Hemery *et al.*, 2010; García-López J.M. and Alluéa, 2011, Casalegno *et al.*, 2007

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.

	Alpine	**Southern**	**Northern**	**Continental**	**Atlantic**	
Energy						
Wind energy production	→	↗ → ↘ [1]	↗ →	→	↗ → ↘	23.3.4
Hydropower generation	↗ ↘ [2]	↘	↗ →	↘	↗ ↘	23.3.4
Thermal power production	→ ↘	→ ↘	→	→ ↘	→ ↘	23.3.4, 8.2.3.2
Energy consumption (net annual change)	↘	↗	↘	↘	↘	23.3.4, 23.8.1
Transport						
Road accidents [3]	→ ↘	↘	→ ↘	→ ↘	→ ↘	23.3.3
Rail delays (weather-related)	?	?	↗	?	↗ ↘ [4]	23.3.3, 8.3.3.6
Load factor of inland ships	?	?	?	→ ↘	→ ↘	23.3.3
Transport time and cost in ocean routes	?	?	↘	↘	?	23.3.3, 18.3.3.3.5
Settlements						
River flood damages	→	→	→	↗ ↘	↗ ↘	23.3.1
Coastal flood damages	n/a	↗ →	↗ →	↗ →	↗ →	23.3.1
Tourism						
Length of ski season	→ ↘	?	↘	↘	?	23.3.6, 3.5.7
Human health						
Heat wave mortality and morbidity	→	↗	↗	↗	↗	23.5.1
Food safety	→	↗	↗	↗	↗	23.5.1

Social and cultural Impacts						
Social costs of floods	→	→	→	↗ ↘	↗ ↘	23.5.3
Damage on cultural buildings	↗	↗ ↘	↗	↗	↗	23.5.4
Loss of cultural landscapes	↗	?	↗	↗	↗	23.5.4
Environmental quality						
Air quality (ozone background levels)	?	↗ ↘	↗ ↘	↗ ↘	↗ ↘	23.6.1
Air quality (particulates)	?	→	→	→	→	23.6.1
Water quality	→	↘	→	→	↘	23.6.3

Key:
Green means a "beneficial" change
Red means a "harmful" change
? means no relevant literature found

Confidence levels:
Risks were identified based on assessment of the literature and expert judgment.

Footnotes:

[1] Simulations have been performed, but mostly for the period after 2070.

[2] The increasing trend is for Norway.

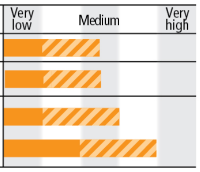
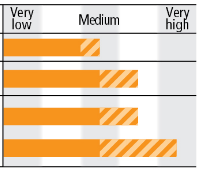
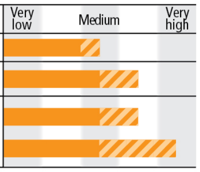
[3] The decreasing trend refers mainly to the number of severe accidents.

[4] Impacts have been studied and quantified for UK only. The increasing trend stands for summer delays and the decreasing trend for winter delays.

[5] In both seasons, no significant impacts are expected by 2020, while more substantial changes are expected by 2080. For 2050 impacts are assumed to vary linearly (although this may not be the case).

[6] The constant trend stands for the Mediterranean, where some studies estimate no changes due to climate change at least until 2030 or even 2060.

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 and prospects	Climatic drivers	Supporting ch. sections	Timeframe	Risk for current and high adaptation
Increased economic losses and people affected by flooding in river basins and coasts, driven by increasing urbanisation and by increasing sea-levels and increasing peak river discharges (*high confidence*)	Adaptation can prevent most of the projected damages (high confidence). The experience in hard flood protection technologies is significant. Main issues include the high costs for increasing flood protection demand for land in Europe, and environmental and landscape concerns.	🌧 🌀 🌊	23.2.3, 23.3.1, 23.7	Present Near-term (2030-2040) Long-term (2080-2100) 2°C 4°C	
Increased water restrictions. 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 run-off (as a result of increased evaporative demand) (*high confidence*)	Proven adaptation potential from changes in technologies and adoption of more water efficient technologies and of water saving strategies (irrigation, crop species, land cover, industries, domestic use). Further adaptation possible through solar desalinization (to limit fossil fuel demand).	🌡❗ 🌧	23.4.3, 23.4.4, 23.7.2	Present Near-term (2030-2040) Long-term (2080-2100) 2°C 4°C	
Increased economic losses and people affected by extreme heat events: impacts on health, welfare (overheating in buildings), labour productivity, crop production, reduced air quality (*medium confidence*)	Implementation of warning systems, adaptation of dwellings and work places, and transport and energy infratructure. Reductions in emissions to improve air quality. Improved wild fire management.	🌡❗	23.3.2, 23.3.4, 23.3.3, 23.5, 23.6.1, 23.6.3, 23.7.4	Present Near-term (2030-2040) Long-term (2080-2100) 2°C 4°C	

Climatic drivers of impacts				
🌡 Warming trend	🌡❗ Extreme temperature	🌧 Extreme precipitation	🌀 Damaging cyclone	🌊 Sea level

Risk & potential for adaptation

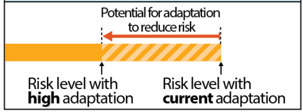


Table 23-6: Observed changes in key indicators in ecological and human systems attributable to climate factors.

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	18.3.1.3 WG1 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 some locations	Medium confidence	No causal role for climate	Barredo, 2009; Barredo et al., 2012	23.3.1
Agriculture, Fisheries, Forestry, and Bioenergy Production					
C3 crop yield	CO_2 induced positive contribution to yield since preindustrial for C3 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	Lobell *et al.* 2011 ; Brisson et al., 2010; Kristensen 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 NE. Atlantic, decrease in warmer regions, due to warming trend and hydroclimatic variations	High confidence	Medium confidence	Beaugrand *et al.*, 2002; Edwards and Richardson, 2004	6.3.2
Ocean systems	Northward movement of species and increased species richness due to warming trend	High confidence	Medium confidence	Philippart *et al.* , 2011	6.3.2
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 1990-200 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	18.3.2.1
Forest fires	Increase in burnt area	High confidence	High confidence (high agreement, robust evidence)	Camia and Amatulli 2009; Hoinka et al., 2009; Carvalho et al., 2010; Salis et al., in press; Pereira et al., 2005; Koutsias et al., 2012	23.4.4

NOTE: The studies included in this table are those with good evidence of a detection of a long term trend in the outcome of interested, 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.

BOX 23-1 TABLE

	Alpine	**Atlantic**	**Continental**	**Northern**	**Southern**
Provisioning services:					
Food production	No (1) ∨ (4)	∨ (1)	∨ (1)	∧ (1) ∨ (1)	∨ (1)
Livestock production	No (1) ∨ (1)				
Fibre production	∨ (1)				
Bioenergy production	∧ (1)			∧ (1)	∨ (1)
Fish production		No (1) ∨ (1)	∨ (1)	No (1) ∨ (1)	No (1) ∨ (2)
Timber production	∧ (5) No (2) ∨ (5)	∧ (2) No (3)	∧ (1) No (2) ∨ (1)	∧ (6) No (1)	V (2)
Non-wood forest products				∧ (1) No (1)	∨ (1)
Sum of effects on provisioning services	∧ (6) No (4) ∨ (11)	∧ (2) No (4) ∨ (2)	∧ (1) No (2) ∨ (3)	∧ (9) No (3) ∨ (2)	No (1) ∨ (7)
Regulating services:					
Climate regulation (carbon sequestration)					
- General/forests	∧ (4) No (1) ∨ (3)	∧ (4) No (1)	∧ (3) No (1)	∧ (4) No (1) ∨ (1)	∧ (3) ∨ (1)
- Wetland		No (1) ∨ (1)	∨ (1)	No (1) ∨ (1)	No (1) ∨ (1)
- Soil carbon stocks	No (1) ∨ (2)	No (1) ∨ (2)	No (1) ∨ (1)	∨ (3)	No (1) ∨ (1)
Pest control	∧ (1)		∧ (1)	∧ (1)	∨ (1)
Natural hazard regulation*					
- Forest fires / wildfires		∨ (1)	∨ (2)		∨ (1)
- Erosion, avalanche, landslide	∧ (2) ∨ (1)				
- Flooding	∨ (1)				
- Drought			∨ (1)		No (1) ∨ (1)
Water quality regulation		∨ (1)		∨ (1)	
Biodiversity	∧ (2) ∨ (4)	∧ (2) No (1) ∨ (4)	∧ (2) ∨ (4)	∧ (3) ∨ (2)	∧ (1) ∨ (8)
Sum of effects on regulating services	∧ (9) No (2) ∨ (11)	∧ (6) No (4) ∨ (9)	∧ (6) No (2) ∨ (9)	∧ (8) No (2) ∨ (8)	∧ (4) No (3) ∨ (14)
Cultural services:					
Recreation (fishing, nature enjoyment)		∨ (1)		∧ (1) ∨ (2)	∨ (1)
Tourism (skiing)	∨ (1)			∨ (1)	

	Alpine	**Atlantic**	**Continental**	**Northern**	**Southern**
Asthetic/heritage (landscape character, cultural landscapes)	∧ (1)	∨ (1)	No (1) ∨ (1)		∨ (1)
Sum of effects on cultural services	∧ (1) ∨ (1)	∧ (1) ∨ (1)	No (1) ∨ (1)	∧ (1) ∨ (3)	∨ (2)

Key:

∨ = decreasing impacts
∧ = increasing impacts
No = neutral effect
(1) = number in brackets refers to the number of studies supporting the change (increasing, decreasing, neutral) in ecosystem service.

Footnotes:

* 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 Section 23.6 and AR5 4.3.4.

References:

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

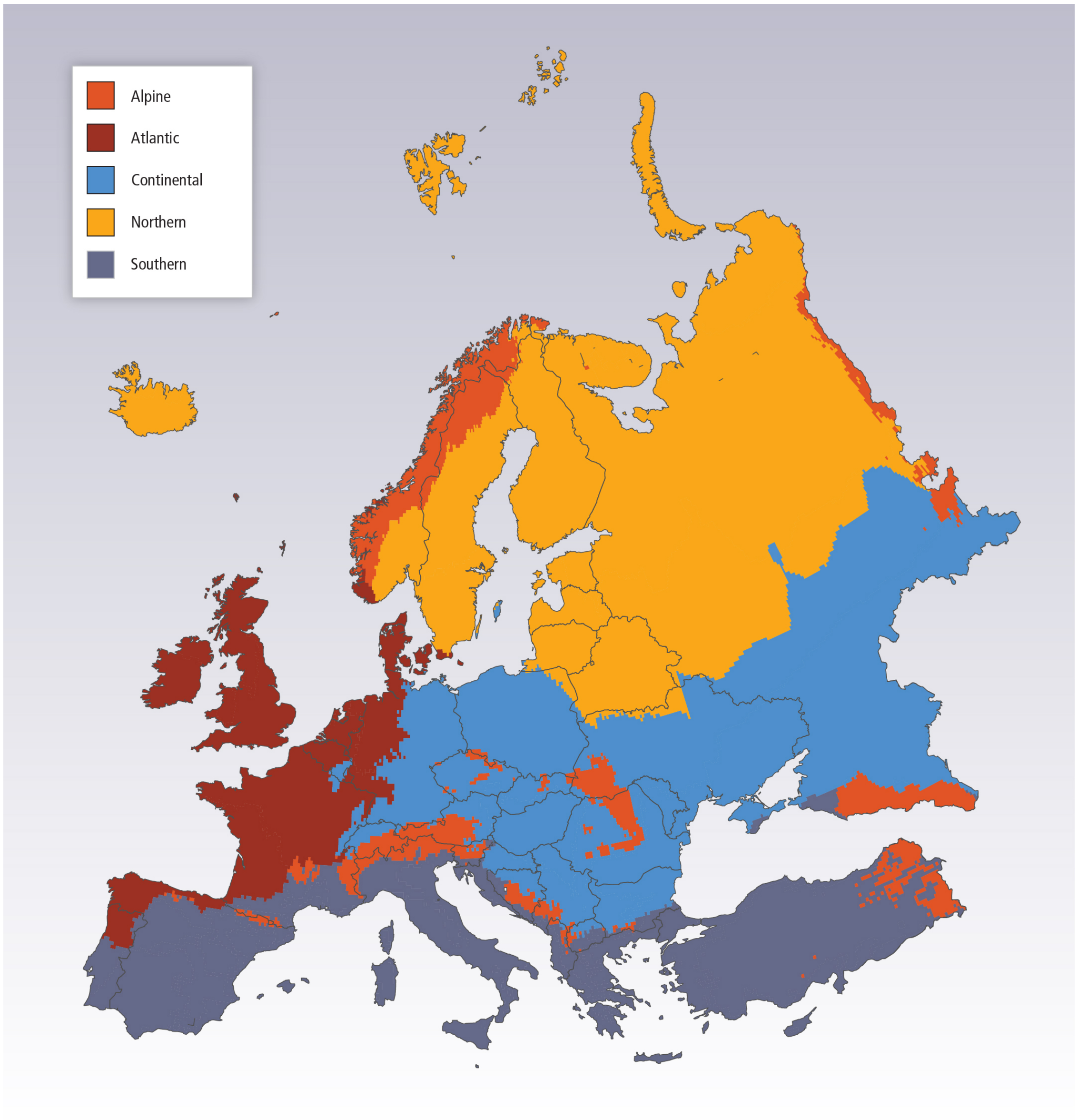


Figure 23-1: Sub-regional classification of the IPCC Europe region. Based on Metzger et al., 2005.

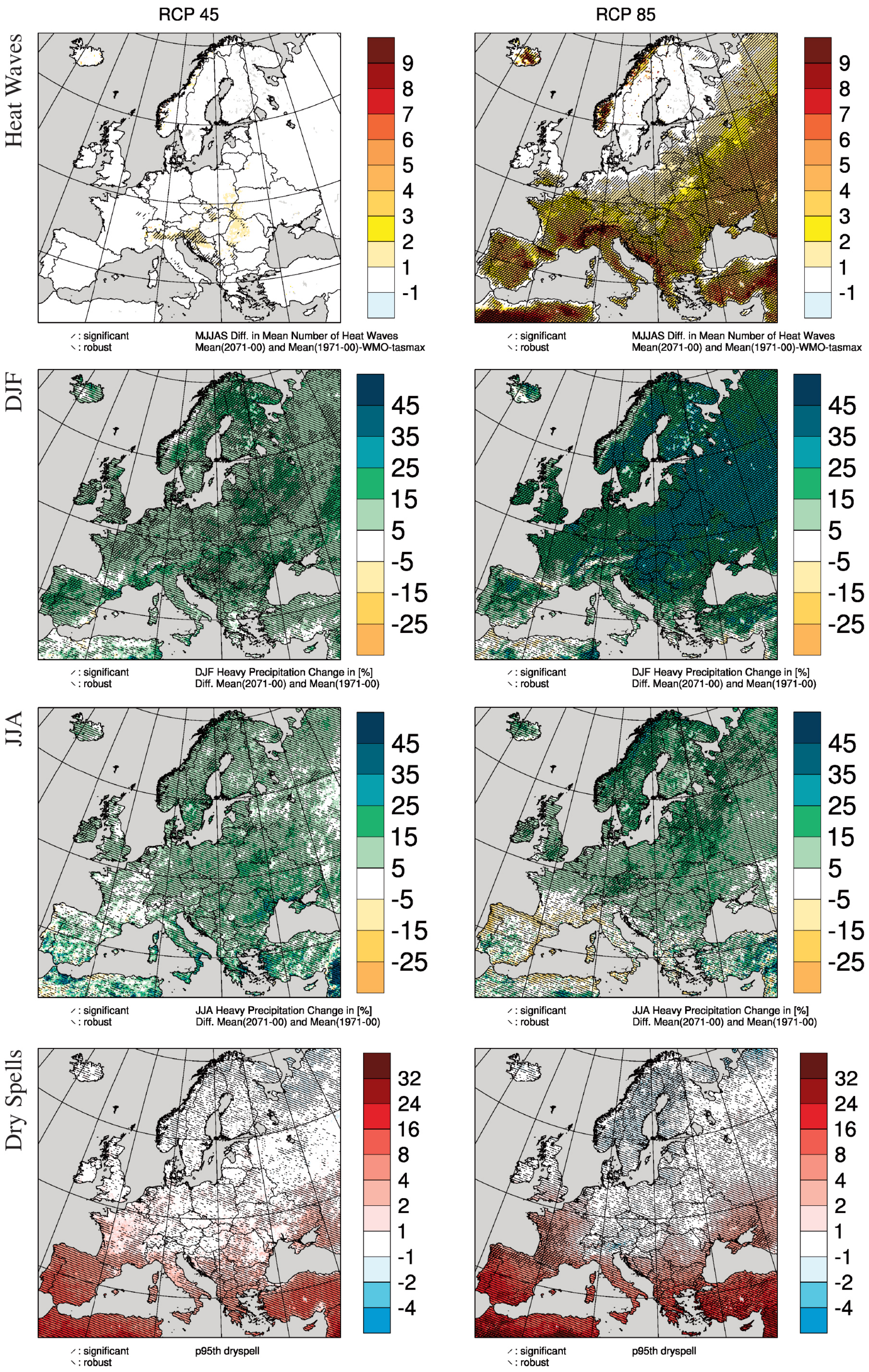

RCP 45
RCP 85
Heat Waves
9
8
7
6
5
4
3
2
1
-1
⟋: significant
⟍: robust
MJJAS Diff. in Mean Number of Heat Waves
Mean(2071-00) and Mean(1971-00)-WMO-tasmax
DJF
45
35
25
15
5
-5
-15
-25
DJF Heavy Precipitation Change in [%]
Diff. Mean(2071-00) and Mean(1971-00)
JJA
JJA Heavy Precipitation Change in [%]
Diff. Mean(2071-00) and Mean(1971-00)
Dry Spells
32
24
16
8
4
2
1
-1
-2
-4
p95th dryspell

Figure 23-2: First row: 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. Second and third rows: Projected seasonal changes in heavy precipitation defined as the 95th percentile of daily precipitation (only days with precipitation > 1mm/day are considered) for the period 2071-2100 compared to 1971-2000 (in %) in the months December to January (DJF) and June to August (JJA). Fourth row: 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 1mm. Hatched areas indicate regions with robust (at least 66% of models agree in the sign of change) and/or statistical 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 EURO-CORDEX initiative. Adapted from Jacob et al. (2013). **[Illustration to be redrawn to conform to IPCC publication specifications.]**

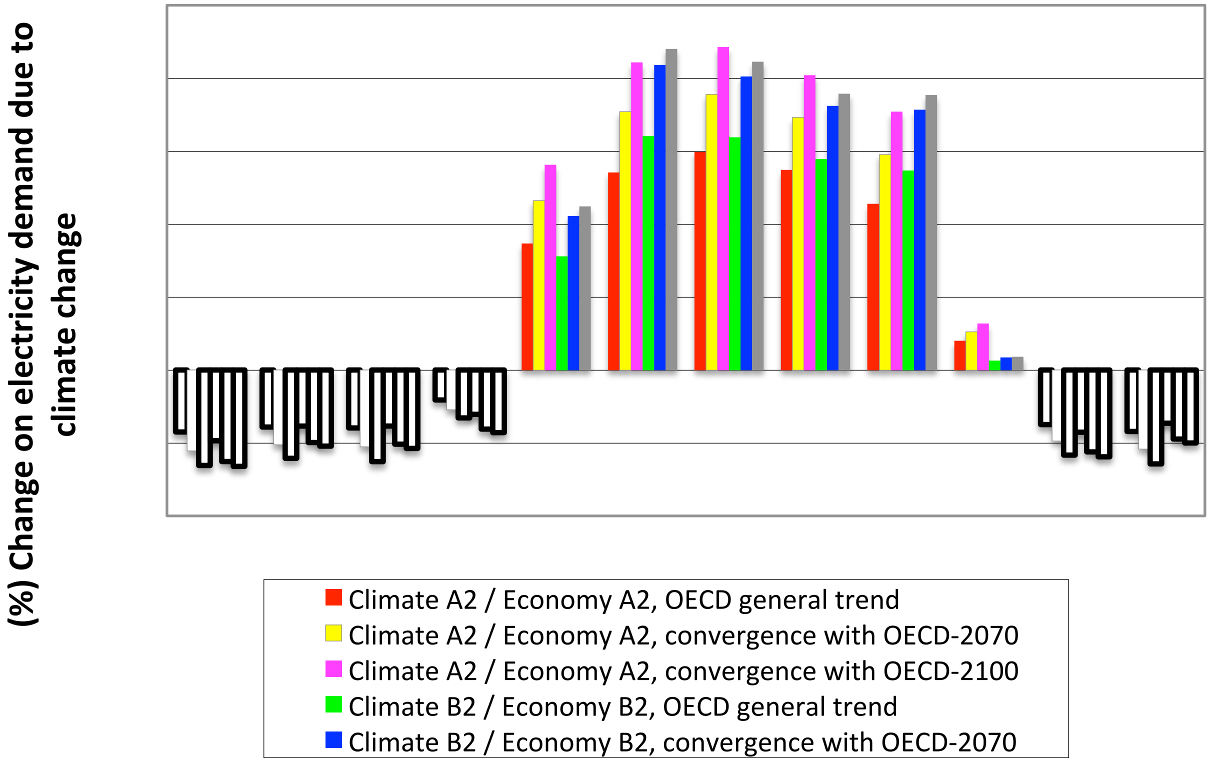
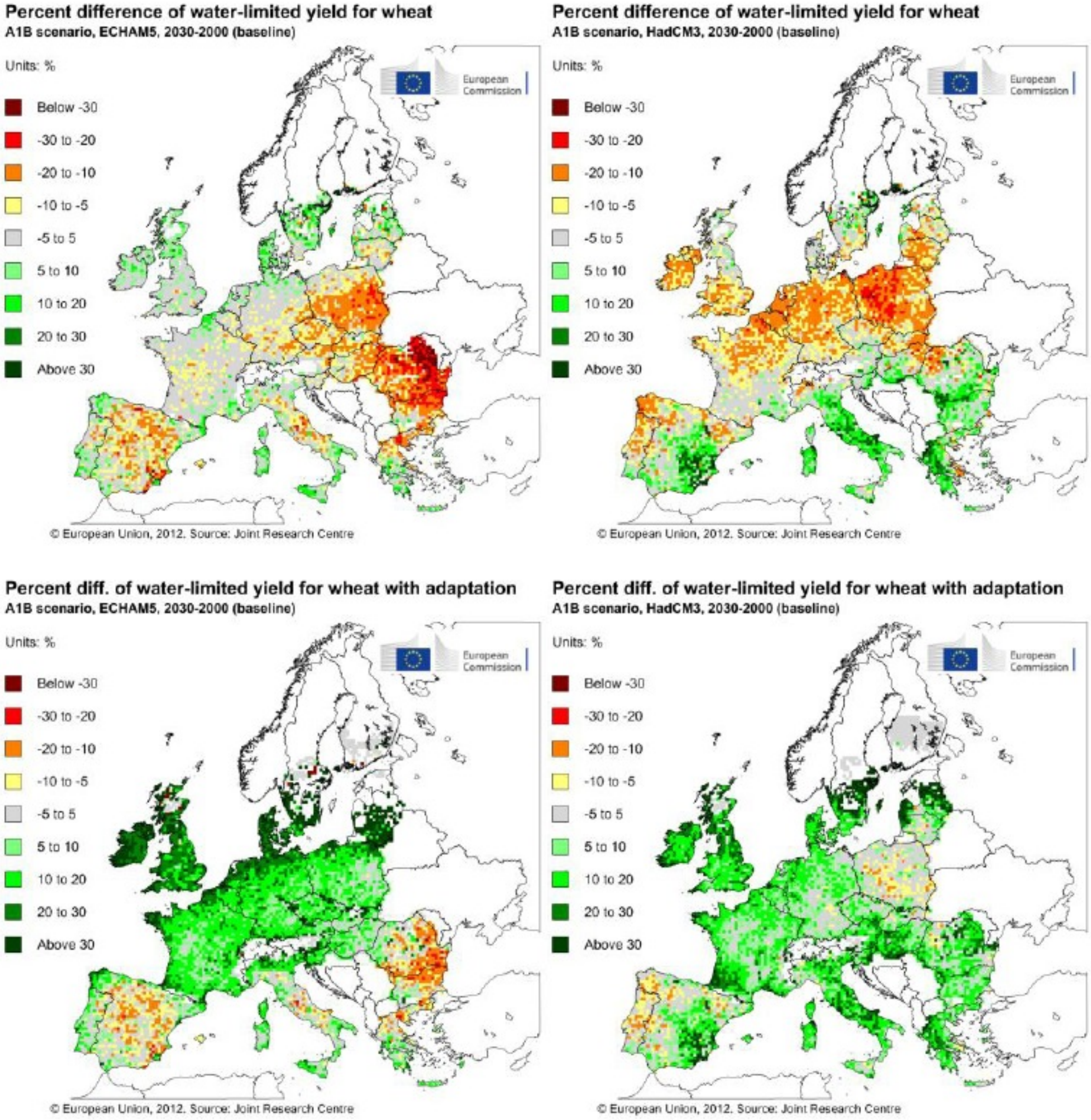


Figure 23-3: Percentage change in electricity demand in Greece attributable to climate change, under a range of climate scenarios and economic assumptions. Source: Mirasgedis et al., 2007.
[Illustration to be redrawn to conform to IPCC publication specifications.]



Percent difference of water-limited yield for wheat
A1B scenario, ECHAM5, 2030-2000 (baseline)

Percent difference of water-limited yield for wheat
A1B scenario, HadCM3, 2030-2000 (baseline)

Percent diff. of water-limited yield for wheat with adaptation
A1B scenario, ECHAM5, 2030-2000 (baseline)

Percent diff. of water-limited yield for wheat with adaptation
A1B scenario, HadCM3, 2030-2000 (baseline)

© European Union, 2012. Source: Joint Research Centre

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 ECHAM5 (left column) and HadCM3 (right) GCMs. Upper maps to do not take adaptation into account. Bottom maps include adaptation. Source: Donatelli et al., 2012.
[Illustration to be redrawn to conform to IPCC publication specifications.]

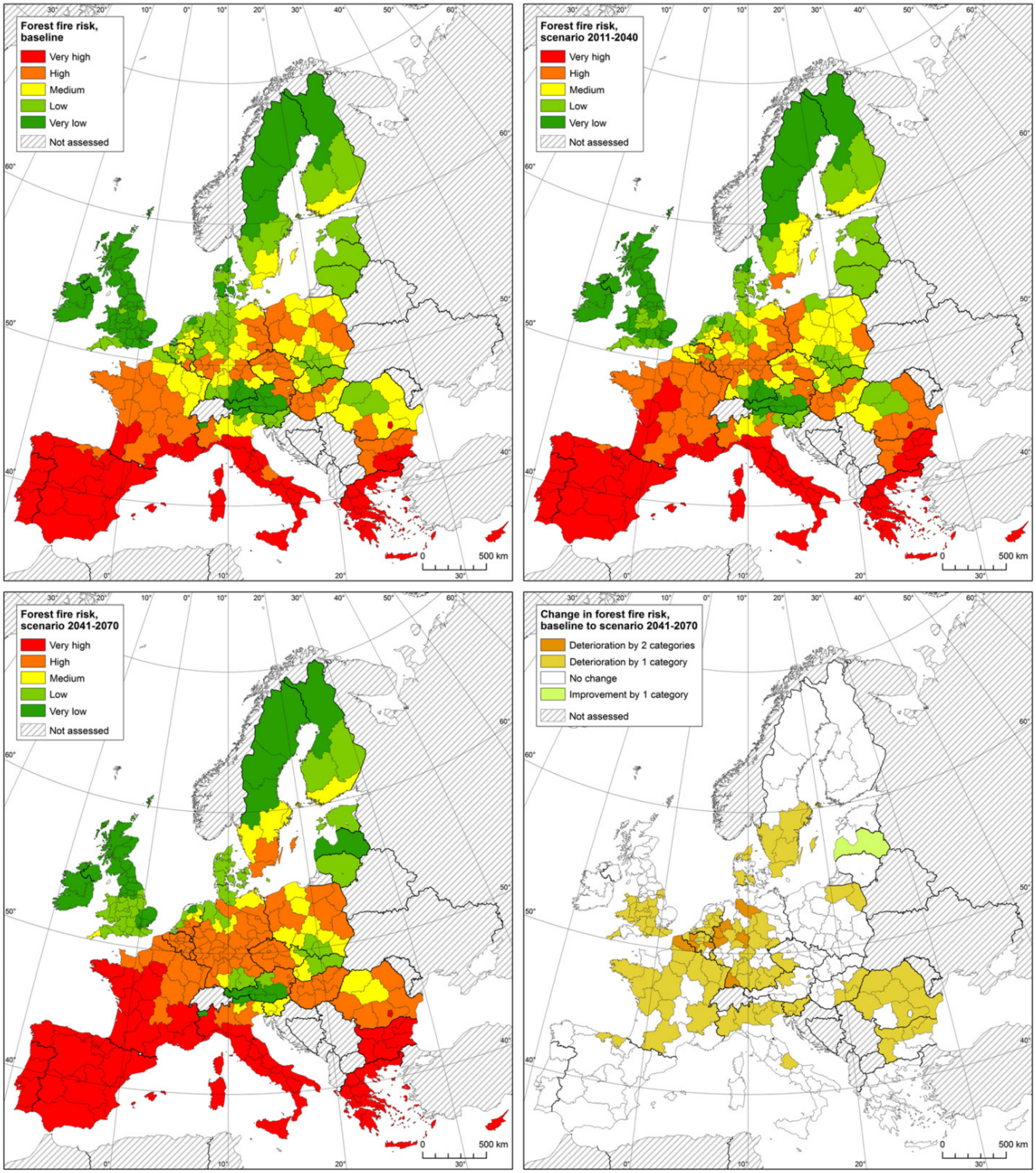


Figure 23-5: Changes in forest fire risk in Europe for two time periods: baseline (left) and 2041–2070 (right), based on high-resolution regional climate models and the SRES A1B emission scenario. Source: Lung et al., 2013. **[Illustration to be redrawn to conform to IPCC publication specifications.]**

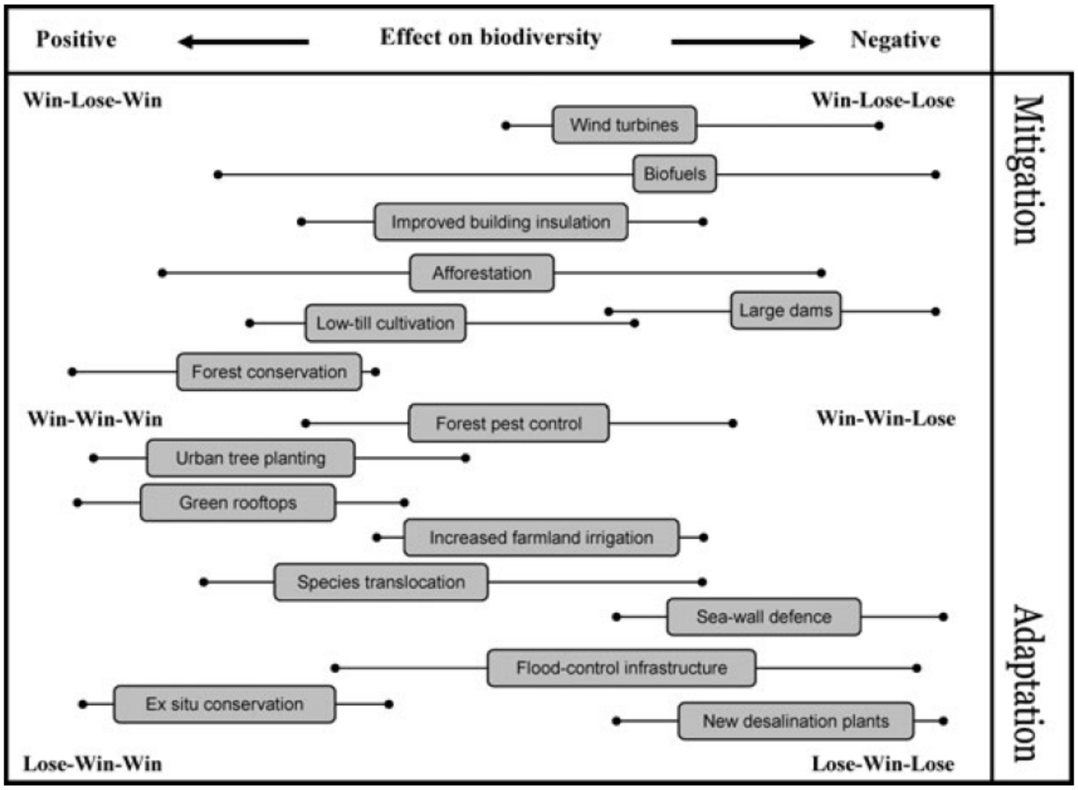


Figure 23-6: Adaptation and mitigation options and their effects on biodiversity. The horizontal axis ranges from positive effects on biodiversity (left-hand side) to negative effects (right-hand side). Each mitigation/adaptation option is located on the biodiversity effect axis (solid bars), including 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 centre of the vertical axis have benefits for both mitigation and adaptation. Thus, options located at the centre left of the figure have benefits for mitigation, adaptation and biodiversity and hence are labelled as 'win-win-win'. Other combinations of benefits and dis-benefits are labelled accordingly, e.g. win-lose-win, lose-win-lose, etc. Based on Paterson et al., 2009.

[Illustration to be redrawn to conform to IPCC publication specifications.]