Chapter 23. Europe

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Contents

Executive Summary

Observed climate trends and future projections confirm the main conclusions of AR4 regarding current and future climate change in Europe [23.2]: climate models project significant changes in temperature [high confidence] and rainfall [high confidence] in Europe [23.2.1] with increases in temperature projected throughout Europe and increasing precipitation in the North and decreasing precipitation in the South [23.2.2.2]. There will be a marked increase in the frequency and intensity of heat waves [high confidence], meteorological droughts [medium confidence] and heavy precipitation events [high confidence] with variations across Europe [23.2.2.3]; small or no change in wind speed extremes [low confidence] except increases in winter peak wind speed over Northern Europe [medium confidence] [23.2.2.3].

Climate change in Europe has already affected multiple sectors: distribution and composition of animals and plant species [high confidence] [Table 23.6, Table 23.4, 23.6.4]; crop yields in relation to European sub-regions [medium/high confidence] [23.4.1]; health, particularly in Southern Europe [medium confidence] [23.5.1]; forests due to increase of wildfires in Southern Europe [high confidence] and from storms [low confidence] [23.4.4] and European cultural heritage[low confidence] [23.5.4] [Table 23.6]. The observed impacts of extreme weather events indicates the current vulnerability of Europe across multiple sectors [Table 23.3]. Climate change will increase the frequency and intensity of heat waves, particularly in Southern Europe [high confidence] [23.2.2] with adverse implications for health, agriculture, energy production, transport, tourism, labour productivity, and built environment [Table 23.4].

Climate change in Europe will affect multiple sectors [Table 23-4]. All of the ecosystem services (Provisioning, Regulating and Cultural services) will be degraded by climate change at least in one or more European sub-regions. The most affected ecosystem services are: Cultural, Regulating and Provisioning services [Table 23.2].

Climate change will affect economic activity in southern Europe more than other sub-regions [medium confidence] [Table 23.4, 23.9.1], and increase future intra-regional disparity [low confidence] [23.9]. The Mediterranean (part of Southern region) 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]. Compared to AR4, there is more evidence of risks in northern Europe in several sectors. Shifts in agriculture production across sub-regions will occur [medium confidence]. Loss of ecosystem services is projected in Alpine regions [high confidence] [23.10].

Synthesis of evidence across sectors and subregions confirm that there are limits to adaptation from social, economic and technological factors [23.5]. Adaptation is further impeded because climate change affects multiple sectors [23.10]. The majority of assessments are based on climate projections driven by lower emissions than the current trajectory. Limited evidence exists potential impacts in Europe under high rates of warming (>3-4 degrees per century) [23.10], with the exception of some studies of crop yields.

Sectoral impacts
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 likely to further increase coastal and river flood risk in Europe and, if unabated, will substantially increase flood damages (monetary losses and people affected) [23.3.1, 23.5.1]. Adaptation can prevent most of the projected damages [high confidence – based on medium evidence, high agreement] [23.3.1; 23.7.1; 23.8.3]. Climate change will increase the problems associated with overheating in domestic housing [medium confidence] [section 23.3.2].

No significant impacts are projected before 2050 in winter or summer tourism except for ski tourism in low altitude and mid altitude sites and under limited adaptation [medium confidence] [23.3.6]. After 2050, tourism activity will decrease in southern Europe [low confidence] and increase in northern/continental Europe [medium confidence]. Artificial snowmaking will prolong the activity of some ski resorts [medium confidence] [23.3.6].

Climate change will 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 will reduce severe accidents in road transport [medium confidence] and adversely affect inland water transport particularly the Rhine in summer after 2050 [medium confidence]. Damages to rail infrastructure from high temperatures will increase [medium confidence]. Adaptation through maintenance and operational measures can reduce adverse impacts to some extent.

Climate change will decrease hydropower production from reductions in rainfall in all sub-regions except Scandinavia [high confidence] [23.3.4]. Climate change will have no impact on wind energy production before 2050 [medium confidence] and only a small impact after 2050 [low confidence]. Climate change will inhibit thermal power production during summer [medium confidence] [23.3.4]. Plant modifications and operational changes can reduce adverse impacts. Climate warming will decrease space heating demand [high confidence] and increase cooling demand [high confidence]; the income growth drives largest part of this increase during 2000-2050 period (especially in eastern regions) [medium confidence] [23.3.4]. Energy efficient buildings and cooling systems as well as demand-side management will reduce future energy demands [23.3.4].

Heat-related deaths and injuries will increase, particularly in Southern Europe [medium confidence] [23.5.1]. Climate change will change the distribution and seasonal pattern of some human infections, including those transmitted by arthropods [medium confidence]. The introduction of new infectious diseases due to climate change is unlikely [medium confidence] [23.5.1]. Climate change and sea level rise will damage European cultural heritage, including buildings, local industries, landscapes, and iconic places such as Venice [medium confidence] and some cultural landscapes will be lost forever [low/medium confidence] [23.5.4] [Table 23.5].

Climate change will alter the productivity of bioenergy crops in Europe by shifting their distribution northward [high 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 [medium confidence] [23.4.5].

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 will increase yields in Northern Europe [medium confidence] but decrease cereal yields in Southern Europe [high confidence] [23.4.1]. In Northern Europe, climate change will increase the seasonal activity of pests and plant diseases [high confidence] [23.4.1]. Climate change will adversely affect dairy production in Southern Europe because of heat stress in lactating cows [medium confidence] [23.4.2]. Climate warming has caused the spread of blue tongue disease in ruminants in Europe [high confidence] [234.2] and northward expansion of tick vectors [medium confidence] [23.4.2, 23.5.1].

Climate change will change the geographic distribution of wine grape varieties [high confidence] and this will reduce the economic value of wine products and the livelihoods of local wine communities in Southern and Continental Europe [medium/low confidence] [23.4.1, 23.3.5, 23.5.4]. Some adaptation is possible through technologies and good practice [Box 23-1].

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 [medium confidence]. System costs will increase under all climate scenarios [high confidence] [23.4.3]. Integrated management of water is needed to address future competing demands between agriculture, conservation and human settlements [23.7.2].

Observed warming has shifted sea fish species ranges to higher latitudes [high confidence] and reduced body size in species [low confidence] [23.4.6]. Climate change will not decrease net fisheries economic turnover in some parts of Europe (e.g. Bay of Biscay) [low confidence] due to introduction of new (high temperature tolerant) species. Climate change will not entail relocation of fishing fleets [high confidence] [23.4.6]. Observed higher water temperatures have adversely affected both wild and farmed freshwater salmon production [high confidence] [23.4.6]. High temperatures will increase frequency of harmful cyanobacterial blooms [medium confidence] [23.4.6].

Climate warming has adversely affected trends in ground level tropospheric ozone [low confidence] [23.6.1.]. Climate change will increase the frequency of tropospheric ozone events (exceedences) in the future [low confidence] even assuming future emissions reductions [23.6.1]. Climate change will decrease surface water quality due to higher temperatures [medium confidence] [23.6.3]. There is little evidence regarding the effect of climate change on soil erosion, salinisation or soil fertility [23.6.2].

Observed climate warming has increased forest productivity in northern Europe [medium confidence] [23.4.4] and fire incidence in southern Europe [high confidence] [23.4.4]. Climate change will increase damage from pests and diseases in all sub-regions [high confidence] [23.4.4] and damage from wildfires in Southern Europe [high confidence] and from storms [low confidence] [23.4.4]. Climate change will cause ecological and socio-economic damages from shifts in forest tree species range, with a general trend of a south-west to north-east [medium confidence], and in pest species distributions [low confidence] [23.4.4]. Short-term and long-term strategies in forest management may be an adequate measure to enhance ecosystem resistance and resilience [medium confidence] [23.4.4].

Observed climate change is affecting a wide range of flora and fauna, including plant pests and diseases [medium confidence] [23.4.1, 23.4.4] and the vectors of animal diseases [medium confidence] [23.4.3]. Climate change will cause changes in habitats and species, with local extinction [high confidence] and continental scale shift in Europe [medium/low confidence] [23.6.4]. The habitat of alpine plants will 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]. The introduction and expansion of invasive species, especially those with high migration rates, from outside Europe will increase with climate change [medium confidence] [23.6.4]. Climate change will entail the loss or movement of coastal wetlands [high confidence] [23.6.5]. Conservation policies and selection of protected areas have not considered so far impact of climate changes. Biodiversity is affected in unprotected areas more than in protected areas but Natura 2000 areas retain climate suitability for species no better and sometimes less effectively than unprotected areas [low confidence] [23.6.4].

Cross-sectoral adaptation

The capacity to adapt in Europe will be higher than for other world regions, but there are important differences in impacts and the capacity to respond within the European sub-regions. In Europe, adaptation policy has been developed at international (EU), national and local government level [23.7] but so far evidence relates to studies of the prioritisation of options, and there is limited systematic information on current implementation (or effectiveness) [Box 23-2]. 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 little evidence of adaptation planning in rural development or land-use planning [23.7.4; 23.7.5]. Economic estimates for adaptation requirements in Europe are available and increasingly from detailed bottom-up sector-specific studies for coastal defences, energy production, energy use, and agriculture [23.7.6]. The costs of adapting dwellings or upgrading coast defence will increase under all scenarios [high confidence] [23.3.2].

There are opportunities for policies that improve adaptive capacity and also help meet mitigation targets [23.8]. Some agricultural practices can potentially mitigate GHG emissions and at the same time adapt crops to increase resilience to temperature and rainfall variability [23.8.2]. Climate policy in transport and energy sectors to reduce emissions can improve population health [23.8.3] [high confidence]. However there are also potential for unintended consequences of mitigation policies in the built environment (especially housing) and energy sectors [23.8.1].

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 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 from 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 according to compare impacts across (rather than within) sub-regions, however, 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 climate sensitivity, 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 and social welfare and;
- protection of environmental quality and biological conservation.

The benefit of assessing evidence in a regional chapter is that integrated impacts across sectors can be described, as well as cross-sectoral decision making required to address many climate change issues.

The chapter also 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 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 [see supplemental information for list of countries in each group].

This chapter includes several sections that were not in AR4. Because many adaptation and mitigation policies are now in place in Europe, the evidence for potential co-benefits and unintended consequences of such strategies is reviewed (Section 23.8). The implications of climate change for the distribution of economic activity within European region is discussed in Section 23.9. The final section synthesise the key findings with respect to: observed impacts of climate change, key vulnerabilities and identifies research gaps.

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 23-2 on national adaptation policies). The EU Adaptation Platform catalogues adaptation actions reported by Member States. The EU adaptation strategy is due in March 2013. See Chapter 15 for a more extensive discussion of institutions and governance in relation to adaptation planning and implementation in Europe.

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 was expected to magnify regional differences within Europe for natural resources (in particular 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 integrated comprehensive, or evaluated (AR4 WG2 12.8).

23.2. Current and Future Trends

23.2.1 Non- Climate Trends

Countries in the European region are diverse with respect to both demographic and economic trends. Population health and welfare in all European countries has been improving, with reductions in adult and child mortality rates. However, inequalities both within and between countries in Europe persist (Marmot *et al.*, 2012). Population is generally increasing in the EU27 countries, primarily due to net immigration although population growth is slow (total and working age population) (Rees *et al.*, 2012). Some countries, including the Russian Federation, have had decreases in population since the 1990s. Migration pressure into Europe is increasing (Eurostat, 2011a) but within the EU27 movement between countries is encouraged as part of economic policy. The ageing of the population is a significant trend in Europe, as in all high income populations. This will have both economic and social implications, and many regions are likely to experience a decline in labour force (Rees *et al.*, 2012).

Since AR4, economic growth has slowed (or stalled) in several European countries. In some countries, this has been associated with 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 will probably lead to some modification of the economic outlook and may affect future social protection policies (with implications for adaptation).

Agriculture is the most dominant European land use and. Europe is one of the world's largest and most productive suppliers of food and fibre. Rapid changes to farming systems in the post-war decades allowed an unprecedented increase in agricultural productivity, but also had a number of negative impacts on the ecological properties of agricultural systems, such as carbon sequestration, nutrient cycling, soil structure and functioning, water purification, and pollination. Most scenario studies suggest that agricultural land areas will continue to decrease in the future as they have done over the past 50 years (see Busch (2006) for a discussion). Agriculture accounts for 22 % of total national freshwater abstraction in Europe and more than 80 % in some southern European countries (EEA, 2009). Limited water availability is already a significant problem in many parts of Europe and the situation is likely to deteriorate further in future decades. 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). 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).

The forested areas of Europe account for 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. It is also very likely that increasing temperatures and CO_2 concentrations, nitrogen deposition, and the reduction of air pollution (SO_2) have had a positive effect on forest growth. Land use scenarios suggest that forested areas will expand 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 increased numbers of fires, is already contributing to an increased risk of desertification. Projected risks for future desertification are the highest in the same areas (EEA-JRC-WHO, 2008).

Europe has relatively moderate urban sprawl levels. Urbanisation 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, GDP 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. A recent past and likely future trend in Europe is peri-urbanisation in which residents move out of cities to locations with a rural character, but retain a functional link to cities by commuting for employment purposes (Reginster and Rounsevell, 2006) (Rounsevell and Reay, 2009). Other important environmental trends include improvements in outdoor air quality and declines in water quality (eutrophication) in some areas (ELME, 2007).

Several scenario studies have been completed for Europe covering socio-economic indicators (Mooij de and Tang, 2003), land use (Verburg *et al.*, 2010; Letourneau *et al.*, 2012)(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), economics (Dammers, 2010) and European policy trends (Helming *et al.*, 2011)(Lennert and Robert, 2010). Many of these scenario studies also account for future climate change (see Rounsevell and Metzger (2010) for a review). Long term projections (to the end of the century) will be 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.*, 2012). Probabilistic representation of socio-economic futures have been developed for agriculture and land use change at the global scale level including Europe (Baumanns *et al.*, 2012; Hardacre *et al.*, 2012), although a lack of evidence remains about the use of probabilistic information (Bryson et al., 2010) or scenarios in general for policy making.

23.2.2. Observed and Projected Climate Change

23.2.2.1. Observed Climate Change

The average temperature in Europe has continued to increase, but with regionally and seasonally differences in the rate of warming. Since the 1980s, warming has been strongest over Scandinavia, especially in winter, whereas the Iberian Peninsula warmed mostly in summer (Haylock *et al.*, 2008). The decadal average temperature over land area for the period 2002-2011 is 1.3°C+/- 0.11°C above the 1850-1899 average (EEA, 2012), based on HadCRUT3 {{1535 Brohan, P. 2006}}, MLOST {{1537 Smith, T.M. 2008}} and GISSTemp {{1536 Hansen, J. 2010}}. Consistent with previous trends, the rate of warming has been greatest in high latitudes in Northern Europe (see also Polar Regions chapter 28). Observed regional climate change is also described in Chapter 21.

High-temperature extremes (hot days, tropical nights, and heat waves (Vautard R et al, 2013) have become more frequent, while low-temperature extremes (cold spells, frost days) have become less frequent in Europe (EEA, 2011). The recent cold winters in northern and western Europe reflect the high natural variability in the region (Peterson *et al.*, 2012), 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). These two heat waves revised the seasonal temperature records over approximately half of Europe.

Annual precipitation trends in the 20th century showed an increase in Northern Europe (10–40%) and a decrease in some parts of Southern Europe (up to 20 %) (EEA, 2008)(Del Rio *et al.*, 2011). At the continental scale, winter snow cover extent has a high variability and a non significant negative trend over the period 1967-2007 (Henderson and Leathers, 2010). For a more detailed assessment on regional observed changes in temperature and precipitation extremes (see Table 3-2 of SREX, (Berg *et al.*, 2013). Windspeeds have declined over Europe over the last decades (Vautard *et al.*, 2010) but there is a *low confidence* in this trend due to problematic anemometer data and climate variability (SREX, section 3.3).

Europe is marked by increasing mean sea level with regional variations, except in the Baltic sea where the relative sea level decreases due to vertical crustal motion (Haigh *et al.*, 2010; Menendez and WoodWorth, 2010; Albrecht *et al.*, 2011; EEA, 2012). Extreme sea levels increased due to mean sea level rise (*medium confidence*, SREX, section 3.5, (Haigh *et al.*, 2010; Menendez and WoodWorth, 2010). Few studies exist on waves (SREX, section 3.5, (Charles *et al.*, 2012) leading to a *low confidence* (based on poor evidence) of anthropogenic influence on the observed trends.

23.2.2.2. Projected Climate Changes

There is now more knowledge about the range of possible future climates in Europe, particularly sub-regional information from high resolution climate model output and downscaling (WGII Chapter 21). Within the recognized limitations of climate projections (see WGI Annex 1 (Atlas) and WGII Chapter 21), new research on inter-model comparisons have provided a more robust range of future climates with which to assess future impacts (WGI Chapter 9). Since AR4, climate impact assessments are able to use a range of temperature and rainfall changes rather a single average measure (ensemble mean). Europe is fortunate to have access to comprehensive and detailed sets of climate projections for decision making (SREX, section 3.2.1, (Mitchell *et al.*, 2004)(Fronzek *et al.*, 2012; Jacob *et al.*, 2013).

Even under a climate warming 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). Climate models show significant agreement in warming (magnitude and rate) all over Europe, with strongest warming in Southern Europe in summer, and in Northern Europe in winter (Kjellström *et al.*, 2011)(Goodess *et al.*, 2009)(Schmidli *et al.*, 2007).

Precipitation signal is regionally and seasonally very different. Trends are less clear, but agreement in precipitation increase in Northern Europe and decrease in Southern Europe, the zone in between has less clear sign of change (*medium confidence*) (Kjellström *et al.*, 2011). Changes in the annual cycle indicate a decrease in precipitation in the summer months up to Southern Sweden, an increase in winter precipitation with more rain than snow and a decrease of long term mean snow pack (although snow-rich winters will remain) (Räisänen and Eklund, 2011). There is lack of information about past and future changes in hail occurrence. Changes in future circulation patterns are inconsistent, except in Northern Europe (Beck *et al.*, 2007)(Kjellström *et al.*, 2011)(Pryor and Barthelmie, 2010)(Pryor and Schoof, 2010)(Rockel and Woth, 2007)(Ulbrich *et al.*, 2009). Mean wind speed trends are rather uncertain due to shortcomings in wind simulations in GCMs (SREX and (McInnes *et al.*, 2011)).

Recent results highlight that regional coupled simulations over the Mediterranean region provide a better characterization of impact parameters, such as snow cover and aridity index. These simulations have detected changes in key impact indicators, such as snow or river discharge, which were not revealed by CMIP3 global simulations (Dell'Aquila *et al.*, 2012).

For the period 2081-2100 (compred to 1986-2005) the projected global sea level rise is 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*, WG1, section 13.7.2). However, at the regional scale, changes can differ from the mean changes (Slangen *et al.*, 2012). There is a *low confidenc*e on projected regional changes (WG1, 13.7). Some high-end (low probability/high impact) estimates of extreme mean sea-level rise projections have been made for The Netherlands (Katsman *et al.*, 2011), indicating 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.

23.2.2.3. Projected Changes in Climate Extremes

There will be a marked increase in many types of extremes in Europe, in particular, in heat waves, droughts and heavy precipitation events (WGII Chapter 21, Lenderink and Van Meijgaard, 2008). Table 23-1 describes projected changes of selected climate parameters and climate indices for the period 2071-2100 with respect to 1971-2000, spatially averaged for the five Europe sub-regions.

[INSERT TABLE 23-1 HERE
Table 23-1: Projected Changes of Selected Climate Parameters and Indices[1] for the Period 2071-2100 with Respect to 1971-2000 Spatially Averaged for Europe Subregions. A) A1B scenario. Numbers are based on 9 (indicated with*) and 20 (indicated with **) regional model simulations taken from EU-ENSEMBLES project for the SRES A1B emission scenario. The likely range defines the range of 66% of all projected changes around the ensemble median. B) RCP4.5 scenario. Numbers are based on 7 (indicated with *) and 8 (indicated with **) regional model simulations taken from EURO-CORDEX project for the RCP 4.5 emission scenario. The likely range defines the range of 66% of all projected changes around the ensemble median.]

A detailed assessment on extremes in the future climate is reported in WGII Chapter 21 and SREX. 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 shows projected changes in the mean number of heat waves in an extended summer season for the period 2071-2100 compared to 1971-2000 for SRES A1B and RCP4.5 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, 2009).

Changes in extreme precipitation depend on the region, with a *high confidence* of increased extreme precipitation in Northern Europe (all seasons) and Central Europe (except summer). Future projections are inconsistent in Southern Europe (all seasons) (SREX Table 3-3). Figure 23-3 shows projected seasonal changes of heavy precipitation events for the period 2071-2100 compared to 1971-2000 for SRES A1B and RCP4.5.

[INSERT FIGURE 23-2 HERE
Figure 23-2: 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 season) (Jacob et al, 2013). Heat waves are defined as periods of more than 5 consecutive days with daily maximum temperature exceeding the daily maximum temperature of the May to September season of the control period (1971-2000) by at least 5°C. 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 part of Turkey, unfortunately no regional climate model projections are available. A) Changes represent average over 9 regional model simulations (A1B) taken from the EU-ENSEMBLES project. B) Changes represent average over 8 regional model simulations (RCP4.5) taken from the EURO-CORDEX project.]

[INSERT FIGURE 23-3 HERE
Figure 23-3: Projected seasonal changes of 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 (%) (Jacob *et al.*, 2013). For the eastern parortunately no regional climate model projections are available. The figures are sorted as follows: left side (DJF, JJA) and right side (MAM, SON). 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). A) Changes represent average over 20 regional model simulations (A1B) taken from the EU-ENSEMBLES project. B) Changes represent average over 7 regional model simulations (RCP4.5) taken from the EURO-CORDEX project.]

A number of studies based of GCMs and RCMs exhibit a small tendency toward increased extreme wind speed (A1B scenario, 2081-2100 relative to 1981-2000) in Northern Europe in winter in relation to changes in storm tracks (*medium confidence*, SREX, Figure 3-8 (Pinto *et al.*, 2007a; Pinto *et al.*, 2007b)(Rockel and Woth, 2007)(Donat *et al.*, 2010)(Pinto *et al.*, 2010)(Rauthe *et al.*, 2010)(Schwierz *et al.*, 2010)(Donat *et al.*, 2011)(McInnes *et al.*, 2011)(Haugen and Iversen, 2008). Over northern Europe small increase in winter peak wind speed is projected (WGII chapter 21, 21.4.1.1.3). In other parts of Europe, changes are inconsistent.

Extreme sea level events will increase (*high confidence*, WG1, 13.8, SREX 3.5.3), mainly dominated by the global mean sea level increase. Storm surge 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 British Isles and Ireland (Debernard and Rÿed, 2008)(Wang *et al.*, 2008), except South of Ireland (Wang *et al.*, 2008). There is *medium agreement* for the South of North Sea and Dutch coast were 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.*, 2012)(Planton *et al.*, 2011).

23.2.3. Observed and Projected Trends in the Riverflow and Drought

Observed changes have occurred in river discharges in response to changing precipitation patterns and glacier mass balances (AR5 WG2 Chapter 3). Streamflows have decreased in the south and east of Europe and increased in northern Europe in small natural catchments (Stahl *et al.*, 2010)(Wilson *et al.*, 2010)(AR5 WG2 3.2.3). In general, there are large uncertainties in establishing flood trends in Europe (Kundzewicz *et al.*, 2013). In France, upward trends in low flow indices were observed over 1948-1988 and downward trends over 1968-2008 (Giuntoli *et al.*, 2013). Some studies show increases in extreme river discharge (peak flows) 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 Northwestern France (Renard *et al.*, 2008); other studies show decreases in extreme discharges, for example, in the Czech Republic (Yiou *et al.*, 2006), or no change (Switzerland; (Schmocker-Fackel and Naef, 2010); Germany; (Bormann *et al.*, 2011). This pattern fits with analyses at the European level, because the high variability of extreme discharges is driven by atmospheric circulation variations (Bouwer *et al.*, 2008) (Kundzewicz *et al.*, 2010) [see also SREX report, AR5 WG2 Chapter 3]. One study suggests that river training partly masks increasing flood flows in the Rhine basin (Vorogushyn *et al.*, 2012). The attribution of the UK 2000 summer flood to anthropogenic forcing was proposed by (Pall *et al.*, 2011) although later study has shown a weaker effect (Kay *et al.*, 2011).

Future climate change is projected to affect future hydrology of river basins [SREX report, AR5 WG2 Chapter 4]. Europe wide analyses indicate increases in the occurrence of high river discharges (100-year return period) in Continental Europe, but decreases in some parts of Northern and Southern Europe (Dankers and Feyen, 2008)(Rojas *et al.*, 2012). In contrast, studies of future changes in individual catchments indicate increases in the occurrence of 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 (Lenderink *et al.*, 2007)(Te Linde *et al.*, 2010a)(Krahe *et al.*, 2009; Hurkmans *et al.*, 2010), the Meuse basin (Leander *et al.*, 2008)(Ward *et al.*, 2011), the Danube basin (Dankers *et al.*, 2007), and French Mediterranean basins (Quintana-Segui *et al.*, 2011). Substantial declines in low flows could occur in the UK (Christierson *et al.*, 2012), as well as in Turkey (Fujihara *et al.*, 2008).

Lack of observational data,and the complex definitions related to different perspectives (meteorological, agricultural, hydrological, socioeconomic) of droughts make the analyses of observed changes in drought characteristics difficult (SREX, Chapter 3, Box 3-3). Southern Europe has experienced trends towards more intense and longer droughts, but they are still inconsistent (Sousa *et al.*, 2011). Drought trends in all other subregions were not statistically significant (SREX chapter 3, section 3.5.1). Regional and global climate simulations project (with medium confidence) an increase in duration and intensity of droughts in central and southern Europe and the Mediterranean region (Gao and Giorgi, 2008; Feyen and Dankers, 2009; Vidal and Wade, 2009)(Tsanis *et al.*, 2011) WG2 Chapter 21) using different definitions of droughts (see also SREX chapter 3, section 3.5.1). In a study by

Wong et al. (Wong *et al.*, 2011) it is shown that even in regions where summer precipitation is expected to increase, soil moisture and hydrological droughts may become more severe due to increasing evapotranspitation.

Figure 23-4 illustrates projected changes the length of dry spells for the period 2071-2100 compared to 1971-2000 (in days) for SRES A1B and RCP4.5. For A1B emission scenariothe projected increase in dry spells is much larger in Southern Europe.

[INSERT FIGURE 23-4 HERE
Figure 23-4: Projected changes in the 95th percentile of the length of dry spells for the period 2071-2100 compared to 1971-2000 (in days) (Jacob et al., 2013). Dry spells are defined as periods of at least 5 consecutive days with daily precipitation below 1mm. For the eastern part of Turkey, unfortunately no regional climate model projections are available. 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). A) Changes represent average over 20 regional model simulations (A1B) taken from EU-ENSEMBLES project. B) Changes represent average over 7 regional model simulations (RCP4.5) taken from EURO-CORDEX project.]

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

23.3.1. Settlements

New studies since AR4 confirm that European urban areas and related production systems, physical infrastructure and human settlements, are at risk (combination of hazard probability, exposure and vulnerability) from changes in weather extremes, such as flooding, mass movements, and wildfires (see section 23.4.4). Europe currently has a high flood risk, due to the presence of highly urbanised areas in river basins and on coastlines. New studies since AR4 confirm that climate change is likely to increase flooding (coastal, river and pluvial) in Europe in some areas, even with an upgrade of flood defences. Risk assessments have attempted to quantify more policy-relevant outcomes, such as population at risk of flooding and economic damage costs and health and environmental outcomes. New risk assessments have also included economic growth and population growth.

23.3.1.1. Coastal Flooding

Extreme sea level events and coastal flood risk are projected to increase in Europe [Section 23.2.2, SREX report, AR5 WG2 Chapter 5] and remain a key challenge for several major European cities (Nicholls *et al.*, 2008)(Hallegatte *et al.*, 2008)(Hallegatte *et al.*, 2011). Important energy infrastructure, including 158 major oil and gas infrastructure and terminals, and 71 operating nuclear reactors are located at exposed coastal locations (Brown *et al.*, 2013). Climate change may increase the frequency of severe storm surges, particularly in north-western Europe (see Section 23.2.2.3). Upgrading coastal defences would substantially reduce the impacts and damage costs (Hinkel *et al.*, 2010). Without adaptation, the number of people affected by coastal flooding in the 2080s is projected to increase in the range of 775,000 to 5.5 million people per year in the EU27 under the SRES B2 and A2 scenarios (Ciscar *et al.*, 2011). The Atlantic, Northern and Southern European regions are projected to be most affected by coastal floods. 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 wider costs being higher (Bosello *et al.*, 2012). The highest damage costs are estimated for the Netherlands, Germany, France, Belgium, Denmark, Spain and Italy (Hinkel *et al.*, 2010).

Changes in future flood losses due to climate change have also 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), port cities including Amsterdam and Rotterdam (Hanson *et al.*, 2011), and the Netherlands (Aerts *et al.*, 2008). The increasing cost of insurance and unwillingness of investors to place assets in affected areas is a potential growth impediment to the economy in coastal regions and islands (Day *et al.*, 2008). One study estimated that a 1m sea-level rise in Turkey would potentially affect 3 million additional people and put 12 billion USD capital value at risk, with adaptation costs at around 20 billion (10% of GNP) (Karaca and Nicholls). In Poland, up to 240,000 people would be affected by increasing flood risk on the Baltic coast (Pruszak and Zawadzka, 2008).

23.3.1.2. River and Pluvial Flooding

The observed increased trend in flood disasters and flood damages in Europe is well documented (see 18.4.2.1 for detailed discussion), however, the main cause of the increase is increased exposure of persons and property in flood risk areas (Barredo, 2009). Several new studies provide estimates of the impact of changing precipitation patterns on future economic losses from river flooding, with uncertainties depending on modelling approaches and scenarios (Bubeck *et al.*, 2011). In particular, studies now also quantify the contribution of changes in population and economic growth, generally indicating this contribution to be about equal or larger than climate change per se (Feyen *et al.*, 2009)(Maaskant *et al.*, 2009)(Bouwer *et al.*, 2010)(Te Linde *et al.*, 2011)(Rojas *et al.*, 2012). These studies indicate that 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). A European (EU15) analysis estimated that river flooding could affect 250,000-400,000 additional people by the 2080s, and lead to more than a doubling of annual average damages, with the main increases projected in Central Northern Europe and the UK (Ciscar, 2009)(Ciscar *et al.*, 2011). When economic growth is included with projected flood frequency changes, river flood losses in Europe were projected to increase 17-fold under the A1B scenario (Rojas *et al.*, 2012).

Few studies have estimated future damages from inundation in response to an increase in intense rainfall (Hoes, 2006). Processes that influence flash flood risks 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 only partly offset anticipated impacts from intense rainfall (Zhou *et al.*, 2012).

23.3.1.3. Mass Movements

Very few studies are available on observed trends or future projections in the frequency of landslides (Crozier, 2010). Landslides are strongly connected to intense precipitations and the local conditions of slope stability. In the European Alps, an apparent increase in the frequency of rock avalanches and large rock slides was documented over the period 1900-2007 (Fischer *et al.*, 2011) and also projected an increase in the frequency for landslides for the future (Huggel *et al.*, 2010), while (Jomelli *et al.*, 2007) and Huggel et al. (Huggel *et al.*, 2012) describe a complex response to climate change. Some land use practices changes have led to increased landslide hazards, counterbalancing favourable climate trends, as reported in Calabria (Polemio and Petrucci, 2010) and in the Apenines (Wasowski *et al.*, 2010). There is a medium confidence that landslides that are related to glacier retreat and temperature will be affected by climate change. The evolution of precipitation driven phenomena such as shallow landslides is rather uncertain because of the difficulty to estimate local precipitation trends with accuracy and other factors such as land use. A study of the Mam Tor landslide in the UK indicated a possible increase in stability towards 2100 in response to rainfall changes (Dixon and Brook, 2007). Climate warming may have contributed to the observed decrease in the frequency of snow avalanches in the Alps (Eckert *et al.*, 2010)(Teich *et al.*, 2012), although one study suggest that conditions for avalanches may become more favourable with warming in the future (Castebrunet *et al.*, 2012).

23.3.2. Housing

Housing infrastructure in Europe is vulnerable to extreme weather events. Despite a wide body of literature on the thermal modelling of the existing housing stock, exactly why and how dwellings currently overheat is uncertain (Crump *et al.*, 2009) and there is very little observational data as to the actual extent of current overheating in countries in Europe. Buildings that were originally designed for certain thermal conditions will need to function in a drier and hotter climate in the future (WHO, 2008). The impact of rising temperatures on comfort (and hence energy demand for cooling and heating) is well understood. Climate change in Europe seems set to result in increased use of cooling energy and reduced use of heating energy. For example, a study of energy demand in Slovenia (Dolinar *et al.*, 2010) projected reductions of energy use for heating of up to 25% depending on the region but up to six times more energy for cooling. More estimates of changes in summer and winter energy demand are described below in

Energy Section, although the assumptions regarding future air conditioning uptake are often not clear. Further, the potential trade-offs and synergies in future energy use for residential heating and space cooling conditioning in the context of future emissions (mitigation) and adaptation is discussed in section 23.8.1 below. A range of adaptive strategies are available to address impacts of climate change on buildings including effective thermal mass and solar shading (Wilby, 2007). There is little evidence regarding the estimated costs of retrofitting European housing stock (Parry *et al.*, 2009).

Climate change may increase the frequency and intensity of drought-induced soil subsidence (Corti *et al.*, 2009). One study indicates that it is likely that the level of damage in France, for example, has more than doubled in the period 1989-2002 compared to the period 1961–1990 (Corti *et al.*, 2009). This is mostly a consequence of increased temperature since the 1990s, suggesting a link to climate change. Some European regions were affected for the first time by soil subsidence following the hot summer of 2003, possibly as a consequence of lack of adaptation.

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). An urban land surface scheme coupled to a global model was used to quantify the impact of large-scale and local drivers of climate change on the urban environment and indicated that these effects should not be treated independently when making projections of urban climate change. Climate change was found to increase the number of ‘hot’ days by a similar amount for both urban and rural situations but rural and urban increases differed significantly for the frequency of ‘hot’ nights. Modelling of London's nocturnal heat island indicated an increase in magnitude of urban heat island under project climate scenarios (Wilby, 2008). Modification of the external environment, via enhanced urban greening for example, provides other opportunities for modification of risks and co-benefits for health and welfare.

23.3.3. Transport

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

On *road transport*, in line with AR4, in case of increased precipitation, an increase in collisions but a decrease of their severity is expected due to reduced speed (Brijs *et al.*, 2008)(Kilpeläinen and Summala, 2007). However, lower traffic speed will cause welfare losses due to additional time spent driving (Sabir *et al.*, 2010). Future 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 54-72% in 2020-2070 compared to 2007 (Nokkala *et al.*, 2012).

For *rail*, consistent with AR4, increased buckling due to higher temperatures, as observed in 2003 in the UK, is expected to increase the average annual cost for heat-related delays in some regions, while opposite effects are expected for ice and snow-related delays (Dobney *et al.*, 2010)(Lindgren *et al.*, 2009). The impacts of extreme precipitation, as well as the net overall regional effect of climate change remain unclear. Efficient adaptation comprises proper maintenance of track and track bed.

Regarding *inland waterways*, the navigability of rivers will be affected. In Rhine, for temperature increases by 1-2 ^{o}C by 2050, high water levels in winter will occur more frequently and, from 2050, days with low water levels during summer will also increase (Jonkeren *et al.*, 2011)(Te Linde *et al.*, 2011)(Te Linde, 2007)(Hurkmans *et al.*, 2010). Future low water levels will imply restrictions on the load factor of inland ships, increasing transport prices, as was the case in the Rhine and Moselle market in 2003 (Jonkeren, 2009)(Jonkeren *et al.*, 2007). Potential adaptation includes modal shift, increased number of navigational hours per day in periods with low water levels and infrastructure modifications (e.g. canalization of river parts) (Jonkeren *et al.*, 2011; Krekt *et al.*, 2011). Using smaller ships could be an attractive option if most barges were not considerably below the optimal size (Demirel, 2011). Regarding *long range ocean transport*, the economic attractiveness of the Northwest Passage and the Northern Sea Route depends also on factors such as passage fees, bunker prices and cost of alternative sea routes (Verny and Grigentin, 2009)(Liu and Kronbak, 2010)(Lasserre and Pelletier, 2011).

On *air transport*, estimates on climate change impacts are very few. Pejovic et al. (Pejovic *et al.*, 2009) found that for London's Heathrow Airport, future temperature and wind changes would have a minor net annual change effect (but much larger seasonal variations), while thunderstorms, snow and fog will increase weather-related delays.

23.3.4. Energy Production, Distribution, and Use

On *wind energy*, no significant changes are expected before 2050 in Northern, part of the Alpine and upper Continental Europe (Pryor and Schoof, 2010)(Pryor and Barthelmie, 2010)(Seljom *et al.*, 2011)(Barstad *et al.*, 2012). After 2050, in line with AR4, sites in these regions may experience a small (<10-15%) increase in energy density (W/m^2) during winter and a decrease in summer (Harrison *et al.*, 2008). For Southern and Atlantic Europe, estimations are more uncertain and present spatial and seasonal variations (Rockel and Woth, 2007)(Bloom *et al.*, 2008)(Najac *et al.*, 2011)(Nolan *et al.*, 2012; Pašičko *et al.*, 2012). The impact of future increases in extreme wind speeds in Northern and Continental Europe (see section 23.2.1) on the operation and maintenance of wind farms remains unclear.

For *hydropower*, Scandinavia will face an increase of power generation up to 14% during 2071-2100 compared to historic or present levels (Golombek *et al.*, 2012)(Johannesson *et al.*, 2012)(Haddeland *et al.*, 2011); for 2021-2050, increases up to 8.5% were estimated, while others predicted increases even by 15-20% (Seljom *et al.*, 2011; Hamududu and Killingtveit, 2012). In Continental and part of Alpine Europe, reductions by 6-46% were estimated, depending on the emission scenario, location and time horizon (Schaefli *et al.*, 2007)(Mauser and Bach, 2009)(Paiva *et al.*, 2011; Pašičko *et al.*, 2012)(Stanzel and Nachtnebel, 2010). For Southern Europe, a decreased production by 5-15% in 2050 compared to 2005 has been estimated (Hamududu and Killingtveit, 2012). Improved water management, including pump storage if appropriate, stands as the main adaptation option (Schaefli *et al.*, 2007)(García-Ruiz *et al.*, 2011).

Biofuel production is covered in section 23.4.6. No literature on climate change impacts on solar energy production was found (since AR4). On *thermal power*, in line with AR4, van Vliet et al. (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 lower figures have been also estimated (Linnerud *et al.*, 2011)(Förster and Lilliestam, 2010). Closed-cooling circuits are efficient for adaptation (Koch and Vögele, 2009) but are usually feasible only for new plants. In *power transmission*, increasing lighting faults and decreasing snow-sleet-and blizzard faults for 2050-2080 were estimated for UK (McColl *et al.*, 2012).

By considering both heating and cooling, the *total annual energy demand* in Europe as a whole during 2000-2100 is estimated to decrease following climate change (Isaac and van Vuuren, 2009). Seasonal changes will be prominent, especially for electricity (see Figure 23-5), with summer peaks arising also in countries with moderate summer temperatures (Hekkenberg *et al.*, 2009). Heating degree days under a +3.7 ^{o}C scenario 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 the Mediterranean, cooling degree days by 2060 will increase, while heating degree days will decrease but with substantial spatial variations (Giannakopoulos *et al.*, 2009). Following climate change, a net annual increase of future electricity generation cost in most of the Mediterranean and a decrease in the rest of Europe was estimated (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). Passive-cooling alone may not to be enough, while energy efficient buildings and cooling systems, and demand-side management are effective adaptation options (Artmann *et al.*, 2008; Jenkins *et al.*, 2008; Day *et al.*, 2009; Breesch and Janssens, 2010; Chow and Levermore, 2010).

[INSERT FIGURE 23-5 HERE
Figure 23-5: 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 on future consumption patterns (e.g. soft drinks, ice creams) is very limited, and based on current sensitivity to seasonal temperature (Mirasgedis *et al.*, 2013). Climate change may also affect supply chains, utilities and transport infrastructure with implications for some industries (see also chapter 10). Higher temperatures may alter the products' quality and safety by favouring the growth of food borne pathogens or contaminants (Jacxsens *et al.*, 2010; Popov Janevska *et al.*, 2010) (see also section 24.5.1). The production of some high value crops is likely to be affected by climate warming (see 23.4.1 and Box 23-1 on Wine).

23.3.6. Tourism

In line with AR4, in northern areas of Continental Europe, as well as Finland, southern Scandinavia and southern England, climate for general tourist activities especially after 2070 is expected to improve significantly during summer and less during autumn and spring under different emission scenarios (Amelung and Moreno, 2011); (Amelung *et al.*, 2007)(Nicholls and Amelung, 2008), although local weather may not be a major barrier for these activities (Denstadli *et al.*, 2011). For the Mediterranean, climate for light outdoor tourist activities is 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). Though, other studies 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). Observed visitation data and questionnaires indicate that beach tourists are not deterred by moderately high temperatures but by rain (De Freitas *et al.*, 2008)(Moreno, 2010)(Moreno and Amelung, 2009). Tourist arrivals depend also on the age of tourists and the climate at their country of origin, economic and environmental conditions at destinations (e.g. water stress, increased further by climate change and tourist development) (Hamilton and Tol, 2007)(Moreno and Amelung, 2009; Perch-Nielsen *et al.*, 2010)(Lyons *et al.*, 2009; Eugenio-Martin and Campos-Soria, 2010)(Rico-Amoros *et al.*, 2009). The future capacity of accommodation and transport networks in destinations is also important.

Regarding ski tourism, in agreement with AR4, climate change will affect natural snow reliability and consequently the ski season's length, especially in cases without or limited artificial snowmaking (OECD, 2007)(Steiger, 2011)(Steiger, 2010b)(Moen and Fredman, 2007). Low-lying areas will be the most vulnerable (Uhlmann *et al.*, 2009; Endler *et al.*, 2010; Serquet and Rebetez, 2011; Steiger, 2011; Endler and Matzarakis, 2011a). The response of tourists to marginal snow conditions remains largely unknown (Scott et al., 2012), while changes in weather extremes may also be critical (Tervo, 2008). Up to mid-century, demographic changes may have a higher impact on skiing tourism than climate change (Steiger, 2012). Artificial snowmaking has physical and economic limitations, especially in small/ medium sized and low-altitude ski stations (Sauter *et al.*, 2010)(Steiger, 2010a; Steiger, 2010b)(Steiger and Mayer, 2008), and increases water and energy consumption. Other options may include shift to higher altitudes, operational changes, technical measures and year-round tourist activities, although it is still uncertain whether they can fully compensate climate change adverse impacts. Mountainous areas may face improved climatic conditions for summer tourism due to climate change (Endler *et al.*, 2010; Perch-Nielsen *et al.*, 2010; Serquet and Rebetez, 2011; Endler and Matzarakis, 2011b).

23.3.7. Insurance and Banking

The financial sector has a large base in Europe, and its global and regional activities are potentially affected by climate change (see AR5 WG2 Section 10.7 for a more detailed discussion). The insurance and banking sector is affected by problems with accurate pricing of insurance, shortage of capital after large loss events (weather disasters), and by an increasing burden of losses that can affect markets and insurability, within but also outside the European region (CEA, 2007; Botzen *et al.*, 2010a; Botzen *et al.*, 2010b). On the other hand, risk transfer mechanisms including insurance are also an important means to cover and reduce losses from extreme weather (Botzen and van den Bergh, 2008; CEA, 2009)(Herweijer *et al.*, 2009).

Banking is potentially affected through physical impacts from climate change on their assets and investments, as well as regulation and/or through mitigation actions by changing demands regarding carbon emissions from activities related to their investments and lending portfolios. Few banks have adopted climate strategies that also address adaptation (Furrer *et al.*, 2009)(Cogan, 2008).

Windstorm losses that are generally well covered in Europe by building and motor policies and create a large exposure to the insurance sector. Studies indicate an overall increase storm hazard (see Section 23.2.2.3) and possibly insured losses (see Chapter 17.7.3 for a full discussion), but the natural variations in storm frequency are large. There is no evidence that the increase in historic European storm damages is due to anthropogenic climate change. The increasing number and value of buildings and infrastructure is a major driver at present (Barredo, 2010). 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 losses of concern to the European insurance industry are building subsidence losses related to drought (Corti *et al.*, 2009), insured hail damage to buildings (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 (Clemo, 2008; Botzen *et al.*, 2010a)(Crichton, 2007)(Crichton, 2006)(Wamsler and Lawson, 2011)(Surminski and Philp, 2010). Willingness-to-pay studies in Scotland and the Netherlands show that public attitudes 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 needed in many European countries to provide compensation and back-stopping of private insurance schemes in the event of major losses (Aakre and Rübbelke, 2010; Aakre *et al.*, 2010). Hochrainer *et al.* (Hochrainer *et al.*, 2010; Hochrainer *et al.*, 2010) analysed the performance of the EU Solidarity Fund system that supports European governments in the event of large losses, and argue there is a need to shift its focus from compensation to incentivising risk reduction. Alternative forms of private insurance mechanisms, such as long-term (multi-year) contracts for European flood risks suffer from uncertainty related to future risks under climate change, leading to additional risk to private insurance firms (Aerts and Botzen, 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, and crop productivity (all other factors remaining unchanged) is *likely* to increase in Northern Europe, and decrease in Southern Europe, and the eastern part of Continental Europe.

The frequency and severity of climatic extremes affect agricultural systems (Tubiello *et al.*, 2007)(Coumou and Rahmstorf, 2012) Table 23-5). Climate-induced variability in wheat production has increased in recent decades in France, Italy and Spain (Brisson *et al.*, 2010)(Hawkins *et al.*, 2013) and in some Hungarian regions (Ladanyi, 2008), while in the northernmost agricultural areas of Europe, no consistent reduction in yield variability was recorded despite warming (Peltonen-sainio *et al.*, 2010). In 2003 and 2010, Western Europe and Western Russia, respectively, experienced their hottest summers since 1500 (Luterbacher *et al.*, 2004)(Barriopedro *et al.*, 2011); grain-harvest losses in affected regions reached 20 and 30%, respectively (Ciais *et al.*, 2005; Aerts and Botzen, 2011; Aerts and Botzen, 2011). The 2004/2005 hydrological year was characterised by an intense drought throughout the Iberian Peninsula and cereals production fell on average by 40% (EEA, 2010b). In 2011, the hottest and driest spring on record in France since 1880 reduced annual grassland production and annual grain harvest by 20 and 12%, respectively (AGRESTE, 2011)(Coumou and Rahmstorf, 2012). In the Czech Republic, the grain yield sensitivity to a 1◦C temperature increase during the growing season was -11% and -10% for winter wheat and spring barley, respectively, over 1961-2007 (Trnka *et al.*, 2012).

In many European countries cereal yields have declined in recent decades (Olesen *et al.*, 2011) although the national statistical yields are below the agro-climatic potential yield (Supit *et al.*, 2010). Cereal yields have been negatively affected by warming in some European countries since 1980, for example, in France by -5% for wheat and -4% for maize (Lobell *et al.*, 2011). Restricted crop inputs and changes in crop rotations, as well as the increased frequency of high temperatures and droughts during grain filling, have reduced wheat yield growth in France (Brisson *et al.*, 2010; Kristensen *et al.*, 2011). In contrast, in eastern Scotland, warming is estimated to have contributed to 23–26% of observed increase potato yields since 1960 (Gregory and Marshall, 2012). In North-East Spain, an increased water deficit in the reproductive stage since the 1960s has reduced grape yield by up to 30 kg/ha per millimetre (Camps and Ramos, 2012). This is consistent with agro-climatic modelling showing a widespread decline over the period 1976-2005 in the climatic potential of crop yields, especially in Italy, central and eastern Europe (Supit *et al.*, 2010).

Insight into the potential effect of climate change on any particular species or crop system 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). For a global temperature increase of 5° C, agroclimatic indices adjusted to reflect the effects of atmospheric CO_2 concentration on evapotranspiration and based on outputs from three GCMs, show increased drought stress and shortening of the active growing season with an increasing number of extremely unfavourable years in a number of European regions (Trnka *et al.*, 2011). In the EU27, a 2.5 °C temperature increase in the 2080s could lead to small changes in crop yields, whereas a 5.4 °C scenario could reduce yields by 10% (Ciscar *et al.*, 2011). A study combining three GCMs and two emission scenarios (B1 and A2) with a weather generator and the crop modelling system GCMS applied to wheat, maize and sugar beet, and assuming neither impacts by weeds, pests and diseases nor limitations by nutrients, indicates an initial benefit from the increasing CO_2 concentration for rainfed crop yields in most European regions, contrasting by the end of the century with yields declines in most regions (Supit *et al.*, 2012). Under the A2 scenario, wheat yield is projected to increase at the end of the century compared to the baseline period 1990–2008 (Supit *et al.*, 2012). Another study, using the CropSyst model and bias-corrected downscaled simulations for the A1B emission scenario, shows based on outputs from the HadCM3 GCM, that disease (wheat leaf rust and corn grey leaf spot) limited yields of rainfed wheat and maize would be reduced despite the increase in atmospheric CO_2 by 5-20% in ca. half of the European cropping area in the 2030's compared to a reference period centred on the year 2000, while the corresponding yield changes would be non-significant or slightly positive based on the ECHAM GCM (Donatelli *et al.*, 2012).

The regional distribution of climate change impacts on agricultural production is *likely* to vary widely (Iglesias *et al.*, 2012)(Donatelli *et al.*, 2012), Figure 23-6). Southern Europe would experience the largest yield losses that would reach about 25 % by 2080 under a 5.4 °C temperature increase (Ciscar *et al.*, 2011). Conditional on increased water shortage and extreme weather events (heat, drought) rainfed summer crop failure is *very likely* to rise sharply (Bindi and Olesen, 2011)(Ferrara *et al.*, 2010)(Ruiz-Ramos *et al.*, 2011) in Southern Europe. The Central Europe regions would experience moderate declines in crop yields (Ciscar *et al.*, 2011), as a result of warmer and drier conditions by 2050 (Trnka *et al.*, 2010; Trnka *et al.*, 2011). In Western Europe, for the 2050s, increased heat stress around flowering is *likely* to increase significantly in wheat which may result in considerable yield losses (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 for a large range of scenarios (between 2.5 and 5.4°C warming) (Bindi and Olesen, 2011). However, at high latitudes, even accounting for the positive effects of CO_2 fertilization, impacts on cereal production could become negative with a high risk of marked yield loss beyond 4°C global temperature increase (Rötter *et al.*, 2011). Increased climatic variability would limit winter crops expansion in the northernmost agricultural areas of Europe (Peltonen-sainio *et al.*, 2010), but spring crops from tropical origin like maize for silage could become cultivated in Finland by the end of this century (Peltonen-Sainio *et al.*, 2009).

[INSERT FIGURE 23-6 HERE
Figure 23-6: Percentage change in simulated water-limited yield for winter wheat in 2030 with respect to the 2000 baseline under the A1B scenario as modelled using ECHAM5 (left column) and HadCM3 (right). Upper maps to do not take adaptation into account whereas the bottom maps show the result for the best adaptation strategy for cell (Source: Donatelli et al. 2012).]

Ozone is the most important air pollutant that affects agricultural production. For the European Union, compared to a baseline without crop injuries from ozone, wheat and maize yield reduction from ozone were estimated at 7% in 2000 and would reach 6 and 10 % in 2030 for the B1 and A2 scenarios, respectively (Avnery *et al.*, 2011a; Avnery *et al.*, 2011b). Crop sensitivity to ozone tends to decline with increasing atmospheric CO_2 and in areas where warming is accompanied by drying, such as southern and continental Europe. In contrast, the ozone sensitivity of crops would remain high at higher latitudes the absence of declining air and soil moisture (Fuhrer, 2009).

Some economically damaging weeds, such as the shallow rooted *Alopecurus myosuroides* in UK, could become less competitive with wheat owing to more frequent and severe drought stress events under climate change that favour deeper rooted crop plants such as wheat (Stratonovitch, 2012). However, deep rooted weeds (Gilgen *et al.*, 2010) and weeds with contrasting physiology, such as C_4 species, may become better adapted to future conditions and pose a more serious threat (Bradley *et al.*, 2010).

For crops remaining in their original geographical range, generally warmer conditions would exacerbate arthropod-borne diseases (many viruses and phytoplasmas) and those root and stem diseases that first infect hosts during the autumn and winter, such as stem canker of oilseed rape and eyespot of wheat (West *et al.*, 2012). Rising temperatures during the vegetation period, enhances the appearance of a black rot fungus in fruit trees of Northwestern Europe, but this does not hold for other fruit rot species (Weber, 2009) and some 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. By the 2050s, more severe *Fusarium* blight epidemics are projected in southern England (Madgwick *et al.*, 2011), while the European corn borer (*Ostrinia nubilalis*) would extend its climate niche in Central Europe (Trnka *et al.*, 2007). 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). Yield losses from phoma stem canker epidemics could increase to up to 50 per cent in South England and greatly decrease yield of untreated winter oilseed rape (Butterworth *et al.*, 2010). Increasing temperatures might have a detrimental impact on grapevine yield due to increased asynchrony between larval development of the European grapevine moth and the larvae-resistant growth stages of grapevine (Caffarra *et al.*, 2012). Disease management will also be affected with regard to timing, preference and efficacy of chemical, physical and biological measures of control and their utilization within integrated pest management strategies (Kersebaum *et al.*, 2008).

Farmers across Europe are currently adapting to climate change (Olesen *et al.*, 2011). Simple, no-cost adaptation options such as advancement of sowing and harvesting dates or the use of longer cycle varieties may be implemented although such options may become less successful in a more variable climate (Moriondo *et al.*, 2010; Moriondo *et al.*, 2011)(Howden *et al.*, 2007). Such "autonomous" adaptation by farmers could result in a general improvement of European wheat yields in the 2030s compared to the 2000s (Donatelli *et al.*, 2012) (Figure 23-6). However, earlier sowing is often prevented by lack of soil workability and frost-induced soil crumbling (Oort, 2012). Observations suggest that farmer sowing dates are advancing slower (e.g. by only 0.2 days per decade over the last 50 years, (Siebert and Ewert, 2012) than crop phenology (Menzel *et al.*, 2006)(Siebert and Ewert, 2012)(Oort, 2012) in Europe. Simulation studies which anticipate on earlier sowing 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). In South Italy, for a global mean temperature change of 2°C (above pre-industrial levels), adaptation measures (irrigation and fertilization) would alleviate the negative effects of climate change on crop (tomato and durum wheat) productivity (Ventrella *et al.*, 2012). 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, such as sowing and adequate nitrogen fertilizer management, may reduce risks of yield shortfall (Olesen *et al.*, 2011)(Rötter *et al.*, 2011)(Ventrella *et al.*, 2012). Climate change alters breeding targets. The identification of the most CO_2-responsive genotypes (Ainsworth *et al.*, 2008) and of heat, drought- and salinity-tolerant genotypes (Tester and Langridge, 2010)(Semenov and Shewry, 2011) as well as the preservation of the option value provided by plant genetic diversity, is a pre-requisite to provide starting lines for breeding programmes (Jump *et al.*, 2009). However, crop breeding is 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).

Achieving increased adaptation action will necessitate integration of climate change-related issues with other risk factors, such as market risk (Howden *et al.*, 2007)(Knox *et al.*, 2010). Adaptation to increased climatic variability may imply an increased use of between and within species genetic diversity in farming systems (Smith and Olesen, 2010). The development of insurance products against weather-related yield variations by using precipitation options (Musshoff *et al.*, 2011) may be a tool to reduce risk aversion by farmers. Adaptive capacity to variable and changing conditions is largely attributable to the characteristics of farm types (Reidsma *et al.*, 2009) which may vary given long-term farm structural change induced by climate change (Mandryk *et al.*, 2012). The long term economic viability of farming systems under future scenarios is better characterised by combining ecological and economic optimisation models at the farm scale (Moriondo *et al.*, 2010b).

23.4.2. Livestock Production

Livestock production is impacted by heat. High temperatures lead to a reduction in animal voluntary intake and put a ceiling on dairy milk yield from feed intake (Tubiello *et al.*, 2007). For intensive dairy systems in the Netherlands, heat stress affected dairy production above a daily mean temperature of 18 degrees C (André *et al.*, 2011). For finishing pigs, a meta-analysis shows that growth performance decreases at an accelerating rate when daily temperature increases above a threshold comprised between 21 and 30° (Renaudeau *et al.*, 2011). With dairy cattle in Italy, the mortality risk increased by 60% as a result of exposure during breeding to a combination of high air temperature and air humidity (Crescio *et al.*, 2010). For domesticated animals, climate change adaptation involves changes in diets and farm buildings (Renaudeau *et al.*, 2012) as well as genetic improvement programmes targeting adaptive and performance traits in locally adapted genotypes (Hoffmann, 2010).

Atmospheric CO_2 rise, warming and altered precipitation patterns may change the amount timing and quality of forage production in Europe (Soussana and Luscher, 2007). Experimental manipulation shows the resilience of semi-natural grassland vegetation to prolonged experimental heating and water manipulation (Grime *et al.*, 2008). Nevertheless, even under elevated CO_2, annual grassland production in a French upland site was significantly reduced by four years exposure to climatic conditions corresponding to the A2 emission scenario for the 2070s (Cantarel *et al.*, 2013). Repeated exposure of grasslands to summer droughts increased weed pressure by tap rooted forbs such as *Rumex* (Gilgen *et al.*, 2010). With grass based dairy systems, simulations under the A1B scenario with an ensemble of downscaled GCMs show by the end of the century increases in potential dairy production in Ireland and France, however with increasing risks of summer-autumn forage production failures at French sites (Fitzgerald *et al.*, 2010; Graux *et al.*, 2012) . In continental Europe, grass based dairy systems could suffer from rising water deficits and forage yield variability (Trnka *et al.*, 2009). With sown forage grasses, Mediterranean populations were more resilient than temperate populations to soil water deficit and to heat (Poirier *et al.*, 2012) and could therefore be used to breed better adapted plant material.

The spread of bluetongue virus (BTV) in sheep across Europe has been partly attributed to climate warming (Arzt *et al.*, 2010)(Guis *et al.*, 2012) and was caused by increased seasonal activity of the *Culicoides* vector (Wilson and Mellor, 2009). Climate change is unlikely to extend the distribution of vector *Culicoides imicola* but may increase its abundance in Southern Europe (Acevedo *et al.*, 2010). Ticks, the primary arthropod vectors of zoonotic diseases in Europe, have *likely* changed distributions with climate warming (van Dijk *et al.*, 2010)(Randolph and Rogers, 2010; Petney *et al.*, 2012)(23.5), Climate warming may also increase the risk of fly strike incidence but this can be managed through changes in husbandry practices (Wall and Ellse, 2011). For Europe, climate change is not project to increase by the 2080s the overall risk of incursion of Crimean-Congo haemorrhagic fever virus in livestock through infected ticks introduced by migratory bird species (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 (Falloon and Betts, 2010) the widening of water resource differences between Northern and Southern European regions reported in AR4 (Alcamo *et al.*, 2007). Under the A1B scenario multi-model simulations show for the 21st century that Nordic river basins have the highest probability of exceeding past high flows during winter, while in Central and Southern European basins the probability of reduced low flows in summer is highest (Weiss, 2011). Simulations using ensemble of GCMs and regional climate models under the A2 emission scenario, show significant reductions by the end of the century in groundwater recharge and/or water table level for river basins located in Northern France (Ducharne *et al.*, 2010), Belgium (Goderniaux *et al.*, 2011), Southern Italy (Senatore *et al.*, 2011) and Spain (Guardiola-Albert and Jackson, 2011), while non-significant impacts were found for aquifers in Switzerland and in England (Stoll *et al.*, 2011)(Jackson *et al.*, 2011). In Northern Europe, negative impacts on water quality are expected due to the intensification of agriculture (Bindi and Olesen, 2010). In the Seine river basin, even with reduced N fertilizer application, groundwater nitrate concentrations would increase during the 21st century (Ducharne *et al.*, 2007). Changes in seasonal precipitation distribution, such as less precipitation in summer and higher rainfall during winter, can enhance nitrate leaching due to lower nitrogen use efficiency in dry periods with higher residual mineral nitrogen after harvest and increased percolation during winter (Kersebaum *et al.*, 2008).

Projections in most European regions, show deteriorating agroclimatic conditions and reduced suitability for rainfed agricultural production (Daccache *et al.*, 2012)(Trnka *et al.*, 2011)(Daccache and Lamaddalena, 2010)(Henriques *et al.*, 2008). Water demand for crop irrigation is projected increase by 40 to 250% by 2100, depending on the crop, in the Fluvià watershed (Catalonia, NE Spain) under the B1 and A2 scenarios (Savé *et al.*, 2012).

Increased irrigation may, however, not be a viable option in a number of European regions because of the reduction in total runoff and of declining groundwater resources, especially in the Mediterranean area (Olesen *et al.*, 2011). Supplementary irrigation in central and eastern England would be constrained by water availability, since in the corresponding catchments water resources are already over-licensed and/or over-abstracted (Daccache *et al.*, 2012). In the French Beauce region, one of the hotspots for irrigation in Europe, water resources 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). For a tributary of the Ebro river in Spain, drying is projected to occur mainly during the summer with a reduction in the amount of water available for irrigation, due to projected seasonal reductions in reservoir levels (Majone *et al.*, 2012). The need for irrigation may also appear in regions without irrigation infrastructure, as observed during the 2003 summer heat wave and drought in France (van *et al.*, 2010). In Southern Italy, climate change could increase the number of failures for current irrigation systems up to 54-60%. System costs would increase by 20-27% when designed according to the future irrigation demand (Daccache and Lamaddalena, 2010). Even though the adoption of irrigation leads to higher and less variable crop yields in the future, economic benefits of this adoption decision are expected to be rather small. Thus, without changes in institutional and market conditions, no adoption is expected in countries like Switzerland (Finger *et al.*, 2011).

For Northern Europe, agricultural adaptation may be shaped by increased water supply and flood hazards. The need for effective adaptation will be greatest in Southern and south-eastern regions of Europe which already suffer most from water stress, as a result of increased production vulnerability, reduced water supply and increased demands for irrigation (Trnka *et al.*, 2009)(Falloon and Betts, 2010). High frequency of rainy conditions complicates soil workability (Olesen *et al.*, 2011). Earlier sowing dates may allow earlier irrigation and a reduction of the water application (Gonzalez-Camacho *et al.*, 2008). An increased soil organic matter content may facilitate better soil water retention during drought and enhance infiltration capacities (Lee *et al.*, 2008). Areas with poor water-holding soils could be managed extensively for groundwater recharge harvesting, while better water-holding soils could be used for high input crop production (Wessolek and Asseng, 2006). Improved water management in upstream food production areas could mitigate adverse impacts downstream (Kløve *et al.*, 2011). Alternative options such as the use of low-energy systems, improving irrigation efficiency, switching to deficit irrigation and changing cropping patterns to increase water use efficiency can be used as adaptation pathways (Daccache and Lamaddalena, 2010)(Schutze and Schmitz, 2010).

Water use by agriculture affects aquatic ecosystems through stream flow reduction, alteration in stream flow patterns, wetland degradation and declining water quality. Terrestrial ecosystems are affected through changes in groundwater levels and alterations to runoff due to land use changes (Kløve *et al.*, 2011). Under economically focussed regional futures, water supply availability increases at the expense of the environment. Under environmentally focussed futures, irrigation demand restrictions are imposed. In a global market-drive future irrigation demand is price sensitive and has an impact on the type of crops under all climate scenarios (Henriques *et al.*, 2008). More bioenergy production may result in more water stress in some river basins and regions, in particular in southern Europe and during dry summers (Dworak *et al.*, 2009).

23.4.4. Forestry

Observed and future responses of forests to climate change include changes in growth rates, phenology, species composition, increased fire and storm damage, and increased insect and pathogen damage.

Forest growth and phenology

Tree mortality and forest decline due to severe drought events were observed in forests populations in many Mediterranean countries (Affolter *et al.*, 2010)(Bigler *et al.*, 2006; Raftoyannis *et al.*, 2008) as Italy (Bertini *et al.*, 2011)(Giuggiola *et al.*, 2010), Cyprus (ECHOES Country report, 2009), Greece (Raftoyannis *et al.*, 2008) and in the pre-Alps in France (Rouault *et al.*, 2006; Allen *et al.*, 2010)(Nageleisen, 2008; Giuggiola *et al.*, 2010) not only in arid regions but also in wet forests not normally considered at risk of drought (Choat *et al.*, 2012). Phenological advancement in the leaf bud burst and flowering timing was recorded in deciduous species of Southern and Central Finland (Linkosaloa *et al.*, 2009) and crown defoliation was observed in southern European forests due to climate change during 1987-2007 (Carnicer *et al.*, 2011). Despite such negative trends, an increase in forest productivity was observed since 1986 in Italian mountain beech due to the increase of average temperatures (Rodolfi *et al.*, 2007).

Climate change will affect growth and regeneration of forest tree populations in Europe (Lavalle et al., 2009). Future projections show that in Northern and Atlantic Europe the increasing atmospheric CO_2 and warmer temperatures are expected to result in positive effects on forest growth and wood production, at least in the short–medium term (Lindner *et al.*, 2010). On the other hand, in Southern and conitnental Europe increasing drought and disturbance risks will cause adverse effects and productivity is expected to decline (Lindner *et al.*, 2010). The CO_2 fertilization in both Central Europe and Mediterranean will have positive effects on growth although these results contrast with habitat reductions and decline of stand regeneration (Hlásny *et al.*, 2011; Keenan *et al.*, 2011; E Silva *et al.*, 2012).

Species composition

Shifts in forest tree species range due to climate change has been predicted by model-based projections for the period 2070-2100, with a general trend of a south-west to north-east, under A1B scenario, and uphill shifts in suitable habitats for forest categories (Feehan *et al.*, 2009)(Casalegno *et al.*, 2007) causing large ecological and socio-economic impacts and becoming an important issue to be addressed for forest management (Giuggiola *et al.*, 2010; Hemery *et al.*, 2010; García-López J.M. and Alluéa, 2011). By 2100 climate change is expected to reduce the economic value of European forest land by 14 to 50 % under A1B climate scenario, which equates to a potential damage of several hundred billion Euros unless effective countermeasures are taken, owing to the decline of economically valuable species (Hanewinkel *et al.*, 2012).

Fire and storm damage

In Southern Europe, fire frequency and fire extent significantly increased due to climate change in recent decades especially in the Mediterranean basin (Marques *et al.*, 2011; Pausas and Fernández-Muñoz, 2012) including an expansion of fire-prone areas (Fernandes *et al.*, 2010; Koutsias *et al.*, 2012) and a lengthening of the fire season (Lavalle *et al.*, 2009; Albert and Schmidt, 2010). Extreme weather events (drought, heat waves and strong winds) increased the incidence of forest fires in Southern Europe (Camia and Amatulli, 2009; Hoinka *et al.*, 2009; Carvalho *et al.*, 2011; Koutsias *et al.*, 2012; Salis *et al.*, 2013). The most severe events in France, Greece, Italy, Portugal, Spain, and Turkey in 2009 were associated with strong winds that spread fires during a hot, dry period (see also

(EEA, 2008). However, the observed fire trend is also attributable to changes in land use (Marlon *et al.*, 2008; Carmo *et al.*, 2011), socio-economic development and fire-policy factors (Martinez-Casasnovas and Ramos, 2009; Romero-Calcerrada *et al.*, 2010; Koutsias *et al.*, 2012; Pausas and Fernández-Muñoz, 2012; {{1545 Pezzatti 2011;}}.

Fire is expected to become more prevalent also in the future due to climate change causing negative effects on forest ecosystems and significant emissions of greenhouse gases due to biomass burning (Pausas *et al.*, 2008; Vilén and Fernandes, 2011; Chiriacò *et al.*, 2013), even if often difficult to precisely quantify (Chiriacò *et al.*, 2013). The future climate change impacts on forest fires in Mediterranean basin might depend on the balance between higher flammability due to warmer and drier conditions, socio-economic drivers and landscape planning to reduce fuel loads and fire hazard (Moreira *et al.*, 2011). The fire risk is projected to increase in the Mediterranean region (Lindner *et al.*, 2010; Carvalho *et al.*, 2011; Dury *et al.*, 2011; Vilén and Fernandes, 2011) with increase in the occurrence of high fire danger days (Moreno and Amelung, 2009; Arca *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 the Mediterranean area compared to the present under the A2 scenario by 2100 (Dury *et al.*, 2011). In Northern Europe, fires are projected to be less frequent due to increased humidity (Rosan and Hammarlund, 2007).

The most severe damage to forests in Central Europe occurs during winter storms caused by Northern Hemispheric mid-latitude cyclones. Increasing growing stock, warm winter temperature and high precipitation, increasing maximum gust wind speed have contributed to the recent increase in windstorm damage to forests (Usbeck *et al.*, 2010). The future storm tracks may shift further north with the consequent possibility of increased risk of damage. Boreal forests will get 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 (Pinto *et al.*, 2010; Klaus *et al.*, 2011).

[INSERT FIGURE 23-7 HERE
Figure 23-7: Projected fire risk in Europe for two time periods (2011–2040 and 2041–2070) based on high-resolution regional climate models from the ENSEMBLES project under the SRES A1B emission scenario.]

Insect and pathogen damage
Many opportunist fungi and insects benefit from climate change both directly, because of the survival of a greater number of individuals, and indirectly, because of the changes induced in host phenology (Slippers and Wingfield, 2007). A development of diseases caused by thermophilous pathogens was observed in many European forests (Marcais and Desprez-Loustau, 2007). In temperate zones of Continental Europe, fungi are even more problematic damage agents than insects, with some species that benefit from milder winters and others that spread during drought periods from south to north (Drenkhan *et al.*, 2006; Hanso and Drenkhan, 2007). Projected increased late summer warming events will favour a second generation of bark beetle in southern Scandinavia and a third generation in lowland parts of central Europe (Jönsson *et al.*, 2011). Spruce bark beetle will be able to initiate a second generation in South Sweden during 50% of the years around the mid century and in 63-81% of the years at the end of the century under A2, A1B and B2 scenarios (Jönsson *et al.*, 2009). Bark beetle damages in Austrian spruce forests are projected to double until 2100 assuming no adaptation measures (Seidl *et al.*, 2009).

Forest management and land use
Projected shortening frost periods and thawing permafrost may strongly reduce the accessibility of forests in the Boreal zone with implications for the timber supply (Keskitalo, 2008). Climate change together with socio-economic and technological drivers will influence future European land use leading to declines in the agricultural area and increase in forested and urban areas that would potentially reduce GHG emissions and enhance carbon sinks (Rounsevell and Reay, 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 (Millar *et al.*, 2007). Fragmented small-scale forest ownership can constrain adaptive capacity (Lindner *et al.*, 2010). Forest management with thinning and shrub removal could decrease competition for water and increase carbon uptake. (Giuggiola *et al.*, 2010). Ongoing changes in species composition from conifers to broadleaves and increasing harvest level might lower the vulnerability through reduction of share of old and vulnerable stands (Schelhaas *et al.*,

2010). Strategies to anticipate severe forest mortality in the future 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

Climate change is *likely* to change the distribution of key bioenergy crops. Dedicated crops for bioenergy in temperate regions, including tree species grown as short rotation coppice (SRC) and intensive forestry, and C4 grasses such as Miscanthus and switchgrass, will respond to climate change by shifting their potential distribution and altering their potential productivity and yields. 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 predicted to increase in northern Europe by the 2080s, due to increasing temperatures, and decrease in southern Europe due to increased drought. Mediterranean oil and solid biofuel crops, currently restricted to southern Europe, are predicted to extend further north due to higher summer temperatures. Four global climate models, (HadCM3, CSIRO2, PCM and CGCM2) predict that bioenergy crop production in Spain is especially vulnerable to climate change, with many temperate crops predicted to decline dramatically by the 2080s. The choice of bioenergy crops in southern Europe will be severely reduced in future unless measures are taken to adapt to climate change (Tuck *et al.*, 2006).

The physiological responses of bioenergy crops C3Salicaceae trees and C4 grasses to rising atmospheric CO_2 concentration would improve 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 potential biomass production due to elevated CO_2 outweighs the increased production costs resulting in a northward extension of the area where SRC is greenhouse gas neutral (i.e. it produces exactly the amount of biomass that is required to have the avoided emissions compensate for the total emissions from crop management and bio-energy production). However, the northward expansion of SRC would erode the European terrestrial carbon sink due to intensive management and high turnover of SRC respect 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. Warming induces a shift of species ranges toward higher latitudes and seasonal shifts in life cycle events (Daufresne *et al.*, 2009) (see also 23.6.4). In European seas, warming causes a displacement to the north and/or in depth of fish populations. These displacements of species distribution areas have a direct impact on fisheries (Rosenzweig *et al.*, 2008)(Tasker, 2008)(Cheung *et al.*, 2009; Cheung *et al.*, 2010). A widespread reduction in body size in response to climate change in aquatic systems has been observed through long-term surveys and experimental data showing a significant increase in the proportion of small-sized species and young age classes and a decrease in size-at-age (Daufresne *et al.*, 2009). In the northern North Sea, due to species reorganisation (Beaugrand and Reid, 2012), a general decrease in the mean size of zooplankton over time has been observed. Smaller zooplankton species may have general implications for energy transfer efficiency to higher trophic levels, and for the sustainability of fisheries resources (Pitois and Fox, 2006)(Beaugrand and Kirby, 2010). In British waters, the lesser sandeel (*Ammodytes marinus*), which is a key link in the food web, shows declining recruitments since 2002 that are inversely correlated with temperature and is projected to further decline in the future with a warming climate (Heath *et al.*, 2012). In the Baltic Sea, marine-tolerant species will be disadvantaged and their distributions will partially contract; conversely, habitats of freshwater species will likely expand, 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).

Numerous studies confirm the amplification through fishing of the effects of climate change on population dynamics and consequently on fisheries (Planque *et al.*, 2010). Over the past decade, the cod stock has not been restored from its previous collapse (Mieszkowska *et al.*, 2009)(ICES, 2010). In the North Sea, the decline of 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). Analyses of fish species richness over 1997-2008 of North Sea and Celtic Seas did not detect the impact of fisheries (ter Hofstede *et al.*, 2010), as the steep decline in boreal species (Henderson, 2007) was compensated for by the arrival of southern (Lusitanian) species (Lenoir *et al.*, 2011). An observed weakening of the Iberian upwelling in the inner shelf has slowed down the introduction of nutrients, leading to changes in phytoplankton communities that favour the proliferation of harmful algal blooms, thereby reducing the permitted harvesting period for the mussel aquaculture industry.

The areal extent of some habitats that are suitable for aquaculture can be reduced by sea-level rise. In addition, ocean acidification may disrupt the early developmental stages of shellfish (Callaway *et al.*, 2012). Climate change may also reinforce parasitic diseases and impose severe risks for aquatic animal health. As water temperatures increase, a number of endemic diseases of both wild and farmed salmonid populations are *likely* to become more prevalent and difficult to control and threat levels associated with exotic pathogens may rise (Marcos-Lopez *et al.*, 2010). For oysters in France, toxic algae may be linked to both climate warming and direct anthropogenic stressors (Buestel *et al.*, 2009). With freshwater systems, summer heat waves boost the development of harmful cyanobacterial blooms (Johnk *et al.*, 2008). Therefore, current mitigation and water management strategies, which are largely based on nutrient input and hydrologic controls, must also accommodate the environmental effects of climate change (Paerl and Huisman, 2009)(Halpern *et al.*, 2012).

In the Iberian-Atlantic fishing grounds, the biomass and profits from sardine fishery will further decrease with greater intensity if the effects of global warming on the water temperature become more significant (Perez *et al.*, 2010)(Garza-Gil *et al.*, 2010). In the Bay of Biscay, a major part of the gross economic turnover associated with catches of fish species would potentially not be affected by long-term changes in climate (Floc'h *et al.*, 2008). In the Portuguese coast, a commercial opportunity for fisheries could arise since most the new potential species were marketable species and not many current species were lost under different climate scenarios (Vinagre *et al.*, 2011). Fishing fleets which presently target marine species (e.g. cod, herring, sprat, plaice, sole) in the Baltic may have to relocate to more marine areas or switch to other species which tolerate decreasing salinities. A temporary marine reserve policy in the Eastern Baltic could postpone the negative effects of climate change on fish stocks (Rockmann *et al.*, 2009).

Fishery management thresholds that trigger reductions in fishing quotas or fishery closures to conserve local populations (e.g. cod, salmon) 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).

Integrative assessment help examine policy options (Miller *et al.*, 2010). Experimentation and innovation at local to regional levels is critical for a transition to ecosystem-based management (Osterblom *et al.*, 2010). Human social fishing systems dealing with high variability upwelling systems with rapidly reproducing fish species may have greater capacities to adjust to the additional stress of climate change than human social fishing systems focused on longer-lived and generally less variable species (Perry *et al.*, 2010; Perry *et al.*, 2011). However, the political and social implications of impacts on fisheries are hard to project. The climate-related northward movement of mackerel to Icelandic waters may create economic problems for fisheries in EU and policy debates (Arnason, 2012).

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 (Åström *et al.*, 2011)(Kovats and Hajat, 2008). With respect to sub-regional vulnerability, populations in southern Europe appear to be most sensitive to hot weather (Åström *et al.*, 2013)(Baccini *et al.*, 2011)(Corobov *et al.*, 2011 (in press))(Iñiguez *et al.*, 2010; Tobías *et al.*, 2010), and also will experience the highest heat exposures (Iñiguez *et al.*, 2010; Tobías *et al.*, 2010) (Figure 23-2). However, elderly populations in central (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 (EEA-JRC-WHO, 2008) which have been shown to reduce heat-related mortality in Italy (Schifano *et al.*, 2012) and France. There is little information about how future changes in housing and infrastructure (e.g. retrofitting houses, installing cool rooms in residential homes) would reduce the regional or local burden of heat-related mortality. Most published risk assessments do not include consideration of adaptation (Huang *et al.*, 2011). Further work has been done to characterize heat stress as an occupational hazard (see chapter 11).

Climate change will increase the frequency and the intensity of major heat wave events (Figure 23-2), which are associated with significant acute impacts on mortality and morbiditiy (Robine *et al.*, 2008)(Solymosi *et al.*, 2010). Several studies have estimated the impact of climate scenarios on future heat-related mortality at the city level. A comparison of additional mortality in 15 cities (Baccini *et al.*, 2011) estimated highest attributable burdens in Budapest and Athens (A2 emissions scenario), with least impacts in Dublin, Zurich and Ljubljana by 2030. For most countries in Europe, the current burden of cold-related mortality is greater than the burden of heat mortality, although few studies have quantified benefits of climate warming in terms of the reduction of cold related mortality (Doyon *et al.*, 2008). A Europe-wide assessment, estimated that increase in heat-related mortality would only exceed the decrease in cold-related mortality at some point during the last third of the century assuming no adaptation, and an increased variance in daily temperature distributions (Ballester *et al.*, 2011).

Mortality and morbidity associated with flooding is becoming better understood although the surveillance of health effects of disasters remains inadequate. Additional mortality due to flooding has been estimated in the Netherlands due to sea level rise (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)(Murray *et al.*, 2011).

Evidence about future risks from climate change with respect to infectious diseases is still limited (Semenza *et al.*, 2012)(Randolph and Rogers, 2010). There have been developments in mapping the current and potential future distribution of important vectors in Europe. The Asian tiger mosquito *Aedes albopictus*, is an important vector of dengue and other arboviruses, such as Chikungunya (Queyriaux *et al.*, 2008). The vector is currently present in many countries in southern and eastern Europe (ECDC, 2009). An assessment of the potential impact of climate change indicated limited potential for eastward expansion (ECDC, 2009)(Fisher *et al.*, 2011; Caminade *et al.*, 2012). A study in Italy projected the potential for northward shift of the vector's distribution in that country (Roiz *et al.*, 2011). For *Ae. Aegypti* (dengue vector that is not present in Europe), there are some areas that could potentially become suitable under climate change by 2050, including the Mediterranean areas of Spain, France and Italy as well as south-eastern Europe (ECDC, 2012). However, the risk of introduction of dengue remains very low because it would depend upon the upon the introduction and expansion of the *Ae. Aegypti* together with the absence of effective vector control measures (ECDC, 2012).

Visceral and cutaneous leishmaniasis are sandfly-borne diseases currently present in the Mediterranean region. A comprehensive review described that climate change is unlikely to affect the distribution of these infections in the near term (Ready, 2010). However, in the long term (15-20 years), there was potential for climate change to facilitate the expansion of either vectors or current parasites northwards . 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 warming 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.

Since AR4 there have been several studies and reviews that have investigated the impact of climate change on food safety, at all stages from production to consumption (FAO, 2008; Jacxsens *et al.*, 2010; Popov Janevska *et al.*, 2010)(Miraglia *et al.*, 2009). The transmission of salmonellosis (a food pathogen) is sensitive to temperature but this sensivity has declined in recent years (Lake *et al.*, 2009) and the overall incidence of salmonellosis is declining in most European countries (ECDC, 2011). Climate change may also have affects on food consumption patterns (the reduction in consumption of animal products would benefit methane emissions reduction). 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. 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. Health Systems and 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 leds to significant damage to power and water utilities, and damage to communications (including roads) responsible for 10% and 7% of the total costs, respectively (Chatterton *et al.*, 2010). Several countries have undertaken reviews of flood risks to hospitals, schools, water treatment/pumping stations. In 2007, a forest fire in Greece caused the closure of a major road and access to the international airport. 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 systems (hospitals, clinics) are also vulnerable to extreme events. 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 health cares, as well drug storage and transport.

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 in the longer term, particularly after mid-century.

The current burden for weather disasters is high (see above). Flooding can have long lasting effects of the affected populations (Schnitzler *et al.*, 2007). Households are often displaced while their homes are repaired. A flood event in the UK found that a significant proportion of persons were still displaced 12 months after the event (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 (EC, 2009a). Coastal erosion associated with sea level rise, storm surges and coastal flooding will require coastal retreat in some of Europe’s low lying areas (Nicholls and

Cazenave, 2010)(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]. A study of European reindeer husbandary found that socio-economic factors were likely to be much more important than climate change for future sustainability (Rees *et al.*, 2008) [28.2.3.5].

23.5.4. Cultural Heritage and Landscapes

Climate change will affect the built environment that is culturally valued (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.*, 2010). Cultural heritage is a non renewable resource and impacts from environmental changes are assessed over long timescales (Brimblecombe and Grossi, 2008)(Grossi *et al.*, 2008; Bonazza *et al.*, 2009a; Bonazza *et al.*, 2009b; Brimblecombe and Grossi, 2009; Brimblecombe and Grossi, 2010). 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).

Surface recession on marble and compact limestone will change in response to climate change. In the 2080s, Central Europe, Norway, the northern UK and Spain will experience surface recession ranging between 20 and 30 μm/y. Conversely, a decrease in surface recession of about 1-4 μm/y is projected for Southern Europe, reducing risk (Bonazza *et al.*, 2009a). Marble monuments located in the Mediterranean will continue to experience high levels of thermal stress (Bonazza *et al.*, 2009b). However, frost damage will reduce across Europe because of warming, except in Northern, and Alpine 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 some structures may need additional protection from high winds (Sabbioni *et al.*, 2010). AR4 concluded that then current flood defence schemes would not protect Venice from climate change. Venice now has a flood forecasting system, as well as the MOSE system of flood barriers (Keskitalo, 2010) but recent evidence suggests that climate change may lead to a decrease in the frequency of extreme storm surges (Troccoli *et al.*, 2011 (in press)).

Europe has many unique rural landscapes, which reflect the cultural heritage that has evolved from centuries of human intervention. Examples include, amongst others, 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, 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 on their capacity to function as they have done in the past (Gifford *et al.*, 2011). Because of their cultural importance, many such landscapes are protected through rural development and environmental policies. Alpine meadows, for example, are culturally important within Europe, but although there is analysis of the economic (tourism, farming) and functional (water run-off, flooding, carbon sequestration) aspects of these landscapes there is very little understanding of the consequences for the cultural aspects of these areas and the societies who depend on them. Other European uplands, such as peat rich uplands in northern Europe 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 23-1.

_____ START BOX 23-1 HERE _____

Box 23-1. Implications of Climate Change Impacts for European Wine and Vineyards

There is a significant body of research on the impacts of climate change on wine production and the cultural landscapes embodied in vineyards (Metzger and Rounsevell, 2011) (White *et al.*, 2009). Wine production in Europe accounts for more than 60% of the global total (Goode, 2012) and makes an important contribution to cultural identity. It is also an exemplar of how climate change can affect not only the biophysical response of plants and the geographic distribution of wine grape varieties, but also consumer perceptions of wine that are associated with the cultural diversity of regional production. Taken together these effects make the European wine sector highly sensitive to climate change and one that is already taking climate adaptation seriously (Goode, 2012).

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; Holland and Smit, 2010; Malheiro *et al.*, 2010; Duarte Alonso and O'Neill, 2011; Moriondo *et al.*, 2011; Santos *et al.*, 2011).

Whilst the distribution of grape suitability will change in response to climate change, relocation as an adaptation option is constrained by the concept of 'terroir', which combines the influence of a location's soils, climate and topography with the knowledge and traditions of wine producers, into a unique expression of landscape culture (Metzger and Rounsevell, 2011). Vineyards may be displaced geographically beyond their traditional boundaries, 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 AC 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 23-1 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 (Stoate *et al.*, 2009). Intensively managed ecosystems contribute mostly to vital provisioning services (e.g. agro-ecosystems provide food via crops and livestock, and forests provide wood). The condition of the majority of services shows either a degraded or mixed status across Europe with some exceptions, however, such as the recent enhancements in timber production and climate regulation in forests (Harrison *et al.*, 2010). Appropriate agricultural management practices are critical to realizing the benefits of ecosystem services (Power, 2010). Table 23-2 summarises the potential implications of climate change for ecosystem services in Europe.

[INSERT TABLE 23-2 HERE
Table 23-2: Impacts of climate change on ecosystem services.]

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) (AQEP, 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. Climate warming also affects 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. Fire events have had an impact on local on air quality (Hodzic *et al.*, 2007; Liu *et al.*, 2009; Miranda *et al.*, 2009).

23.6.2. Soil Quality

The current cost of erosion, organic matter decline, salinisation, landslides and contamination is estimated to be EUR 38 billion annually for the EU25 (JRC-EEA, 2010), currently borne by society in the form of damage to infrastructures due to sediment runoff and landslides, treatment of water contaminated through the soil, disposal of sediments, depreciation of land around contaminated sites, increased food safety controls, 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). Soil water content will decline, saturation conditions 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). For the A2 emission scenario and a set of land use scenarios 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). However, a case study on cropped systems in Upper-Austria based on the A2 emission scenario (regional climate model HadRM3H) projects a small reduction in average soil losses under climate change in all tillage systems, however with high uncertainty (Scholz *et al.*, 2008). For a case study hillslope in Northern Ireland, with the A2 scenario downscaled GCMs generally result in erosion decreases, whereas large increases are projected when land use is changed from the current cover of grass to an arable crop which requires annual tillage (Mullan *et al.*, 2012). For scenario period 2071-2100, climate-change-induced changes in suspended sediment transport would increase for two Danish river catchments by 17 and 27% in alluvial and non-alluvial rivers, respectively, for steady-state land use scenarios (Thodsen, 2007; Thodsen *et al.*, 2008).

Under a business as usual land management scenario, taking into account the impacts of climate change on net primary productivity, a comparison of three soil models forced by climate scenarios derived from the HadCM3 climate model indicate a 10 % decline by 2070 in the organic carbon stocks of mineral soils for the croplands of European Russia and the Ukraine. Part of this decline could be mitigated by an environmentally sustainable management scenario (Smith, 2007). For EU25 plus Switzerland and Norway, projections under the A2 scenario for 1990 to 2080 of mineral soil organic carbon stocks in cropland and grassland soils show a small increase in soil carbon on a per area basis under future climate (+1 to +8%) for cropland and (+3 to +6%) for grassland (Smith J. *et al.*, 2005.). Similar values of soil organic C stock increase were simulated by a pasture model under the A1B climate scenario for two French grassland sites (Graux *et al.*, 2012). In these studies, soil carbon decline was faster in regions experiencing rapid warming combined with high soil moisture (e.g. Northern Europe), than in regions exposed to increased drought incidence (e.g. Southern Europe).Climate change may affect the distribution and degradation of organic pollutants, including persistent organic pollutants (Valle *et al.*, 2007).

Adaptive land-use management has a large potential for climate change response strategies concerning soil protection. In central Europe, compared to unsustainably high soil losses for 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 cover is a win-win management strategy that will reduce erosion and loss of soil carbon, and protect a variety of services such as the continued delivery of a high quality water resource (House *et al.*, 2011)(McHugh, 2007). By absorbing up to twenty times its weight in water, increased soil organic matter can contribute to reduce risks of flooding. Maintaining water retention capacity is thus important, e.g. through adaptation measures (Post *et al.*, 2008). Soil conservation methods like zero tillage and conversion of arable to grasslands would maintain their protective effect on soil resources, independent of the climate scenario according to an up-scaling and modelling approach in SW-Germany that considered, however, in limited way climate-induced changes in the frequency and intensity of heavy rainstorms (Klik and Eitzinger, 2010).

23.6.3. Water Quality

Climate change may affect water quality in several ways, with implications for food production and forestry (see above 23.4.3), ecosystem functioning (Table 23-2), human and animal health, and compliance with European and national quality targets including those of the Water Framework Directive. Overall, because of the high heat capacity of water, shallow waters will witness a more rapid temperature increase and a parallel decrease in saturating oxygen concentrations. Since AR4, there is further evidence of adverse effects caused by short-term weather events: reductions in dissolved oxygen, algal blooms (Ulén and Weyhenmeyer, 2007)(Mooij *et al.*, 2008) 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 P-retention and reduce P-load to downstream higher order streams (Hellmann and Vermaat, 2012).

Future impacts of climate change on water quality include increased nutrient fluxes (Delpla *et al.*, 2011); impacts from increased water temperature and discharge reduction in the Seine river (Ducharne, 2008) and increased nutrient loads in Danish watersheds (Andersen *et al.*, 2006); increased summer temperature and drought leading to more favourable conditions for algal blooms and reduced dilution capacity of effluent in the Meuse river (van Vliet and Zwolsman, 2008). Several studies have investigated potential adverse impacts on nutrient flushing episodes and surface water quality in the UK (Whitehead *et al.*, 2006; Whitehead *et al.*, 2009)(Wilby *et al.*, 2006; Howden *et al.*, 2010; Macleod *et al.*, 2012)(See also AR5 WG2 Chapter 4.3.2.5). A modelling study on projected future water quality impacts for all EU27 countries indicated increased nutrient loadings in Northern Europe due to increased surface runoff in Southern Europe due to increased evapotranspiration (Jeppesen *et al.*, 2011).

23.6.4. Terrestrial and Freshwater Ecosystems

Habitats

Current and future climate changes have negative effects of habitat loss on species density and diversity (Mantyka-pringle *et al.*, 2012). Potential habitat shrinkage is occurring even when CO_2 physiological effects and water availability are taken into account (Rickebusch *et al.*, 2008).

Projected habitat loss is greater for species at higher elevations where, up to 36–55% of alpine plant species, 31–51% of subalpine plant species and 19–46% of montane plant species will lose more than 80% of their suitable habitat by 2070–2100 under B1and A1FI scenarios respectively (Engler *et al.*, 2011). Habitats of 150 alpine plant species on European Alps will suffer an average range size reduction of 44-50% and on average 40% of the range still occupied at the end of the century will be climatically unsuitable creating an extinction debt (Dullinger *et al.*, 2012). Suitable climatic conditions for Europe's breeding birds are projected to shift nearly 550 km northeast by the end of the century (Huntley *et al.*, 2007). In Great Britain mean altitude of the uplands is projected to increase for both B1 and A1FI scenarios by 2071–2100 with important implications on habitats, with in the eastern and southern regions low altitude areas (< 300 meters) being the most vulnerable (Clark *et al.*, 2010a).

In respect to the baseline distribution (1961-1990), British blanket peat and sub-arctic palsa mires, will reduce substantially suitable area by the period 2030-2049 under A1B and A2 emission scenarios (Fronzek *et al.*, 2006; Fronzek *et al.*, 2010; Gallego-Sala *et al.*, 2010; Clark *et al.*, 2010b; Fronzek *et al.*, 2011). Also changes in low flows result in reduction of fen and bog areas becoming marginal or unsuitable due to dryness (Harrison *et al.*, 2008). Across most of central, eastern and southern Europe, reduced hydro periods (the length of time and portion of year the wetland holds ponded water) and increased temperatures with parallel reduced oxygen in shallow waters and wetlands will have profound impacts on aquatic habitats and habitat connectivity in river networks may become increasingly fragmented (Elzinga *et al.*, 2007; Della Bella *et al.*, 2008; Blaustein *et al.*, 2010; Gómez-Rodríguez *et al.*, 2010; Hartel *et al.*, 2011; Morán-López *et al.*, 2012; Morán-López *et al.*, 2012).

Despite some local successes and increasing responses (including extent and biodiversity coverage of protected areas, sustainable forest management, policy responses to invasive alien species, and biodiversity-related aid), the rate of biodiversity loss does not appear to be slowing (Butchart *et al.*, 2010). Protected areas play a key role for conservation of biodiversity under climate change compared to unprotected areas, although by 2080, 58 ± 2.6% of the species would lose suitable climate in protected areas. Natura 2000 areas will be not effective or more impacted than unprotected areas, under A1FI, A2, B1, B2 scenarios (Araújo *et al.*, 2011). Similar concerns about effectiveness of protected areas are found for butterflies in Germany (Filz *et al.*, 2012). It has been highlighted the importance of taking into account the climate change projections on the selection of conservation areas (Araújo *et al.*, 2011; Filz *et al.*, 2012; Virkkala *et al.*, 2013).

Plant species

Observed changes in plant communities in European mountainous regions show a shift of species' ranges to higher altitudes due to climate warming (Pauli *et al.*, 2012) resulting in species richness increase in boreal-temperate mountain regions (+3.9 species on average) and decrease in Mediterranean mountain regions (–1.4 species) in 2001-2008 (Pauli *et al.*, 2012). Decline of the more cold adapted species and increase of the more warm-adapted has been observed, suggesting a progressive decline of cold mountain habitats and their biota (Gottfried *et al.*, 2012). The pollen season starts on average 10 days earlier than 50 years ago, an advance of 2.5 days per decade of spring and summer (Feehan *et al.*, 2009).

The most dramatic changes for plant species could occur in Northern Europe, where more than 35% of the species composition in 2100 could be new, and in Southern Europe, where up to 25% of the species now present would disappear (Alkemade *et al.*, 2011). Large range contractions up to 72% in 2080 due to climate change is projected for temperate tree species in European lowlands under A2 scenario (Casalegno et al., 2007). The increase in climatic aridity may compromise the survival of several populations of *Pinus sylvestris* in the Mediterranean basin

(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 scattered distributions of tree species, exacerbated in many cases by human activity, may make them more vulnerable to climate change because they probably have less ability to reproduce or adapt to shifting climate space than more widespread species (del Barrio *et al.*, 2006; Hemery *et al.*, 2010). By 2100, 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).

Animal species

Breeding seasons are lengthening, allowing extra generations of temperature-sensitive insects such as butterflies, dragonflies and pest species to be produced during the year (Feehan *et al.*, 2009). Climate change is altering the timing of spring migration of several bird species with species-specific response (Jonzén *et al.*, 2006; Rubolini *et al.*, 2007a; Rubolini *et al.*, 2007b). Climate change, together with land-use change, is likely to cause impacts on the abundance of birds of different breeding habitat, latitudinal distribution, and migratory behaviour, particularly on distance migrants (Jonzén *et al.*, 2006). Farmland birds and long-distance migrant species in Germany, Switzerland, and Austria declined whereas wetland bird species with southerly ranges increased in abundance (Lemoine *et al.*, 2007a; Lemoine *et al.*, 2007b). A northward shift in bird community composition has been observed (Devictor *et al.*, 2008) even if common species of European birds with the lowest thermal maxima showed the sharpest declines between 1980 and 2005(Jiguet *et al.*, 2010). Northern European species of butterflies appeared to be the most vulnerable in Europe (Heikkinen *et al.*, 2010). However, there is much species-to-species variation with individualistic response to climate change leading to the formation of new future non-analogous communities with species composition unlike any found today (Keith *et al.*, 2009).

Projections for 120 native terrestrial non-volant European mammals suggest that up to 5-9% are at risk extinction during the 21st century, while 32-46% or 70-78% may be severely threatened under A1 and B2 climatic scenarios (Levinsky *et al.*, 2007). Climate cooling would be more deleterious for the persistence of amphibian and reptile species than warming, even if decreases in the availability of water will be also problematic (Araújo *et al.*, 2006). Changes in temperature and precipitation will result in both changes in migratory species and adaptation of migratory activity (Schaefer *et al.*, 2008). Furthermore phenotype adaptation may allow species to persist *in situ*, conserving community composition (Schaefer *et al.*, 2008). However, populations not showing a phenological response to climate change fail to adjust to climate change and may decline (Molnar *et al.*, 2008) or causing ecological mismatches (Saino *et al.*, 2011). Climate change can affect trophic interactions, as co-occurring species do not necessarily react in a similar manner to global change (Schweiger *et al.*, 2012). Novel emergent ecosystems composed of new species assemblages arising from differential rates of range shifts of species can occur (Montoya and Raffaelli, 2010).

Invasive species

Climate change can exacerbate the threat posed by invasive species to biodiversity, both by direct and indirect effects such as changes to farm practices and introductions of exotic material and effects of other environment changes such as elevated CO_2 concentration and change in temperature and precipitation (West *et al.*, 2012). The western corn rootworm (maize pest in North America) has invaded Europe in recent years (Aragòn and Lobo, 2012). The 22.2% of the total number of mammal species in Europe are alien species (Genovesi *et al.*, 2012). Planktonic species typically encountered in tropical areas were observed in natural shallow lakes in the southwest of France during 2006 and 2007 possibly as a result of minimum temperatures increases registered over the last 30 years and could have played a key role in algal survival through winter (Cellamare *et al.*, 2010). The woody shrub Lantana (*Lantana camara* L.) that is highly invasive in many countries of the world may become climatically suitable under future climates in Europe (Taylor *et al.*, 2012). Climate scenarios of milder conditions for Atlantic Europe could lead to Giant rhubarb (*Gunnera tinctoria* (Molina) Mirbel.) and Brazilian giant rhubarb (*Gunnera manicata* L.) becoming more widely invasive (Skeffington and Hall, 2011). However the threat posed by invasive species to biodiversity should be carefully considered as some studies demonstrate that fewer than 15% of species have more than 10% of their invaded distribution outside their native climatic niche (Petitpierre *et al.*, 2012).

23.6.5. Coastal and Marine Ecosystems

Climate change will affect Europe's coastal and marine ecosystems, 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) with changes in eutrophication, invasive species, species range shifts, changes in fish stocks and habitat loss (Doney *et al.*, 2011)(EEA, 2010e). The degree to which these changes will impact Europe's coasts and seas will vary temporally and spatially, requiring a range of adaptation strategies, targeting different policy scales, 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 lead to more exposed coastal areas and storms, changing the coastal geomorphology (BACC, 2008)(HELCOM, 2007). Warming SSTs will continue to 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 varying rates of phenologies (Durant *et al.*, 2007), for example the reorganization in the timing and location of phytoplankton and zooplankton affects prey availability for North Sea cod (Beaugrand *et al.*, 2010)(Beaugrand and Kirby, 2010). Temperature-driven changes have affected the distribution of fisheries in all seas within the past 30 years, e.g., a decrease in the range of Atlantic cod in northern seas, while an increase in the abundance of coastal species such as the anchovy in subtropical regions. The range of the red mullet is increasing in extent from Norway to the northwest of Africa including the Mediterranean and Black Sea. In the Bay of Biscay, responses to climate change in 20 species of flatfish from 1987 to 2006 show that expanding species have a lower latitude range, than the declining species (Hermant *et al.*, 2010).

Warmer waters are also linked to invasive species which displace native species, further altering trophic dynamics, and productivity of coastal marine ecosystems, requiring a redefinition of invasive and native species (Molnar *et al.*, 2008)(Rahel and Olden, 2008). Changes in the semi-enclosed seas will be indicative of future conditions in other coastal-marine ecosystems (Lejeusne *et al.*, 2009). In the Mediterranean, a relatively high proportion of endemic species has been associated with the arrival of alien species at the rate of one introduction every 4 or 5 weeks in recent years (Streftaris *et al.*, 2005). While in the Mediterranean the endemic species distribution 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 (Beaugrand and Kirby, 2010).

Other future impacts of climate change in Europe's coastal-marine ecosystems include changes in circulation and nutrients in both open and semi-enclosed seas and coastal areas. Stratification of open seas will be primarily affected by the timing and strength of wind, whereas coastal areas will be vulnerable to storm surges (Philippart *et al.*, 2011). Freshwater input from melting of land-based ice has increased since the 1960s with a 10-30% increase from riverine input anticipated by 2100. Freshening of marine salinity is expected in upcoming decades throughout the North East Atlantic, with the Arctic freshening during the 21st century due to river run off, ice melt, and increases in the rate of the global water cycle. Drier summers along Biscay and Iberian coasts may lead to a decrease in nutrient input and enrichment with less runoff. Eutrophication will continue as a major issue in the Baltic (HELCOM, 2009). Yet, wetter winters and summers in the Arctic and North Sea may lead to higher nutrient input (OSPAR, 2010). Eutrophication and deteriorating marine water quality will lead to fewer fish, more jelly fish and more frequent algal blooms particularly in the semi-enclosed seas such as the Baltic (HELCOM, 2009). Before the end of 2100, surface waters of the Baltic Sea could inhibit calcium forming species, more so than the Black and Mediterranean Seas (CIESM, 2008).

Dune systems will be lost due to coastal erosion from combined storm surge and sea level rise in some places, requiring restoration and economic measures (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 and sea defences may lead to narrower coastal zones ("coastal squeeze") (EEA, 2010e)(Jackson and McIlvenny, 2011)(OSPAR, 2010).

23.7. Cross-Sectoral Adaptation Decision-making and Risk Management

Most scientific studies on impacts and adaptation in Europe consider single sectors or outcomes, and have been discussed in previous sections of this chapter. For decision-making, more comprehensive and multi-sectoral approaches are required.

Since AR4, considerable progress has been made to advance planning and implementation of adaptation measures as well as the costing of adaptation (Section 23.7.6). Many European countries have now developed a series of national studies and strategies to address adaptation (see Box 23-2). The European Union has started a process of adaptation planning, focussing on information sharing (e.g. through the Climate Adaptation platform) as well as proposals for legislation following up on the White Paper on Adaptation (Dreyfus and Patt, 2012) and the EU Adaptation Strategy (to be published in March 2013).

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Box 23-2. National and Local Adaptation Strategies

Several studies have evaluated national or local adaptation strategies with respect to implementation (Biesbroek *et al.*, 2010). Many adaptation strategies were found to be agendas for further research, awareness raising and/or coordination and communication for implementation (e.g. (Pfenniger *et al.*, 2010)(Dumollard and Leseur, 2011). Actual implementation often relates to natural hazard prevention, environmental protection, 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)(Biesbroek *et al.*, 2010)(Swart *et al.*, 2009) found for seven national adaptation strategies 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. 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, 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 cross-sector impact and adaptation linkages as an important weakness in the city plans (Hunt and Watkiss, 2011). Flexibility in adaptation decision making needs to be maintained (Hallegatte *et al.*, 2008)(Biesbroek *et al.*, 2010).

_____ END BOX 23-2 HERE _____

23.7.1. Coastal Zone Management

Coastal zone management and coastal protection plans that integrate adaptation concerns are now implemented. Underlying scientific studies increasingly assess effectiveness and costs of options (Hilpert *et al.*, 2007)(Kabat *et al.*, 2009)(Dawson *et al.*, 2011) (see also section 23.7.6). Measures to mainstream adaptation into sectoral policies need to provide early response measures for floods and coastal erosion, and ensure that climate change considerations are incorporated into marine strategies with mechanisms for regular updating (OSPAR, 2010; UNEP, 2010).

In the Dutch plan for coastal protection (Delta Committee, 2008), adaptation to climate change, increasing river runoff and sea level rise plays a prominent role. It also includes synergies with nature conservation, increasing storage for water supply (Kabat *et al.*, 2009), and links to urban renovation. Its 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 increasing compartimentalisation 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 the Thames Estuary and London from future storm surges and flooding (Environmental Agency, 2009). An elaborate analysis has provided insight in the pathways for different adaptation options and decisions that depend on the eventual sea-level rise.

23.7.2. Integrated Water Resource Management

Water resources management has experienced a general shift from "hard" to "soft" measures which 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.*, 2012) 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 (Kwadijk *et al.*, 2010; Haasnoot *et al.*, 2012). 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). A study of policymakers, including local basin managers, identified several important barriers to the implementation of adaptation strategies in the water sector (Brouwer *et al.*, 2013).

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, as well as other proposals to reduce impacts from natural hazards and improve civil protection response. But most countries have so far focussed on hazard assessment and less on analysis 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, responsive measures, as well as other options for insuring and transferring losses (see SREX report; and 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

Through effects on land use and the spatial configurations of cities, spatial planning policies can build resilience to the impacts of climate change (Bulkeley, 2010). However, the integration of adaptation considerations into spatial planning is limited to a general level of policy formulation that lacks concrete instruments and measures for implementation in practice (Mickwitz *et al.*, 2009)(Swart *et al.*, 2009). There is evidence to suggest a systematic failure of planning policy to account for climate and other environmental changes (Branquart *et al.*, 2008) and a lack of institutional frameworks in support of adaptation is a major barrier to the governance of adaptation through spatial planning (ESPACE, 2007). In many countries, climate change adaptation is treated primarily as a water management or flooding issue, which omits other important aspects of adaptation leading to partial solutions (Mickwitz *et al.*, 2009)(Wilson, 2006)(Van Nieuwaal *et al.*, 2009). For example, in the UK, surveys of local authorities found an overall increase in the area covered by buildings in areas at risk from flooding compared with change across the locality as a whole (2001-2011) (ARUP, 2011).

City governance is also dominated by the issues of climate mitigation and energy consumption rather than assisting cities in adapting to climate change through spatial planning (Bulkeley, 2010). 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 urban environment in the cities of Helsinki, Espoo, Vantaa and Kauniainen, and their surroundings with approximately 1.2 million inhabitants (ca. 20% of the Finnish population). It includes approaches for dealing with increasing heat waves, more drought periods, milder winters, increasing (winter) precipitation, heavy rainfall events, river floods, storm surges, drainage water floods and sea level rise.

Green infrastructure provides climate adaptation and mitigation benefits as well as offering a range of other benefits to urban areas, including health improvements, better amenity value, inward investment, increasing property values and the reduction of noise and air pollution. Thus green infrastructure is an attractive climate adaptation strategy since it simultaneously 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 (Wilson, 2008).

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 will involve several strategies that 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.

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. A significant number of 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. For other sectors, such as health and welfare, estimates are generally lacking. Table 23-3 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, the large differences in the cost estimates between coastal and river protection in Europe and the Netherlands (Table 23-3) are due to the objectives for adaptation and the large differences in the level of acceptable risk: e.g. Rojas *et al.* (2012) 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 23-3 HERE
Table 23-3: Adaptation cost estimates for European countries.]

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

The impacts of and responses to climate change cannot be considered in isolation. 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 policies (Mokrech *et al.*, 2012). 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 (Zylicz, 2010). 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 policy (decarbonisation strategies) is 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 (Davies and Oreszczyn, 2012). Energy efficiency interventions may effect indoor summer temperatures, some acting to reduce temperatures and others acting to increase temperatures (Mavrogianni *et al.*, 2012) and on the concentration of indoor pollutants (Shrubsole *et al.*, 2012). The effect of mitigation measures such as electrical equipment improvements is more complicated; a simulation of a typical UK office indicated that the reduction of internal heat gains as a result of more energy efficient PCs, low energy LCD display technology, improved power management and energy efficient lighting can reduce the peak cooling requirement by up to 27% even under a 2030 warming climate, i.e. +1 ^{o}C compared to 2005 (Jenkins *et al.*, 2008; Jenkins, 2009). However, as space heating requirements would also increase following these interventions, 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. There have been few studies on the future demand for energy-intensive space cooling in Europe, although the majority of energy modelling studies assume increased uptake driven by climate and non-climate factors (see chapter 10). 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, consequently increasing energy consumption and thus greenhouse gases emissions.

In tourism, adaptation and mitigation may be antagonistic, as in the case of artificial snowmaking in European skiing 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 European Union (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 suggest a significant decline of the forest carbon sink until 2030 in the baseline scenario of about 25–40 compared to 2010 estimate. Including additional bioenergy targets of EU member states has an effect on the development of this sink, which is not accounted in the EU emission reduction target (Bottcher *et al.*, 2012).

Many agricultural practices can potentially mitigate GHG emissions, the most prominent of which are improved cropland and grazing land management and restoration of degraded lands and cultivated organic soils (Smith and Olesen, 2010). Reducing excesses of nitrogen fertilization and substitution of mineral N fertilizers by biological N fixation, as well as improved nutrition of domestic ruminants to reduce methane from enteric fermentation and improved manure management can play a significant role. Lower, but still significant mitigation potential is provided by water and rice management and agro-forestry (Smith and Olesen, 2010). Preserving European soil and forest carbon stocks through careful land use planning and agricultural and forestry management will be required to avoid positive feedbacks on global warming (Schulze *et al.*, 2010) especially during heat and drought extreme events (Ciais *et al.*, 2005). Synergies and trade-offs between mitigation and adaptation need to be incorporated into economic analyses of the mitigation costs (Smith and Olesen, 2010).

In arable production systems, adapting by increasing the resilience to temperature and 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 adding 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). In contrast, increased irrigation under climate change will increase energy use and may reduce water availability for hydro-power (reduced mitigation potential) (Wreford *et al.*, 2010). Nevertheless, irrigation may enhance soil carbon sequestration in arable systems (Rosenzweig *et al.*, 2008)(Rosenzweig and Tubiello, 2007). In livestock intensive systems, warmer conditions in the coming decades might trigger the implementation of enhanced cooling and ventilation systems (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 (Fitzgerald *et al.*, 2010)(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).

Mitigation measures may encourage the production of energy crops, or forestry, in areas that are vulnerable to extreme events (e.g. fires, storms, droughts) or with high water demand, therefore increasing demands on adaptation (Wreford *et al.*, 2010). Conversely, the potential expansion of agriculture at high latitudes may release large amounts of carbon and nitrogen from organic soils, thereby leading to increased demands on mitigation (Rosenzweig and Tubiello, 2007). Available land for bioenergy crops is foremost to be found in Eastern Europe (De Wit *et al.*, 2011). The total available land in Europe (EU27 and Ukraine) for bioenergy crop production could amount to 900 000 km^2 by 2030. Agricultural residues of food and feed crops may provide an additional source for biofuel production. Up to 246 Mt agricultural residues could be available for biofuel production (assuming up to 50% of crop residues can be used without risks for agricultural sustainability) which is comparable to feedstock plantations of 15-20 million hectares (Fischer *et al.*, 2010b). Bioenergy crops could occupy significant areas of rural land within 20 years in the UK (Haughton *et al.*, 2009).

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

Marine protected areas (MPAs) provide place-based management of marine ecosystems through various degrees and types of protective actions. MPA networks are generally accepted as an improvement over individual MPAs to address multiple threats to the marine environment. While MPA networks are considered a potentially effective management approach for conserving marine biodiversity, they should be established in conjunction with other management strategies, such as fisheries regulations and reductions of nutrients and other forms of land-based pollution. Information about interactions between climate change and more "traditional" stressors is limited. MPA managers are faced with high levels of uncertainty about likely outcomes of management actions because climate change impacts have strong interactions with existing stressors, such as land-based sources of pollution, overfishing and destructive fishing practices, invasive species, and diseases. Management options include ameliorating existing stressors, protecting potentially resilient areas, developing networks of MPAs, and integrating climate change into MPA planning, management, and evaluation (Keller *et al.*, 2009). Results in a Mediterranean coastal zone demonstrate that the declaration of a marine reserve alone does not guarantee the sustainability of marine resources and habitats but should be accompanied with an integrated coastal management plan (Lloret and Riera, 2008).

Figure 23-8 illustrates the consequences of the relationships between mitigation and adaptation options and biodiversity (Paterson and Lima, 2010)(Paterson *et al.*, 2009). There are very few management approaches that are win-win-win in terms of mitigation, adaptation and biodiversity and some of these (e.g. forest pest control) have limited implications in terms of adapting to climate change. Other adaptation options, such as desalinisation, sea defences and flood control infrastructure have decidedly negative effects on both mitigation and biodiversity. However, some approaches, such as forest conservation and urban green space (see earlier) have multiple benefits and potentially significant effects.

[INSERT FIGURE 23-8 HERE
Figure 23-8: Adaptation and mitigation options and their effects on biodiversity. Based on Paterson et al., 2009.]

There has been relatively little research about the impacts of future land use demand for bioenergy production, food production and urbanisation on nature conservation.

23.9. Intra-Regional and Inter-Regional Issues

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 (Metzger *et al.*, 2008; Lung *et al.*, 2012)(Acosta-Michlik *et al.*, 2013; Greiving et al., ESPON). 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. Eastern European countries have, in general, lower adaptive capacity than Western or Northern European countries.

23.9.1. Implications of Climate Change for Distribution of Economic Activity within Europe

Table 23-4 summarises the future impacts by each sub-regions. A key finding is that all 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 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, agriculture, and forestry.

[INSERT TABLE 23-4 HERE
Table 23-4: Assessment of future climate change impacts by sub-region and sector (by 2050, medium emissions).]

Economic assessments of impacts across sectors and across Europe indicate large variations across subregions (Ciscar *et al.*, 2011). Annual loss in household welfare in the EU27 resulting from the four market impacts (agriculture, river floods, coastal areas, and tourism) would range between 0.2-1% by 2080s (Ciscar *et al.*, 2011). Northern Europe is the only region project to have net economic benefits in these sectors, driven mainly by the positive effects on agriculture. Coastal systems, agriculture, and river flooding are the most important of the four market impacts assessed.

Impacts of climate change losses on local economies are more serious in a large-scale scenario when neighbouring provinces are also affected by drought and heat wave events. This is due to the supply-side induced price increase leading to some passing on of disaster costs to consumers (Mechler *et al.*, 2010). Growing temperatures across Europe could affect the relative quality of life in different regions which in turn could change the intensity and direction of internal migration flows (as one factor in individuals migration decision making strategy could be temperature) (Kerr and Kerr, 2011).

Climate change may also affect policies regulating agriculture and fisheries across European sub-regions. The Less Favoured Areas (LFA) scheme is a broad European policy mechanism for improving the viability of agriculture in areas with natural handicaps. Land suitability for agricultural production is classified based on climate, soil, and terrain criteria. By 2030, part of Northern Europe would leave areas with climate constraint zone basically because of mean annual temperature increase, while part of central and South Europe would enter these areas as a result of increased aridity (Donatelli *et al.*, 2012). The European Union Common Fisheries Policy is also questioned by changes in the distribution of fish stocks which could affect total allowable catches and their allocations to member states (Arnason, 2012).

23.9.2. Climate Change Impacts Outside Europe and Inter-Regional Implications

In an increasingly globalised world, impacts of climate change in other countries are likely to affect countries within the Europe region. Further, the region is very closely linked to its near neighbours. Countries around the Mediterranean share similar ecologies and therefore some vulnerability (see Box 23-3; see also Chapter 22).

_____ START BOX 23-3 HERE _____

Box 23-3. Climate Change Impacts in the Mediterranean

The Mediterranean area (which encompasses two IPCC regions: Europe and Africa) is particularly vulnerable to climate change. Mediterranean ecosystems have been strongly modified from millennia of human occupation and use. At present, habitat loss and degradation, as well as extraction, pollution, eutrophication and the introduction of alien species, and recently climate change, are the most important threats that affect the greatest number of taxonomic groups occurring in the Mediterranean Sea (Costello *et al.*, 2010; Coll *et al.*, 2012). Areas with high marine biodiversity in the Mediterranean Sea are mainly located along the central and north shores, with lower values in the south-eastern regions (Coll *et al.*, 2012). Areas of potential high cumulative threats are widespread in both the western and eastern basins, with fewer areas located in the south-eastern region. The interaction between areas of high biodiversity and threats for invertebrates, fishes and large animals in general (including large fishes, marine mammals, marine turtles and seabirds) is concentrated in the coastal areas of Spain, Gulf of Lions, north-eastern Ligurian Sea, Adriatic Sea, Aegean Sea, south-eastern Turkey and regions surrounding the Nile Delta and north-west African coasts. Socio-economic factors are likely to increase competition for water and land degradation in the region (Hoff, 2012). Agricultural production will be exposed to increased heat waves and droughts with a potential for negative impacts that will be exacerbated by the competition for water with other sectors (see 23.4.3). It is uncertain if tourism flows will decline in the Mediterranean countries (see 23.3.6). Climate change is expected to trigger a more severe fire regime and more difficult conditions for ecosystem restoration after fire (Anav *et al.*, 2010)(Moriondo *et al.*, 2006)(Duguy *et al.*, 2012).

_____ END BOX 23-3 HERE _____

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 faciliated the spread of animal diseases (Conraths and Mettenleiter, 2011). Important "exotic" vectors that have become established in Europe include the vector *Aedes albopictus* (Becker, 2009) (see Section 23.5.1 above) and a novel vector of blue tongue virus (see 23.4.3).

Another inter-regional implication concerns the changes in the location of commercial fish stocks shared with non-member states. 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, in the North Atlantic, the mackerel stock has recently been extending beyond the EU jurisdiction into the Exclusive Economic Zones of Iceland and the Faroe Islands (Astthorsson *et al.*, 2012).

There are few robust studies of future climate-change related population movement either within or into the European region. 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, environmental resource depletion and weather disasters in future inter-continental population movements (Kolmannskog and Myrstad, 2009; Kolmannskog, 2010). 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.

23.10. Synthesis of Key Findings

23.10.1. Key Vulnerabilities

Context to key vulnerabilities:

- Many key vulnerabilities are already well known since the AR4, but some new vulnerabilities are emerging in AR5
- The policy/governance context in Europe is extremely important in determining key vulnerabilities (either mitigating or exacerbating vulnerability) since Europe is a highly regulated region.
- Vulnerability will be strongly affected by changes in the non-climate drivers of change (e.g. economic, social, governance, technological drivers), and for many sectors this will be more important than climate change.
- Future vulnerability will also be strongly affected by cross-sectoral (indirect) interactions, e.g. flooding-ecosystems, agriculture-species, agriculture-cultural landscapes, and so on.
- Extreme events (heat waves and droughts) have had significant impacts on populations as well impacts on multiple economic sectors, and resilience to future heat waves has only been addressed within some sectors.

Already known vulnerabilities (AR4) confirmed in AR5:

- More heat-related deaths and health issues due to an increase in heat waves, particularly in Southern Europe.
- Increases in pests and diseases, with implications for plant, animal and human health.
- Increase in energy demand in summer and reduction in winter.
- The key vulnerability for forests arises from species decline and increase in wild fires and pests and diseases
- Alpine species in particular are vulnerable to climate change (due to a lack of migration potential)
- The ski tourism sector is highly vulnerable to reductions in snow cover arising from warming
- Decrease of the hydropower potential in southern regions and increase in northern regions
- Reduced production in some thermal power plants due to cooling water shortages
- Coastal zones (including both natural environments and settlements) are highly vulnerable to sea level rise
- Settlements across Europe are vulnerable to flooding.

Emerging vulnerabilities:

- 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.
- Water will be less available and will be in increased demand and degraded state of water tables. There is the potential for increased competition between the agricultural, domestic, power sector, industrial and natural (animal and plant species) users of water. Future problems are likely to occur unless integrated water management is widely adopted.
- 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.
- New evidence regarding implications during summer on inland waterways (decreased access) and long range ocean transport (increased access).
- 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.
- 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.
- 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.
- Extreme events affect multiple sectors and have the potential to cause a systemic impact. 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.
- 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.
- 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: Multi-sectoral impacts of climate extremes during the last decade in Europe.]

23.10.2. 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. Climate 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 limited 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 ecological and human systems.]

23.10.3. 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.

Some specific research needs have been identified:
- More research on co-benefits and unintended consequences of adaptation options, and the effects of adaptation in one sector on other sectors in Europe. For example, air conditioning.
- Improved economic tools and methods for costing and valuation of specific adaptation options including the use of this information in decision making.

- Synergies and trade-offs between mitigation and adaptation need to be further researched and incorporated into economic analyses of the mitigation costs.
- Effects of climate change on infrastructure and the built environment, in the context of adaptation and mitigation policies.
- Impacts from high end climate change (above 4°C), with a lack of impact studies in Europe.
- Resilience of cultural landscapes and communities, and how to manage adaptation, particularly low technology (productively marginal) landscapes
- Climate change impact on ecosystem services (including valuation of ecosystem services) and how this would contribute to the improvement of management of natural resources.
- Development /improvement of regional climate services (seasonal, decadal forecasts)
- Impact of climate change on rural development in order to inform policy in this area.
- Capacity of local and national government to respond to climate change.
- Information on governance (including local and national institutions) for adaptation in the built environment, and infrastructure, including flood defences, over-heating, urban planning.
- More research on the assessment and quantification of climate for tourism, as well as on the response of tourists to past and future marginal climatic conditions for tourism.
- More research on the impacts of climate change on transport, especially on the vulnerability of road and rail infrastructure in different regions, 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).
- [needs to be more specific] Better characterization of the determinants of changes in yield and food quality and improvement of technologies for precision farming.
- Research on the resilience/vulnerability of populations to extreme events, including responses to flood and heat wave risks.
- Development of better risk models for vector borne disease, including public health implications and for animal diseases.

A major barrier to research is lack of access to data, which is also variable across regions and countries, specifically socio-economic data, climate data, forestry, routine health data. Reasons include: government agencies require commercialisation, inappropriate confidentiality. There is a need for long term monitoring of environmental and social indicators and to ensure open and access to data (environment, crop, etc) for long term and sustainable research programmes. Cross-regional cooperation could also ensure compatability and consistency of parameters across the region.

Frequently Asked Questions

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

It depends where you want to live (and when). Coastal areas are affected by storm surges that will increase in frequency and extent due to sea level rise. 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 will need to strengthen their coastal defences (including the Netherlands, Germany, France, Belgium, Denmark, Spain and Italy). The decision to protect an area of coastline will depend on the value (market and non-market values) of the land, its infrastructure or economic productivity, and its conservation potential (valuing species or ecosystems). Some countries have already raised their coastal defence standards. More innovative options (than defence or abandonment) are also being explored such as to adapt dwellings and commercial buildings to occasional flooding. Upgrading coastal defenses can significantly reduce (but not fully eliminate) adverse impacts of sea level rise but coasts are also faced with erosion, excessive development, and other types of environmental degradation not related to climate change. 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.

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

New (emerging) diseases appear all the time and current diseases change distribution or prevalence (increases and decreases). The factors that determine whether a disease changes distribution include: importation from increased international travel of persons, vectors or hosts, changes in vector or host susceptibility, drug resistance, climate change, and land use or other habitat changes that affect vectors or hosts. Tropical diseases is a term used to describe diseases that are now only present in the tropics, but malaria was once endemic in Europe and its mosquito vectors are still present. Malaria is not established in Europe despite imported cases because infected persons are quickly detected and treated. Maintaining health surveillance is therefore extremely important. Finally, when an outbreak has occurred (i.e. the introduction of a new disease) determining the causes is very 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?

Agriculture is the most dominant European land use, accounting for almost half of the total EU27 land area. Europe is one of the world's largest and most productive suppliers of food and fibre, but also imports large amounts of agricultural commodities. A reduction in crop yields, particularly wheat in southern Europe, is expected under future climate scenarios. A shift in cultivation areas of added-value crops, such as wine, may also occur. Loss of food production may be compensated by increases in other European sub-regions, under normal climate variability and long term changes. However, if ability of the European market to sustain climate shock events is impaired, the region would require exceptional food importation.

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Table 23-1: Projected Changes of Selected Climate Parameters and Indices[1] for the Period 2071-2100 with Respect to 1971-2000 Spatially Averaged for Europe Sub-regions. The likely range defines the range of 66% of all projected changes around the ensemble median.

A) A1B scenario. Numbers are based on 9 (indicated with *) and 20 (indicated with **) regional model simulations taken from EU-ENSEMBLES project for the SRES A1B emission scenario.

Scenario A1B	Climate Parameters	Measure	Alpine	Atlantic	Continental	Northern	Southern
2071-2100 minus 1971-2000	**Mean annual temperature** in K [xx]	***Median***	***3,4***	***2,5***	***3,3***	***3,8***	***3,6***
		Min	2,8	1,9	2,1	3,2	2,3
		Likely in the range	**3,1 to 4,5**	**2,1 to 3,5**	**2,8 to 4,5**	**3,5 to 5,0**	**3,3 to 4,1**
		Max	5,4	4,7	5,7	5,8	5,5
	Frost days (1) per year [x]	***Median***	***-50***	***-24***	***-44***	***-54***	***-24***
		Min	-37	-13	-26	-38	-12
		Likely in the range	**-38 to -57**	**-15 to -34**	**-27 to -53**	**-40 to -55**	**-12 to -31**
		Max	-72	-39	-56	-71	-34
	Summer days (2) per year [x]	***Median***	***14***	***21***	***32***	***7***	***48***
		Min	4	9	21	3	33
		Likely in the range	**11 to 20**	**16 to 32**	**22 to 41**	**5 to 14**	**33 to 51**
		Max	21	34	43	27	51
	Tropical nights (4) per year [x]	***Median***	***3***	***8***	***21***	***4***	***47***
		Min	1	2	14	1	18
		Likely in the range	**2 to 9**	**6 to 17**	**16 to 35**	**1 to 7**	**35 to 52**
		Max	11	32	43	10	60
	Growing season length (5) days per growing season [xx]	***Median***	***47***	***41***	***52***	***41***	***36***
		Min	27	23	20	25	14
		Likely in the range	**34 to 56**	**33 to 51**	**33 to 62**	**27 to 46**	**27 to 41**
		Max	75	55	81	61	51
	Warm spell duration index (14) days per year [x]	***Median***	***57***	***44***	***42***	***67***	***91***
		Min	46	29	26	37	67
		Likely in the range	**51 to 84**	**35 to 72**	**37 to 69**	**47 to 96**	**85 to 112**
		Max	126	125	94	119	144
	Cold spell duration index (15) days per year [x]	***Median***	***-5***	***-5***	***-6***	***-6***	***-5***
		Min	-4	-4	-4	-5	-3
		Likely in the range	**-4 to -5**	**-4 to -6**	**-5 to -6**	**-5 to -8**	**-4 to -5**
		Max	-8	-9	-9	-9	-8
	Annual total precipitation (27) in % [xx]	***Median***	***7***	***3***	***3***	***16***	***-15***
		Min	1	9	-9	4	-7
		Likely in the range	**5 to 12**	**-4 to 5**	**-1 to 5**	**13 to 21**	**-12 to -18**
		Max	15	-11	12	29	-25
	Annual total precipitation where RR>99p of 1971/2000 (26) in % [xx]	***Median***	***57***	***65***	***53***	***64***	***43***
		Min	35	28	31	32	21
		Likely in the range	**47 to 68**	**42 to 98**	**44 to 77**	**47 to 88**	**35 to 57**
		Max	117	112	110	105	74

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[1] Index definition from http://cccma.seos.uvic.ca/etccdi/list_27_indices.shtml

B) RCP4.5 scenario. Numbers are based on 7 (indicated with *) and 8 (indicated with **) regional model simulations taken from EURO-CORDEX project for the RCP 4.5 emission scenario.

Scenario RCP 4.5	Climate Parameters	Measure	Alpine	Atlantic	Continental	Northern	Southern
2071-2100 minus 1971-2000	**Mean annual temperature** in K [x]	***Median***	***2,3***	***1,7***	***2,0***	***2,8***	***2,0***
		Min	1,8	1,3	1,6	2,0	1,9
		Likely in the range	**1,9 to 2,6**	**1,4 to 1,7**	**1,6 to 2,3**	**2,0 to 3,1**	**1,9 to 2,1**
		Max	3,4	2,1	3,2	4,3	2,7
	Frostdays (1) per year [xx]	***Median***	***-39***	***-27***	***-34***	***-35***	***-20***
		Min	-25	-12	-16	-24	-10
		Likely in the range	**-26 to -41**	**-15 to -30**	**-18 to -38**	**-26 to -41**	**-11 to -25**
		Max	-47	-30	-40	-52	-29
	Summerdays (2) per year [xx]	***Median***	***8***	***11***	***20***	***4***	***27***
		Min	3	6	11	2	21
		Likely in the range	**4 to 11**	**7 to 14**	**13 to 24**	**2 to 13**	**25 to 33**
		Max	18	33	28	16	36
	Tropicalnights (4) per year [xx]	***Median***	***1***	***4***	***10***	***1***	***23***
		Min	0	0	2	0	7
		Likely in the range	**1 to 3**	**3 to 5**	**9 to 27**	**0 to 5**	**18 to 25**
		Max	8	18	30	7	41
	Growing season length (5) days per growing season [x]	***Median***	***25***	***36***	***22***	***19***	***24***
		Min	23	24	17	17	16
		Likely in the range	**23 to 35**	**27 to 40**	**20 to 29**	**19 to 27**	**17 to 31**
		Max	39	45	41	33	38
	Warm spell duration index (14) days per year [xx]	***Median***	***36***	***21***	***24***	***37***	***37***
		Min	27	18	18	22	30
		Likely in the range	**28 to 59**	**19 to 29**	**18 to 44**	**23 to 45**	**33 to 73**
		Max	70	56	53	65	83
	Cold spell duration index (15) days per year [xx]	***Median***	***-5***	***-4***	***-5***	***-6***	***-4***
		Min	-3	-4	-4	-5	-3
		Likely in the range	**-4 to -6**	**-4 to -5**	**-4 to -6**	**-6 to -7**	**-3 to -4**
		Max	-7	-6	-7	-7	-6
	Annual total precipitation (27) in % [x]	***Median***	***5***	***1***	***9***	***10***	***-6***
		Min	3	-1	0	7	-11
		Likely in the range	**4 to 7**	**-1 to 4**	**1 to 13**	**8 to 14**	**-10 to 0**
		Max	12	9	16	22	0
	Annual total precipitation where RR>99p of 1971/2000 (26) in % [x]	***Median***	***53***	***36***	***46***	***43***	***36***
		Min	24	20	17	27	23
		Likely in the range	**25 to 61**	**25 to 67**	**33 to 60**	**28 to 65**	**31 to 55**
		Max	73	73	74	70	62

Table 23-2: Assessment of climate change impacts on ecosystem services by sub-region and sector. Assessment assuming medium economic development, with land use change and no planned adaptation.

	Southern	**Atlantic**	**Continental**	**Northern**	**Alpine**
Provisioning services:					
Food production	Decreasing	Increasing to decreasing	No change to decreasing	Increasing to decreasing	Increasing to decreasing
Livestock production	Decreasing	Increasing to decreasing	Decreasing	Increasing	Increasing to decreasing
Fibre production					Decreasing
Bioenergy production	Decreasing			Increasing	Increasing
Fisheries production	No change to decreasing	No change to decreasing	Decreasing	No change to decreasing	
Timber production	Decreasing	No change to increasing	Increasing to decreasing	Increasing	Increasing to decreasing
Non-wood forest products	Decreasing			No change to increasing	
Regulating services:					
Climate regulation (carbon sequestration)					
- General/forests	Increasing to decreasing	No change to increasing	No change to increasing	Increasing to decreasing	Increasing
- Wetland	No change to decreasing	No change to decreasing	Decreasing	No change to decreasing	
- Soil carbon stocks	Decreasing	Increasing to decreasing	Decreasing	Decreasing	Decreasing
Pest control	Decreasing		Increasing	Increasing	Increasing
Natural hazard regulation					
- Forest fires regulation	Decreasing	Decreasing*	Decreasing*		
- Erosion, avalanche, landslide regulation					Increasing to decreasing
- Flooding regulation					Decreasing
- Drought regulation	Decreasing		No change to decreasing		
Water quality regulation		Decreasing		Decreasing	
Cultural services:					
Recreation (fishing, nature enjoyment)	Decreasing	Decreasing		Increasing to decreasing	Decreasing
Tourism (skiing)				Decreasing	Increasing
Aesthetic/heritage (landscape character, cultural landscapes)	Decreasing	Decreasing	No change to decreasing		Decreasing
Biodiversity	Decreasing	Increasing to decreasing	Decreasing	Increasing to decreasing	

* Forest fires or moorland wildfires increase

Table 23-3: Selected published adaptation cost estimates for European countries.

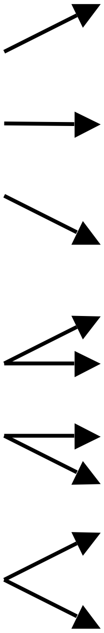
Population	Cost estimate	Time period	Sectors/Outcomes	Reference
Europe	€2.5–5 billion/a	By 2080s	Coastal protection	Brown et al., submitted b
Europe	€1.7 billion/a €3.4 billion/a €7.9 billion/a	By 2020s By 2050s By 2080s	Protection from river flood risk	Rojas et al., submitted
Netherlands	€1.2–1.6 billion/a €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	over period 2010-2100	Multi sector	Swedish Commission on Climate and Vulnerability, 2007
Greece	170-770 million €	2071-2100	Higher electricity generation cost resulting from higher summer energy demand for cooling	Mirasgedis et al., 2007
Cyprus	239 million €	2010-2030	Higher electricity generation cost resulting from higher summer energy demand for cooling	Zachariadis, 2010
Spain	8.8-30.6 million €/a	2008-2050	Higher costs to electricity users and costs paid in the carbon market (emissions trading)	Pilli-Sihvola et al., 2010
Europe (Rhine river)	194-263 million €	Future climatic conditions similar to those of 2003	Higher transport prices for goods as a result of load restrictions on inland ships (due to low river water levels in summer)	Jonkeren, 2009

Table 23-4: Assessment of climate change impacts by sub-region and sector (by 2050, medium emissions)
With economic development, with land use change. No further planned adaptation.

	Alpine	Southern	Northern	Continental	Atlantic	
Infrastructure						
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
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
River flood damages	?	?	?	↗ ↘	↗ ↘	23.3.1
Transport time and cost in ocean routes	?	?	↘	↘	?	23.3.3, 18.3.3.3.5
Length of ski season	→ ↘	?	↘	↘	?	23.3.6, 3.5.7
Food and Fibre production						
Wine production	?	↘	?	↗ ↘	↗ ↘	23.3.5, 18.3.3.1, 23.4.1
Arable Production	↗ ↘	↘	↗ ↘	→ ↘	↗ ↘	23.4.1
Livestock production	↗ ↘	↘	↗	→ ↘	↗ ↘	23.4.2
Water availability for agriculture	→ ↘	↘	→ ↘	↘	↘	23.4.3
Forest productivity	?	↘	↗	?	↗	23.4.4
Pest and plant diseases	↗	↗ ↘	↗	↗ ↘	↗ ↘	23.4.1, 23.4.4
Bioenergy production	?	↘	↗	?	?	23.4.5
Health and Social Impacts						
Heat wave mortality	→	↗	↗	↗	↗	23.5.1

Damage on cultural buildings	↗	↗ ↘	↗	↗	↗	23.5.4
Loss of cultural landscapes	↗	?	↗	↗	↗	23.5.4
Enviromental quality						
Air quality (ozone background levels)	?	?	?	?	?	23.6.1
Water quality	→	↘	→	→	↘	23.6.3
Local loss of native species and extinction of species	↗	↗	↗	↗ →	↗	23.6.4

Code. Green means a "beneficial change" and Red means a "harmful", ? No relevant literature found



Increasing

No change in

Decreasing

A range from no change to increasing

A range from no change to decreasing

A range from increasing to decreasing

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: Multi-sectoral impacts of climate extremes during the last decade in Europe.

Year	Region	Meteorological Event/ Breaking Record*	Production Systems and Physical Infrastructure, settlements	Agriculture, Fisheries, Forestry, Bioenergy	Health and Social Welfare	Environmental Quality and Biological Conservation
2003	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% (Aerts and Botzen, 2011)	Approx 35,000 deaths in August in Central and Western Europe (Robine *et al.* 2008)	Water quality. High outdoor pollution levels. (EEA 2012)
2004/ 2005	Iberian Peninsula	Hydrological drought		Grain harvest losses of 40% (EEA, 2010b)		
2007/ 2008	England and Wales, Southern Europe	May–July wettest since records began in 1766. Hottest summer on record in Greece since 1891 (Founda & Giannakopoulos 2009)	Disruption, economic loss and social distress turned the summer 2007 floods into a national catastrophe. Broad-scale estimated total losses were £4 billion (Chatterton et al. 2010),	Social distress.		
2010	Western Russia	Hottest summer since 150 (Barriopedro *et al.*, 2011)		Fire damage to forests. Crop yields	Heat mortality in Moscow region (Revich and Shaposhnikov, 2010)	High outdoor pollution levels. (Revich and Shaposhnikov, 2010.
2011	France	Hottest and driest spring on record in France since 1880	Reduction on snow cover for skiing	Decline in crop yields. (AGRESTE, 2011)		

* based on Coumou and Rahmstorf, 2012.

Table 23-6: Limits to Adaptation Measures in Europe.

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, 2010a; Steiger, 2010b) (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)
Forests	Fire incidence	landscape planning and fuel reduction	Higher flammability due to warmer and drier conditions	(Moreira *et al.*, 2011).

Table 23-6: Impact of observed changes in key indicators in ecological and human systems

Indicator	*Change in indicator*	*Confidence in detection*	*Confidence in attribution to change in climate factors [**]*	*Key references*	*Section*
Infrastructure, etc.					
Storm losses in Europe	Increase since 1970s	Increasing trend (high confidence)	No causal role for climate	Barredo, 2010	23.3.7
Hail losses	Increase in parts of Germany	Increasing trend (low confidence)	No causal role for climate	Kunz *et al.*, 2009	23.3.7
Flood losses	Increasing general trend in economic losses in Europe since 1970s; none in some locations	Increasing trend (medium confidence)	No causal role for climate	Barredo, 2009; Barredo et al., 2012	23.3.1
Agriculture					
Agriculture	CO2 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
Agriculture	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	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
Ocean systems	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
Health and Social Welfare					
Atopic disease	Increased allergic sensitization to pollens	Very low confidence (single study)	Very low confidence	Ariano *et al.* 2010	11.4
Cold-related mortality	Decline in cold related mortality in England and Wales	Low confidence (confounding)	Low confidence	Christidis et al. 2010	11.4
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	4.2.4.7
Migratory birds	Earlier arrival of migratory birds in Europe over the 1970/2000 period	Medium confidence (medium agreement, medium evidence)	Medium confidence	Moller *et al.*, 2008	4.4.1.1
Tree spices	Upward shift in tree line in	Medium evidence	Medium confidence	Gehrig-Fasel *et*	18.3.

	Europe	(medium agreement, high evidence)		*al.*, 2007, Lenoir *et al.*, 2008	2.1,
Forest fires	Area burnt	Increasing area	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- this is not attribution to anthropogenic forcing. See chapter 18 for a more complete discussion.*

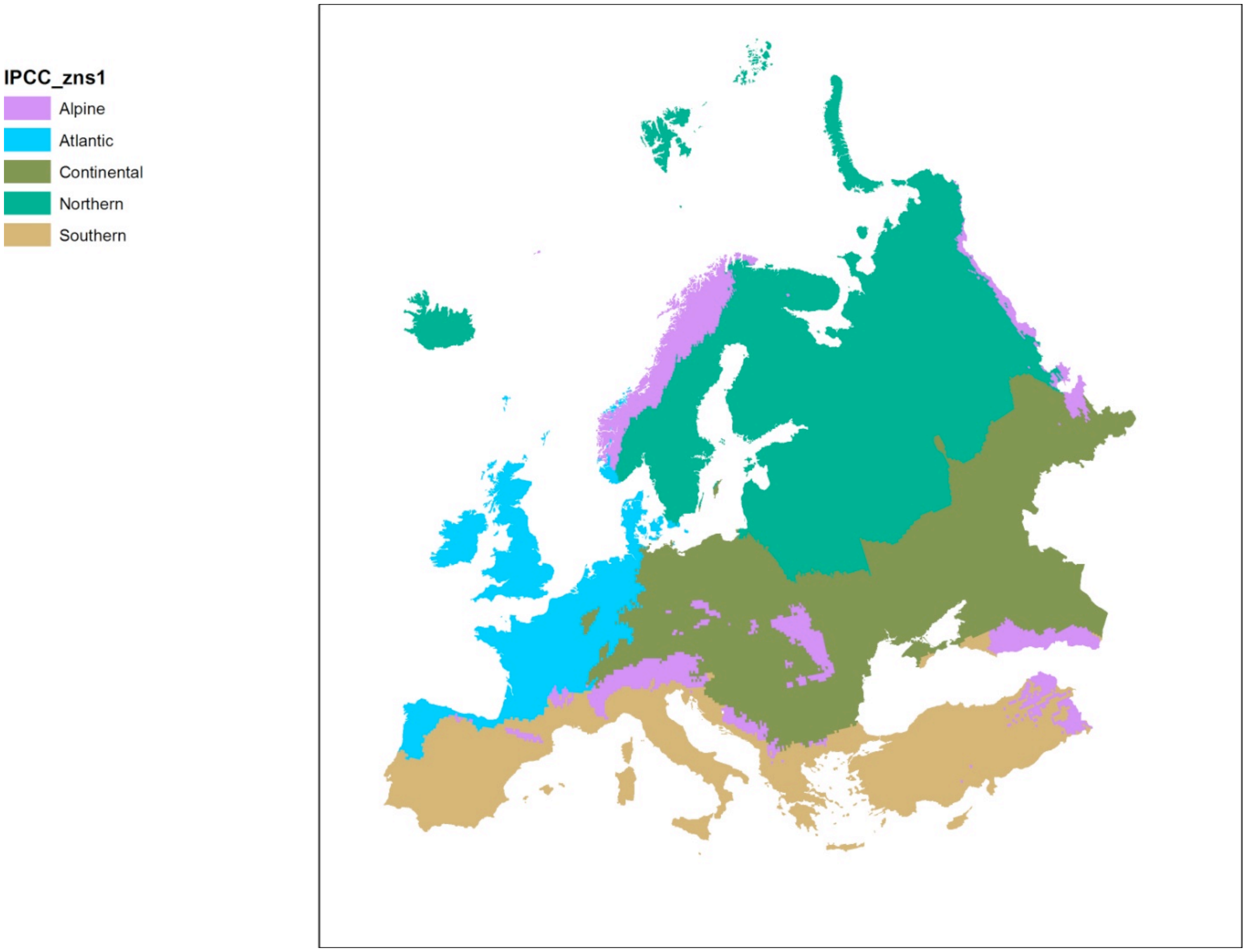
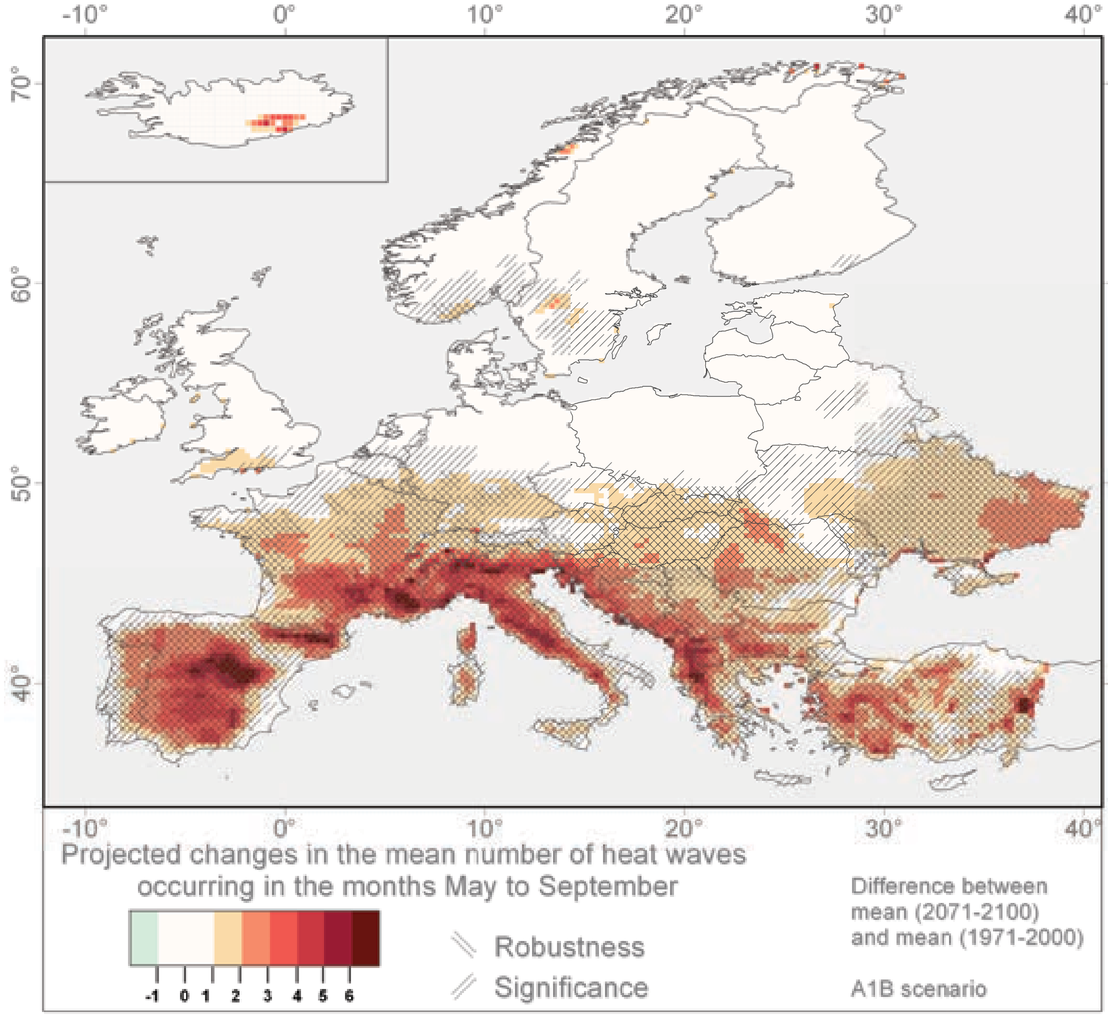


Figure 23-1: Sub-regional classification of the IPCC Europe region. Based on Metzger et al., 2005.

Figure 23-2: 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 season) (Jacob et al, 2013). Heat waves are defined as periods of more than 5 consecutive days with daily maximum temperature exceeding the daily maximum temperature of the May to September season of the control period (1971-2000) by at least 5°C. 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 part of Turkey, unfortunately no regional climate model projections are available.

A) Changes represent average over 9 regional model simulations (A1B) taken from the EU-ENSEMBLES project.



B) Changes represent average over 8 regional model simulations (RCP4.5) taken from the EURO-CORDEX project.

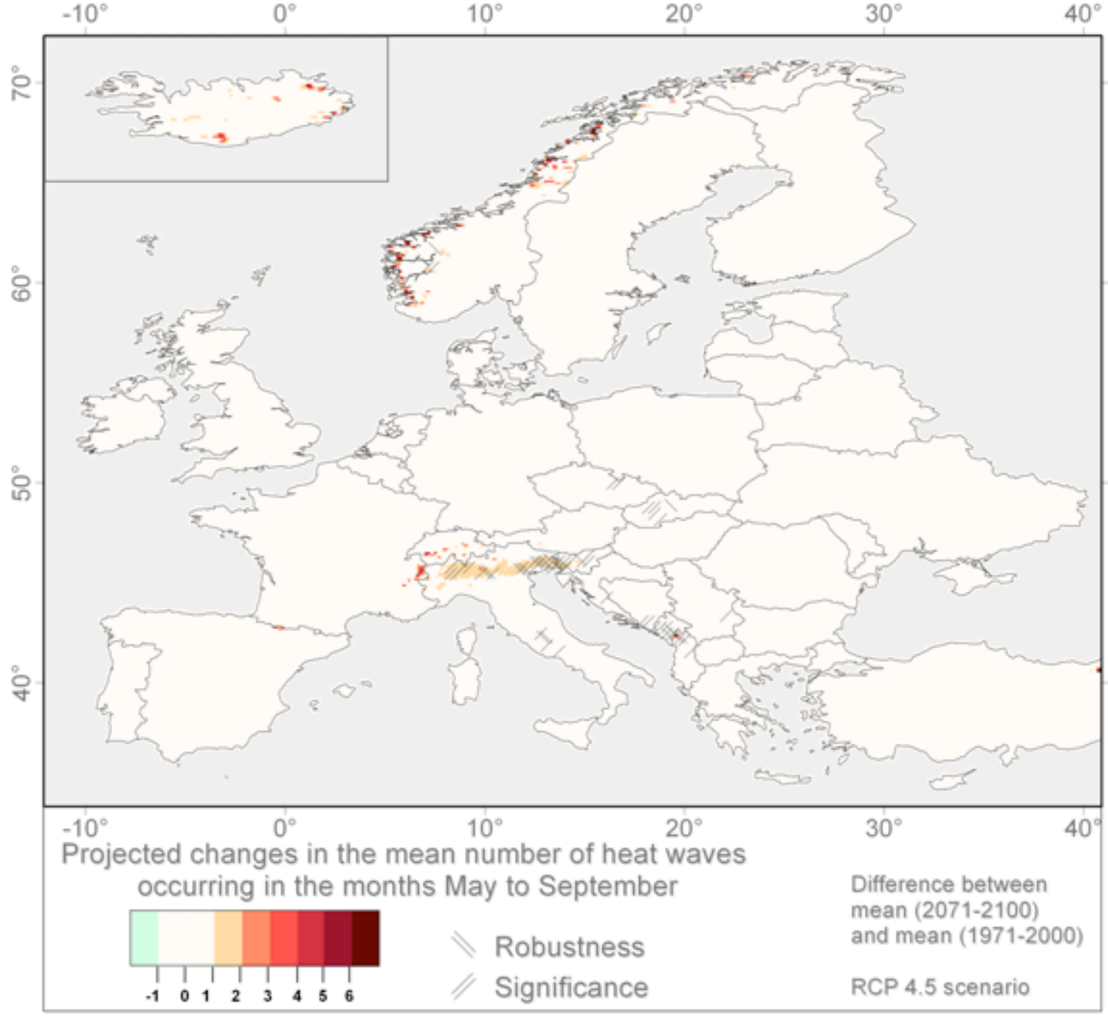
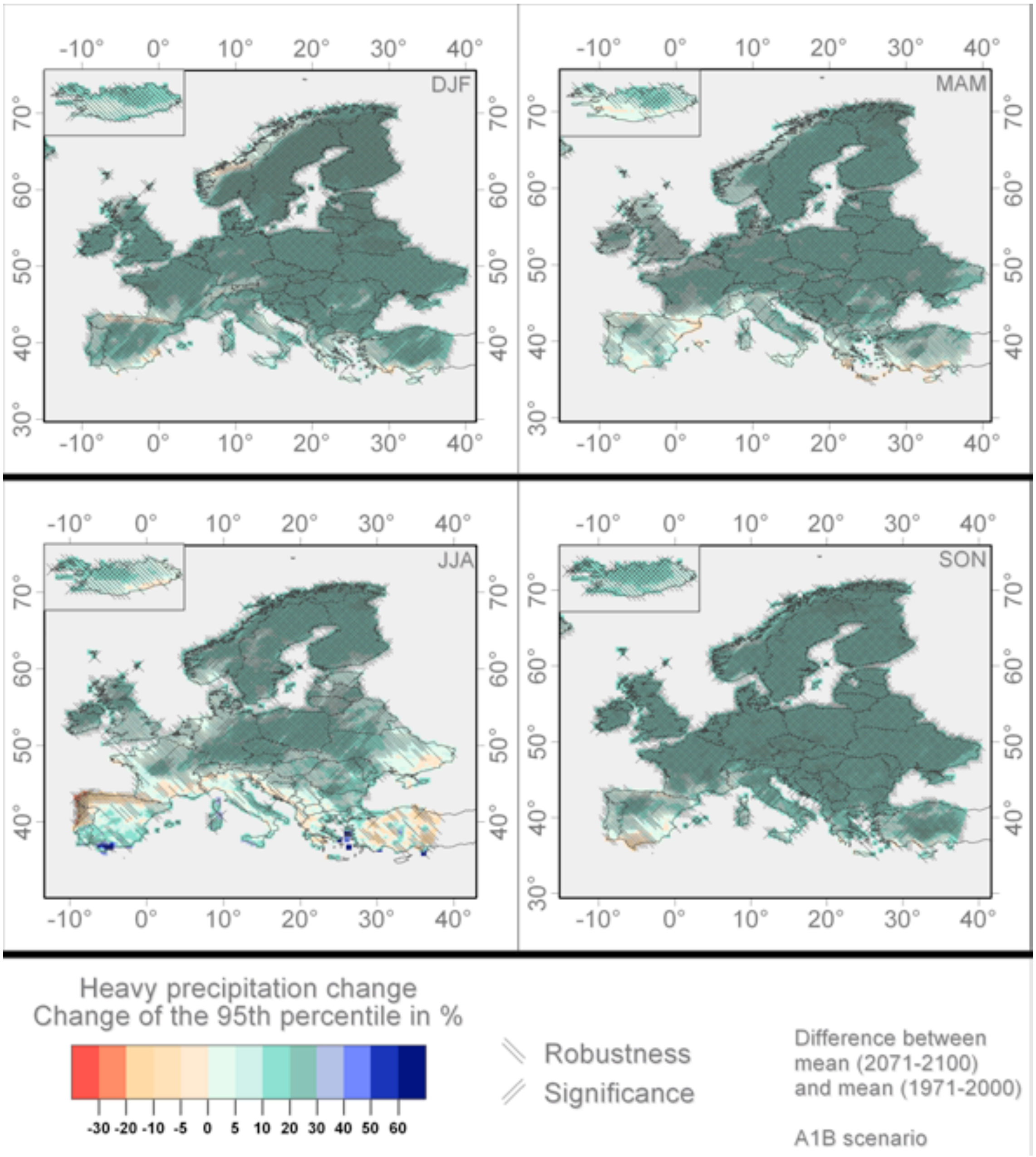


Figure 23-3: Projected seasonal changes of heavy precipitation defined as the 95th percentile of daily precipitation (only days with precipitation > 1mm/day are considered) for the period 2071-2100 compared to 1971-2000 (%) (Jacob et al., 2013). For the eastern part of Turkey, unfortunately no regional climate model projections are available. The figures are sorted as follows: left side: DJF, JJA; right side: MAM, SON. 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).

A) Changes represent average over 20 regional model simulations (A1B) taken from the EU-ENSEMBLES project.



B) Changes represent average over 7 regional model simulations (RCP4.5) taken from the EURO-CORDEX project.

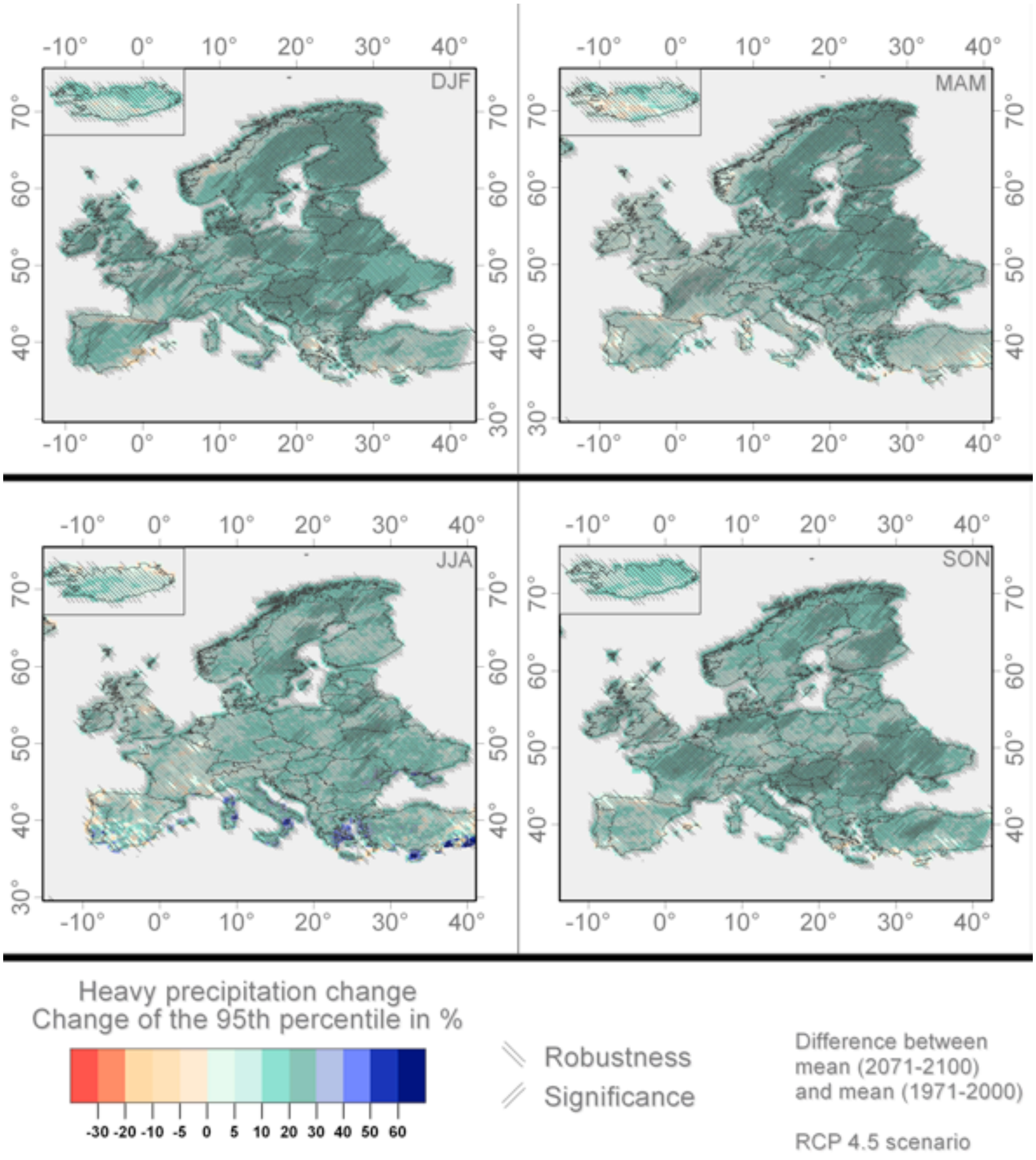
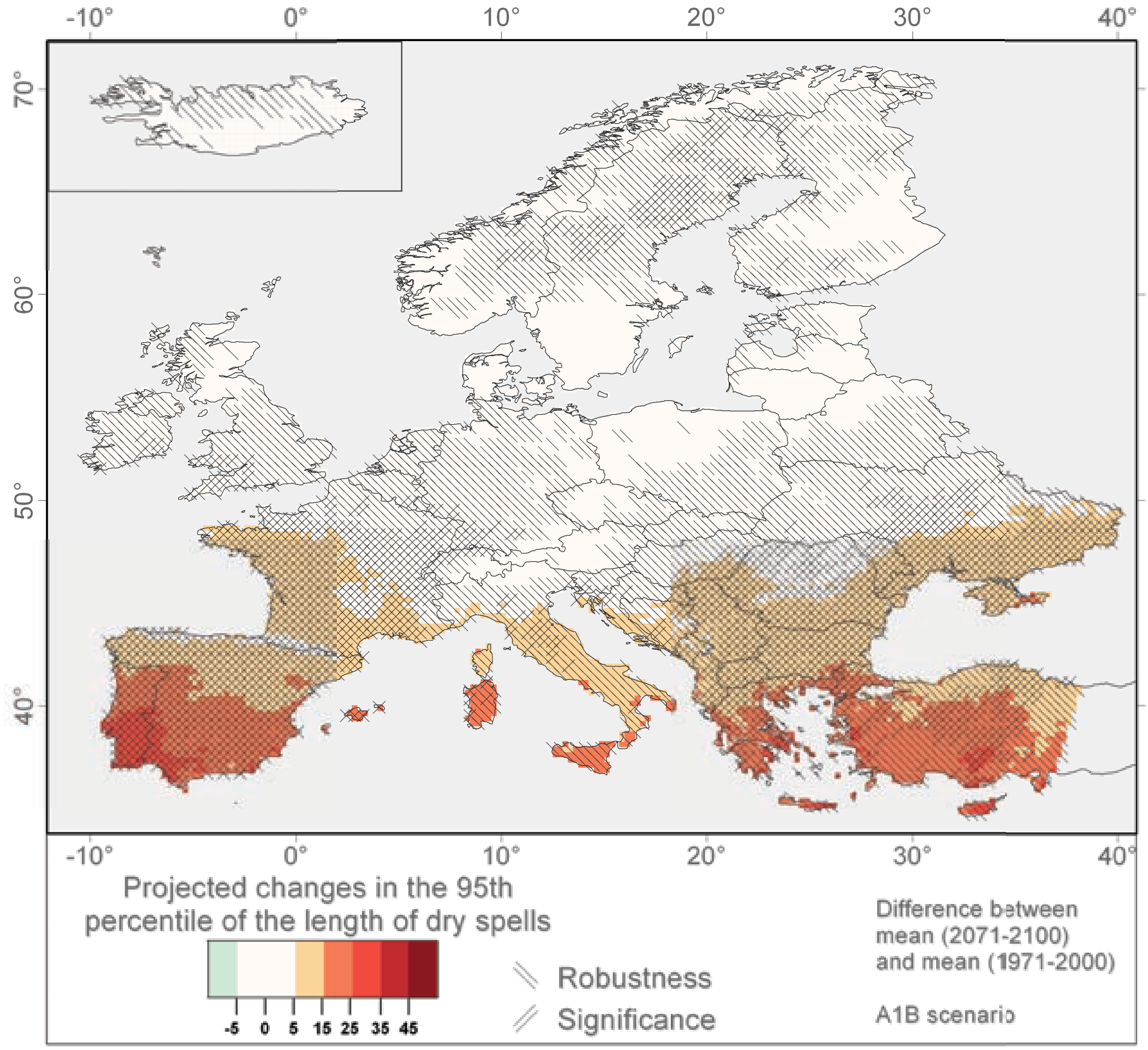


Figure 23-4. Projected changes in the 95th percentile of the length of dry spells for the period 2071-2100 compared to 1971-2000 (in days) (Jacob et al., 2013). Dry spells are defined as periods of at least 5 consecutive days with daily precipitation below 1mm. Hatched areas indicate regions with robust (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 part of Turkey, unfortunately no regional climate model projections are available .

A) Changes represent average over 20 regional model simulations (A1B) taken from EU-ENSEMBLES project.



B) Changes represent average over 7 regional model simulations (RCP4.5) taken from EURO-CORDEX project.

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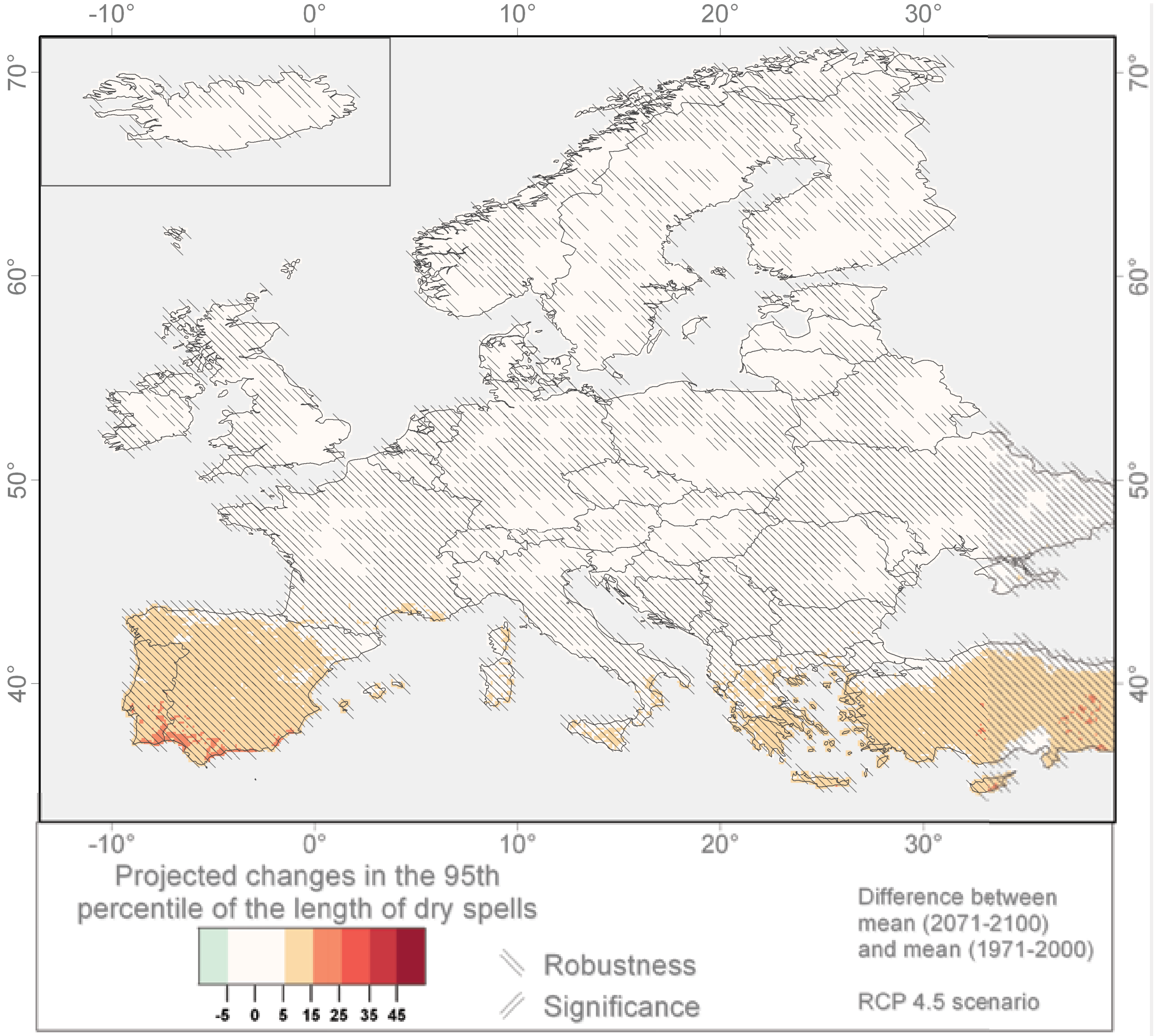

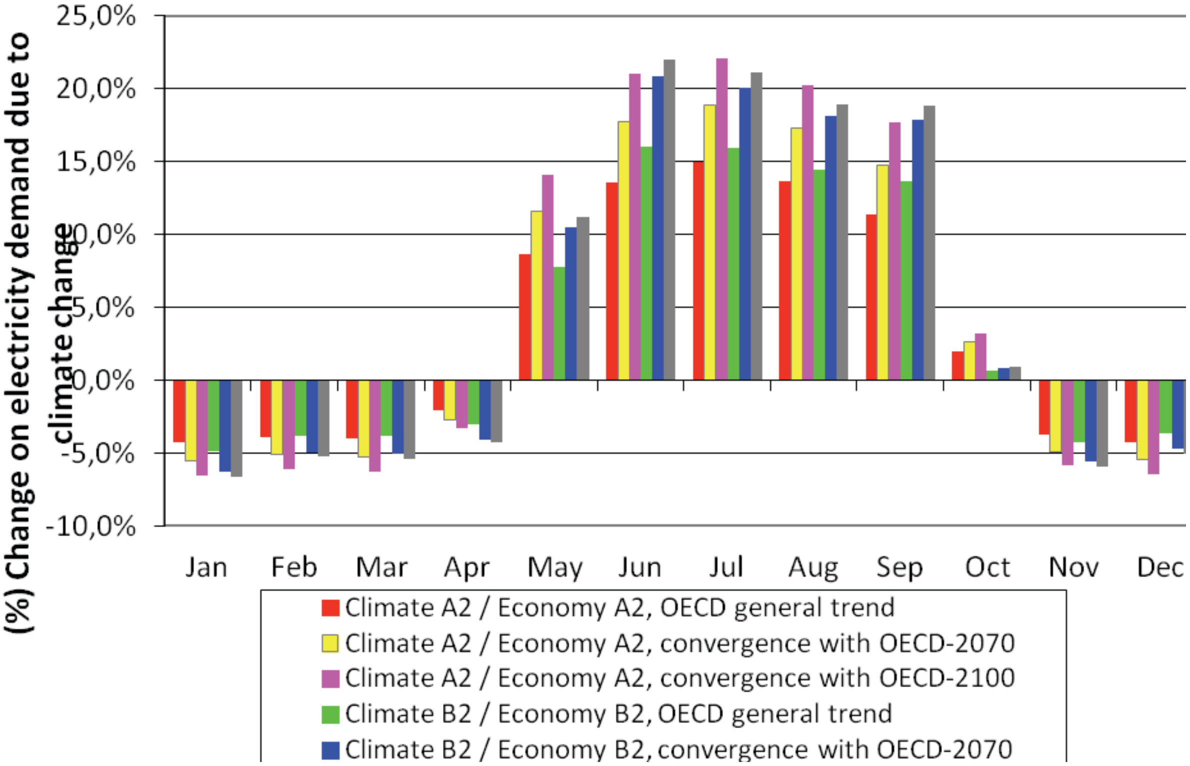

Figure 23-5: Percentage change in electricity demand in Greece attributable to climate change, under a range of climate scenarios and economic assumptions. Source: Mirasgedis et al., 2007.

Figure 23-6: Percentage change in simulated water-limited yield for winter wheat in 2030 with respect to the 2000 baseline under the A1B scenario as modelled using ECHAM5 (left column) and HadCM3 (right). Yield estimates in top maps do not take adaptation into account. Bottom row estimate assume a „best adaptation strategy“ for cell (Source: Donatelli et al. 2012)

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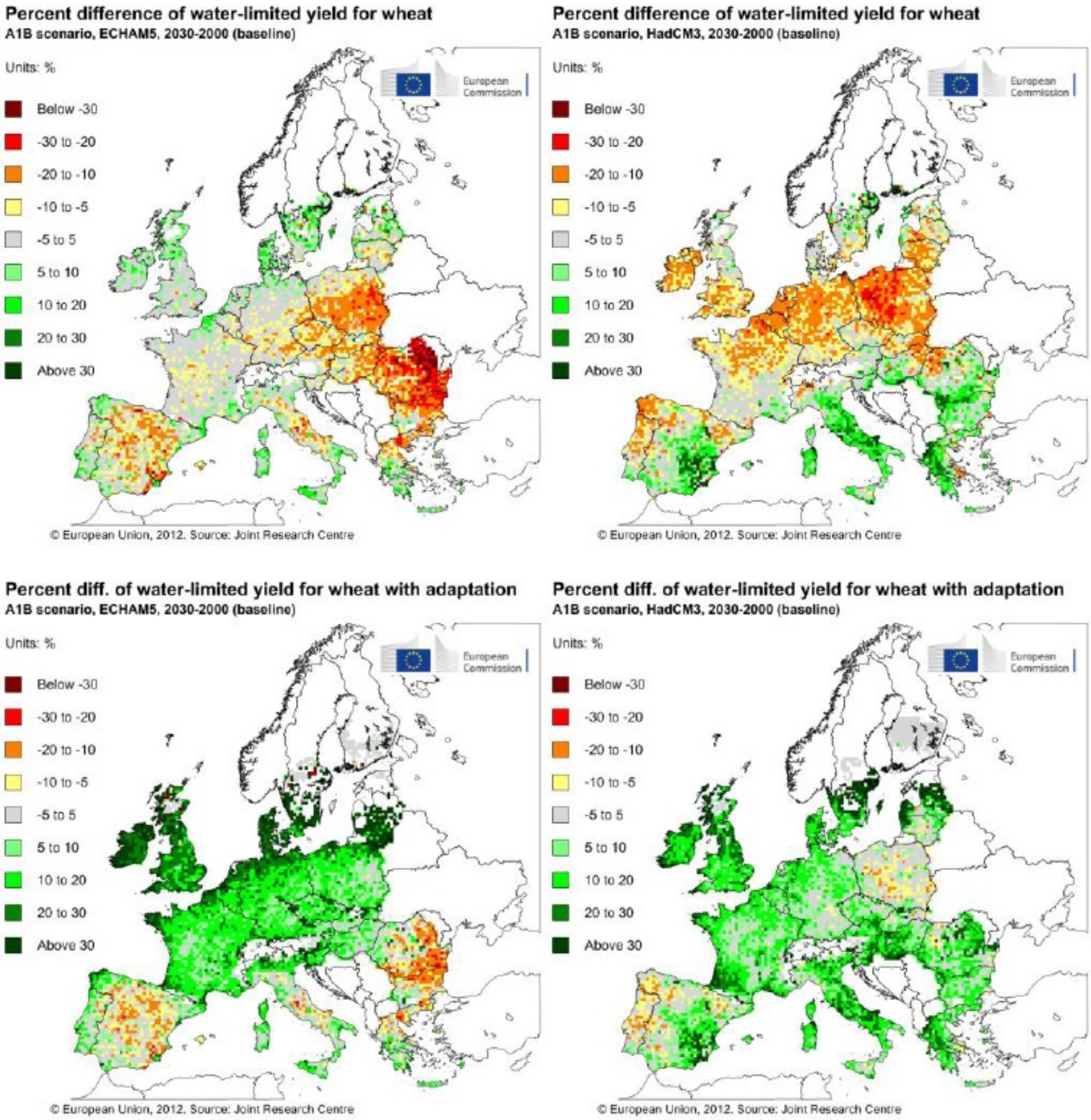

Percent difference of water-limited yield for wheat
A1B scenario, ECHAM5, 2030-2000 (baseline)

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

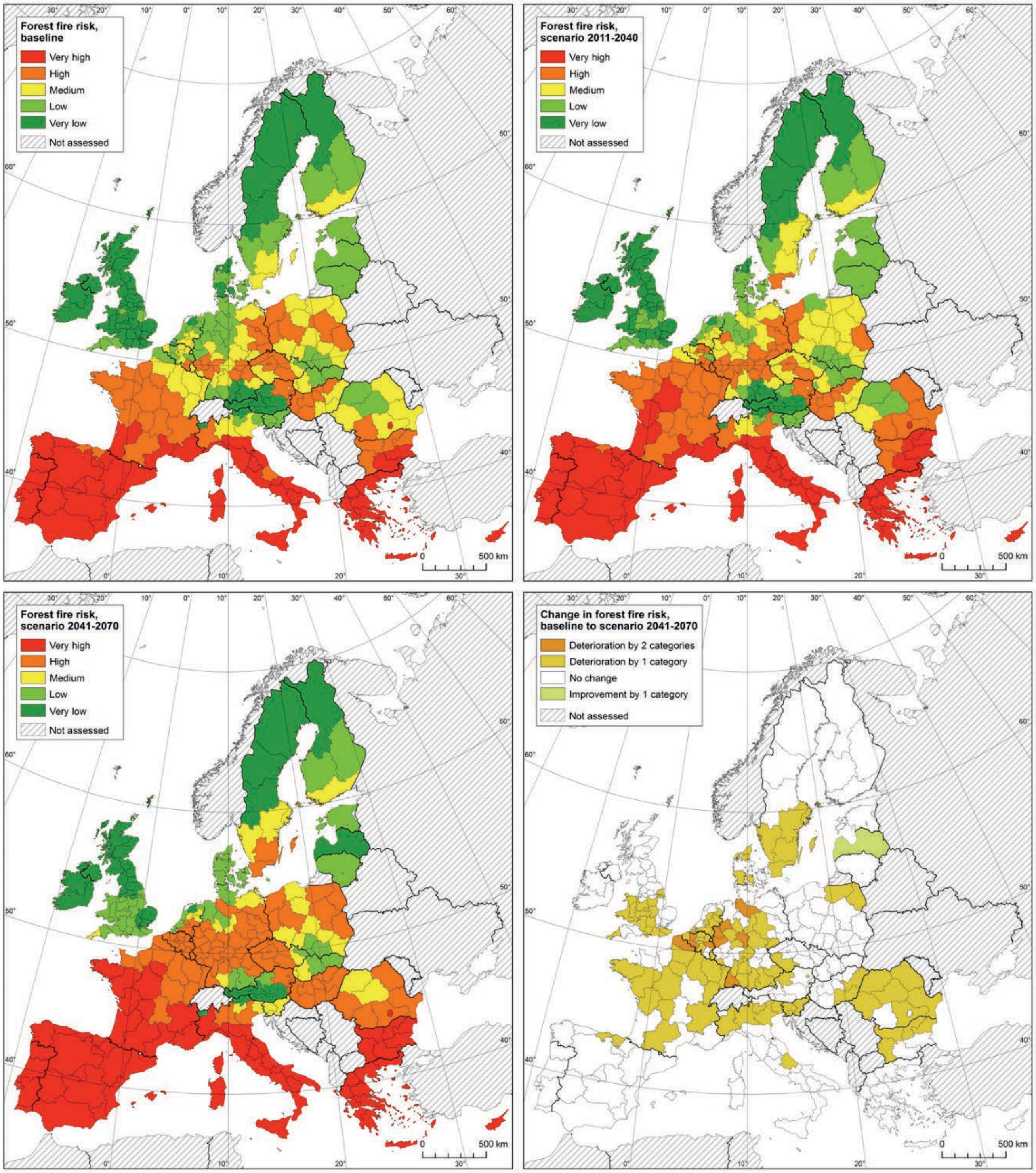

Figure 23-7: Projected fire risk in Europe for two time periods (2011–2040 and 2041–2070) based on high-resolution regional climate models from the ENSEMBLES project under the SRES A1B emission scenario. (Source: Lung et al., 2012)

Figure 23-8: Adaptation and mitigation options and their effects on biodiversity. Based on Paterson et al., 2009.