Chapter 23. Europe

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Executive Summary

Climate models project significant changes in rainfall in Europe [high confidence] [23.2.2.2]. Observed climate trends and future projections are broadly the same as in Fourth Assessment Report. There will be a marked increase in the frequency and intensity of heat waves, meteorological droughts and heavy precipitation [high confidence]

[23.2.3.3]; small or no changes in wind speed extremes [low confidence]; and no change in hail events [low confidence]. Projected changes in climate vary between European sub-regions: Atlantic, Alpine, Northern, Southern and Continental Europe.

Most of the countries in Europe are subject to a high level of regulation for environmental, infrastructure and social policies. The capacity to adapt (technical, economic, etc) will be higher than for other world regions, but there are important differences within the European region. Little progress has been made in accounting for climate change in rural development policy [high confidence]. Some adaptation is already occurring in Europe in the water management sector, such as upstream/downstream links in large catchments [medium confidence].

Climate change is likely to increase coastal and river flood risk in Europe and, if unabated, will substantially increase flood damages (monetary losses, people affected and loss of life). Adaptation can prevent most of the damages projected [high confidence – based on medium evidence, high agreement] [23.3.1; 23.7.1; 23.8.3]. Annual monetary flood damages Europe have increased over recent decades (high confidence) but the contribution of observed climate change is not clear [23.3.2, SREX 4.5]. Some areas in Europe show changes in river flood risk related to observed changes in extreme river discharges (medium confidence – based on limited evidence and medium agreement) [23.2.3]. Climate change is likely to increase problems associated with overheating in domestic housing [medium confidence] [section 23.3.2].

There will be adverse affects of climate change on winter/ski tourism, especially in low altitude areas [high confidence] [23.3.5]. No significant impacts are foreseen before 2050 in other tourism sub-sectors [medium/low confidence, medium evidence] [23.3.5]. After 2050, changes in tourism patterns from southern to northern/central Europe as well as seasonal shifts of tourism within countries are likely [low confidence].

Climate change will have seasonal effects on air, rail and road transport that entail economic damage or adaptation costs (e.g. damage associated with extreme precipitation and temperature, and delays) [medium confidence, low evidence] [23.3.3]. Climate change will not significantly affect transport safety, with very local exceptions (e.g. soil destabilization in high mountains, coastal erosion) [low confidence]. Climate change will adversely affect inland water transport, particularly the Rhine in summer [medium confidence, medium evidence]. Rail infrastructure will face damages due to higher summer temperature [medium confidence, low evidence].

Climate change will decrease hydropower production from reductions in rainfall in all sub-regions but Scandinavia [medium confidence, medium evidence] [23.3.4]. Climate change will have no impact on wind energy before 2050 [medium confidence, medium evidence] and only a small impact after 2050 [low confidence]. Climate change will have serious adverse impacts on thermal power production during summer [medium confidence, medium evidence] [23.3.4]. Climate warming will decrease space heating [high confidence]. Climate change is likely to increase cooling demand for nuclear power production [23.3.4]. Future energy consumption in summer in buildings will increase but the largest part of this increase during 2000-2050 (especially in eastern regions) derives from income growth [high confidence]. More efficient buildings and demand-side management are main adaptation options, although passive cooling alone may be insufficient.

Climate change will increase the frequency and intensity of heat waves, particularly in Southern Europe [high confidence, high agreement] [23.2.2] with adverse implications for health [23.5.1], agriculture, energy production, transport, tourism and housing. Heat-related mortality and morbidity will increase [medium confidence], particularly in Southern Europe. Climate change may change the distribution and seasonal activity of some human infections, including those transmitted by arthropods [medium confidence, low evidence] [23.5.1].

Climate change will alter the productivity of bioenergy crops in Europe, expanding their potential distribution northward [high confidence] [23.4.5] although this will reduce the European terrestrial carbon sink [23.4.5][medium confidence]. Elevated atmospheric CO_2, and improved drought tolerance and plant water use will maintain high yields in Northern and Continental Europe [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. At high latitudes [Northern Europe], climate change will increase yields [medium confidence, medium agreement]. In Southern Europe, climate change will decrease cereal yields [high confidence]. In Northern Europe, climate change will increase the seasonal activity of pests and plant diseases [high confidence, high agreement]. Climate change will adversely affect dairy production in Southern Europe because of heat stress in lactating cows [medium confidence]. 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] but adaptation is possible through technologies and good practice [medium confidence] [23.4.1, 23.3.5, 23.5.4].

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 analysis of water is needed because of competing demands with agriculture and other sectors.

Climate change will have negative impacts on fisheries. 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 may not affect net fisheries economic turnover in some parts of Europe (e.g. Bay of Biscay) [low confidence, single study] due to introduction of new (high temperature tolerant) species. Climate change is unlikely to entail relocation of fishing fleets [high confidence] [23.4.6]. Observed higher water temperatures have adversely affected both wild and farmed freshwater salmon production [high confidence] [23.4.6]. High temperatures are likely to increase frequency of harmful cyanobacterial blooms [medium confidence] [23.4.6].

Climate change will have negative impacts on forestry. Although observed climate warming has increased forest productivity in northern Europe [medium confidence] [23.4.4], climate change will increase damage from pests and diseases in all sub-regions [high confidence] [23.4.4]. Climate change will increase damage from wild fires in Southern and Northern Europe (boreal) [high confidence] and from storms [low confidence] [23.4.4]. Climate change will increase economic damages from shifts in pest species distributions [low confidence] [23.4.4].

It will be more difficult to maintain environmental quality under climate change in some areas [low confidence]. Climate warming has adversely affected trends in ground level tropospheric ozone [low confidence] [23.6.1.]. Climate change will likely affect air quality in the future [low confidence]. Climate change will decrease surface water quality [medium confidence]. No agreement on the effect of climate change on soil erosion and there is little information on future impacts on salinisation or soil fertility.

Climate change will affect species distribution and biodiversity [high confidence] [23.6]. Biodiversity in Natura 2000 areas is impacted by climate change more than in other protected areas [low confidence] [23.6.4]. Climate change will cause changes in habitats and species, with local extinction [high confidence] and continental scale shift in Europe [medium/low confidence]. 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]. 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 [23.4.3]. The introduction and expansion of invasive species from outside Europe will be favoured by climate change [medium confidence][23.6.4]. Species with high migration rates are more invasive due to climate change than other species. Communities of migratory species will be altered through adaptation of migratory activity rather than through exchange of species [medium confidence] [23.6.4], even if phenotypic adaptation can allow species to persist in situ [low confidence] [23.6.4]. Climate change will entail the loss or movement of coastal wetlands [high confidence] [23.6.5].

Climate change and sea level will damage European cultural heritage through impacts on the fabric of buildings due to extreme events and chronic effects [medium confidence]. Climate change will also reduce future frost damage [medium/high confidence] but increase thermal stress damage of marble monuments in Southern Europe [medium confidence].

Climate change will increase the difference in economy and people distribution across European regions [high confidence] improving net economic benefits in the Northern region compared with Southern and Continental and Atlantic Europe [medium confidence] [23.9]. Shifts in agriculture production across sub-regions will occur [high confidence]. **The Mediterranean region** is most vulnerable to climate change as multiple sectors are likely to be adversely affected (tourism, agriculture, forestry, infrastructure, energy, population health) [high confidence] [23.9].

There are important synergies and trade-offs between adaptation and mitigation. Adaptation measures for housing need to be evaluated in the context of other policy requirements, especially energy efficiency (mitigation) and healthy housing. The main measures to maintain winter tourism, i.e. artificial snowmaking, are already being applied in Europe to a large extent and are energy intensive. Adapting soil and forest management to climate change will be required to avoid positive feedbacks on climate change through land based CO_2 emissions and wildfires, especially during heat and drought extreme events.

23.1. Introduction

This chapter reviews the scientific evidence published since AR4 on observed and projected impacts of anthropogenic climate change in Europe. 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 and not political boundaries.

[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, 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 research funding through the European Commission which means that countries in eastern Europe and Russia are less well represented. Further, regional assessments may be reported for the EU15, EU27 or EEA (32) group of countries.

This chapter includes several sections that were not in AR4. Because adaptation and mitigation policies are now in place in many countries in Europe, the evidence is reviewed for synergies between adaptation and mitigation strategies (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. Many countries now have adaptation and mitigation policies in place. The dominant force for climate policy development in the region is the European Union. Most European Union Member States have mitigation targets, as well as the overall EU target, with both sectoral and regional aspects to the commitments. The policies are regionally differentiated with some countries allowed to stabilize or even increase their emissions, as long as others can abate more. EU targets on emissions reductions and the use of renewable energy are on track, however, the energy efficiency target is unlikely to be met.

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 that cover a large range of policy areas (sectors), it is not possible to describe them extensively here (see Section 23.7 on Cross-Sectoral Decision-Making and Box 23-2 on national adaptation policies for further discussion). The new EU Adaptation Platform catalogues adaptation actions reported by Member States. EU policy makers are currently developing an EU adaptation strategy to be implemented for 2014 to 2020. 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

A major finding of AR4 was the detection and attribution of observed changes in climate to anthropogenic forcing, Europe had experienced higher temperatures and a change in precipitation patterns (AR4-12). 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). The frequency of extreme precipitation events has increased in some areas of Europe, mainly in winter over western-central Europe and European Russia (medium confidence, SREX-3.3.2). Dryness has increased, mainly in Southern Europe (medium confidence, SREX-3.3.2).

Climate change is expected to magnify regional differences within Europe for natural resources and assets (in particular in agriculture and forestry). Regional differences in the impacts of climate change were described for: increasing water demand for agriculture (AR4-12.5.7), changes in energy demands (lower in winter, increased in summer, AR4-12.4.8), change in the seasonal distribution of tourism in the Mediterranean area, decrease of snow tourism (AR4-12.4.9). One of the main driver of impacts is the water stress that will increase over Continental and Southern Europe (AR4-12.4.1, SREX-3.3.2, SREX-3.5.1). Most climate related hazards were expected to increase (with significant regional variations, AR4-12.4).

Adaptation measures are evolving from reactive disaster relief to more proactive risk management, for example, heat health warning systems for heat waves (AR4-12.6.1, SREX-9.2.1). National adaptation plans were developed and specific plans have been incorporated in European and national policies (e.g. agriculture, energy, forestry, transport, AR4-12.2.3, 12.5). At the time of the AR4, however, very few governments had systematically examined a comprehensive set of measures (AR4-12.8). Uncertainties in climate impact assessments were noted in liaison with uncertainties in climate impact models and with the fact that most impact studies were conducted for separate sectors. Integrated approaches for both impact and adaptation (including economic evaluation) were lacking.

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 is generally increasing in the EU27 countries, primarily due to net immigration. Some countries, including the Russian Federation, have had decreases in population since the 1990s. The ageing of the population is a significant trend in Europe with Eurostat projections suggesting an increase in the old-age-dependency ratio up to 2050 in all countries. Migration pressure (into Europe) is increasing. Since AR4, there has been a financial crisis, and economic growth has slowed (or stalled) in several European countries. The longer term implications of the financial crisis in Europe are unclear, although it will probably lead to some modification of the economic outlook. Otherwise economic trends are assumed to be broadly the same as described in AR4.

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. 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. Future trends in agricultural land use are uncertain, although most scenario studies suggest that agricultural areas will continue to reduce 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, 2010c).

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. Forest fires mainly have anthropogenic causes, but the total burned area changes significantly from year to year largely because of weather conditions (Lavalle *et al.*, 2009). 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).

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). Other scenarios are also available for Europe (Mooij de and Tang, 2003)(Spangenberg *et al.*, 2011). Detailed national socio-economic scenarios have also been produced (WLO, 2006)(UK National Ecosystem Assessment, 2011).

23.2.2. Observed and Projected Climate Change

23.2.2.1. Observed Climate Change

The average temperature in Europe has continued to increase. Temperature over the land areas in the last decade (2001-2010) was 1.2°C above the 1850-1899 average (1.0 °C for the combined land and ocean area). Considering the land area, 8 out of the last 13 years of the period 1850-2010 were the warmest years since 1850 (EEA, 2011). 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) have become more frequent, while low-temperature extremes (cold spells, frost days) have become less frequent in Europe (EEA, 2011) based on Climate Research Unit (CRU) gridded datasets HadCrut3 (land and ocean) and CruTemp3 (land only). 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 the SREX (Chapter 3). Windspeeds have declined over Europe over the last decades (e.g. (Vautard *et al.*, 2010) but there is a *low confidence* in this trend due to problematic anemometer data (SREX, section 3.3).

Global mean sea level (GMSL) has been rising since 1900 at a rate of 1.7 ± 0.2 mm yr-1 (90% confidence) (WG1, section 3.7.1). Regional rates of sea level change are often higher or lower than the global mean due to internal changes in the ocean, isostasy, and water and ice storage on the continents, as well as long term atmospheric variability (WG1, section 3.7.1, SREX Section 3.5.3). Europe is marked by the isostasy in the Scandinavian area, where the sea level is decreasing (EEA, 2005).

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 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 climate projections for decision making (SREX, section 3.2.1).

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). [Note: this section will be updated with the CMPI5-CORDEX results]. Climate models show significant agreement in warming (magnitude and rate) all over Europe, with strongest warming in Southern Europe (Kjellström *et al.*, 2011)(Goodess *et al.*, 2009)(Schmidli *et al.*, 2007). Less warming in spring is projected, with the largest warming in the winter months.

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, and a decrease of long term mean snow pack (although snow-rich winters will remain) (Räisänen and Eklund, 2011). Changes in future circulation patterns are inconsistent, except in Northern Europe (e.g. (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 toward an increase, but with a *low confidence* 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).

Under all the RCP scenarios, the time-mean rate of the global mean sea level rise during the 21st century is very likely to exceed the rate observed during 1971–2010 (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 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 Extremes

In Europe, as in many mid-latitude regions, there will be a marked increase in many types of extremes, in particular heat waves, droughts and heavy precipitation events. 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 for the Period 2071-2100 with Respect to 1971-2000 Spatially Averaged for Europe Subregions. Numbers are based on 9 (indicated with *) and 20 (indicated with **) regional model simulations taken from EU-ENSEMBLES project. 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. 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, Atlantic (all seasons) and Central Europe (without 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.

[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). Heat waves are defined as periods of at least 5 consecutive days with daily maximum temperature exceeding the normal daily maximum temperature of the May to September season of the control period (1971-2000) by at least 5°C. Changes represent average over 9 regional model simulations taken from the EU-ENSEMBLES project. 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. Based on CMIP3 data, will be substituted by CMIP5 CORDEX data.]

[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 (%). Changes represent average over 20 regional model simulations taken from the EU-ENSEMBLES project. 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). The figures are sorted as follows: top row: DJF, JJA; bottom row: MAM, SON. For the eastern part of Turkey, unfortunately no regional climate model projections are available. Based on CMIP3 data; will be substituted by CMIP5 CORDEX data.]

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). In other parts of Europe, changes are inconsistent.

Extreme sea level events (surge tides) will be dominated by the mean sea level trends (*medium-to-high confidence*, WG1, 13.8). Significant increases in wave height and storm surge levels are projected in northern North Sea (Debernard and Rÿed, 2008) and around the coast of Ireland (Wang *et al.*, 2008). Other studies, however, indicate little or no effect on extreme surge levels for the Adriatic Sea (Lionello *et al.*, 2012; Planton *et al.*, 2011)(Lionello *et al.*, 2012) or the North Sea, even when sea-level rise is included (Sterl *et al.*, 2009).

23.2.3. Observed and Projected Trends in the River Flow and Drought

Observed trends in seasonal river discharges are inconsistent (Shiklomanov *et al.*, 2007). 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), and Northwestern France (Renard *et al.*, 2008); other studies show decreases in extreme discharges, for example, in the Czech Republic (Yiou *et al.*, 2006). 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 4].

Climate change will affect future hydrology of river basins [SREX report, AR5 WG2 Chapter 4]. A Europe wide analysis indicates increases in the occurrence of extreme river discharges in Continental Europe, but decreases in Northern, Atlantic and Southern European sub-regions (Dankers and Feyen, 2008). In contrast, studies of individual catchments indicate future 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), the Rhine basin (Lenderink *et al.*, 2007)(Te Linde *et al.*, 2010a), 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).

Lack of observational data and the complex definition of droughts make the analyses of observed changes in drought characteristics difficult (SREX, Chapter 3, Box 3-3). Southern Europe has experienced trends toward more intense and longer droughts, but there are still inconsistent. 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 using different definitions of droughts (SREX chapter 3, section 3.5.1). Figure 23-4 illustrates projected changes the length of dry spells for the period 2071-2100 compared to 1971-2000 (in days). The projected increase in dry spells is much greater 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). Dry spells are defined as periods of at least 5 consecutive days with daily precipitation below 1mm. Changes represent average over 20 regional model simulations taken from EU-ENSEMBLES project. 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. Based on CMIP3 data, will be substituted by CMIP5 CORDEX data.]

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

23.3.1. Settlements and Flooding

Europe has a high flood risk that threatens production systems, physical infrastructure and human settlements, 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 (from damage to infrastructure) and health effects. New risk assessments have also included economic growth (increased property value) and population growth (which is likely to increase population at risk of flooding). Few studies include non-market costs of flooding attributable to climate change.

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). Climate change would increase the frequency of severe storm surges, particularly in north-western Europe (see Section 23.2.2.3). The global DIVA model (Vafeidis *et al.*, 2008) estimated that impacts from sea level rise in the EU27 could reach a total cost of some 17 billion Euros per year by 2100 (without adaptation), but that adaptation by upgrading coastal defences would substantially reduce impacts and damage costs (Hinkel *et al.*, 2010). According to the same study, without adaptation, the number of people affected annually by sea flooding in the 2080s is projected to increase significantly - in the range of 775,000 to 5.5 million people. The Atlantic, Northern and Southern European regions are likely to be most affected by coastal floods, with highest damage costs are highest for The Netherlands, Germany, France, Belgium, Denmark, Spain and Italy (Hinkel et al., 2010).

Future flood losses attributable 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 direct and indirect impacts of a 1m sea-level rise in Turkey would potentially affect some 3 million additional people and 12 billion USD capital value at risk, with adaptation costs at around 20 billion, some 10% of GNP (Karaca and Nicholls, 2008). In Poland, up to 240,000 people would be affected by increasing flood risk on the Baltic coast (Pruszak and Zawadzka, 2008).

23.3.1.2. River Flooding

The observed increased trend in flood events and flood damages in Europe is well documented (see WGII Chapter 18) however, the main cause of the increased is increased exposure of persons and property in flood risk areas (Barredo, 2009). Several new studies provide estimates of the impact of future climate change on economic losses from river flooding, indicating some regions may see increasing risks, but others may see decreases or little to no change (Feyen *et al.*, 2009)(Lugeri *et al.*, 2010)(Mechler *et al.*, 2010)(Feyen *et al.*, 2012). A European (EU15 only) 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). Local and national scale studies have quantified future river flood risk in the

UK (ABI, 2009), the Netherlands (Maaskant *et al.*, 2009)(Bouwer *et al.*, 2010)(Te Linde *et al.*, 2011). In particular, studies now quantify the populations and property value at risk of flooding (Feyen *et al.*, 2009)(Maaskant *et al.*, 2009)(Bouwer *et al.*, 2010)(Te Linde *et al.*, 2011), generally indicating this contribution to be about equal or larger than the impacts of climate change.

There have been very few studies that have estimated future damages from an increase in intense rainfall (Hoes, 2006). Other studies also underscore the importance of other processes that influence flash flood risks, such as increasing exposure from urban expansion, as well as forest fires that lead to erosion and increased surface runoff (Lasda *et al.*, 2010). Some studies have valuated adaptation measures, including pipe enlargement and increasing infiltration capacity in urban areas that can only partly offset anticipated impacts from intense rainfall (Zhou *et al.*, 2012).

23.3.1.3. Landslides

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), while (Jomelli *et al.*, 2007) found a complex response to climate trends. Some land use practices changes have lead 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 in the fact 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).

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), for example, noted that there is very little real data as to the actual extent of overheating in the UK. However, despite this lack of monitored data to characterise performance, it seems clear that 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, sometimes ambiguous (both in terms of direction and magnitude) and uncertain (Koetse and Rietveld, 2009).

Research on climate change impacts on *road transport* mostly examines effects on traffic safety and congestion. 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)(Chung *et al.*, 2005). Still, a 7-12% lower traffic speed during evening peak hours and congestion in the Netherlands was found to cause an additional welfare loss of around € 0.50 per commuting trip due to additional time spent in driving (Sabir *et al.*, 2010). Regarding snow and ice, and without considering improvements in vehicle technology and safety, 12-43% less accidents are estimated in 2080 as a result of fewer frost days under the UKCIP02 medium-high emissions scenario; however, the effect of this on drivers’ behaviour and consequently on the need for salt usage is yet unclear (Andersson and Chapman, 2011). Increased temperatures, excess and more frequent precipitation, storms and thawing of permafrost are expected to decrease the lifetime of roads and thus increase infrastructure costs. Nevertheless, research on this effect remains limited, showing cost increases, at the order of 10-20% at 2080 compared to 2006 even under design adaptation (Larsen *et al.*, 2008).

For *rail*, insights remain limited. In Sweden, where rail suffered from intense snowfalls in 2006, vulnerability has been assessed only in qualitative terms (Lindgren *et al.*, 2009). In line with AR4, increased buckling due to higher temperatures, as observed in 2003, is expected to increase the average annual cost for heat-related delays in the UK (9.2 million GBP in the baseline, excluding the cost of damage repair) by 18-27% in 2050 and 25-41% in 2080 under the UKCIP02 low and high emissions scenarios (Dobney *et al.*, 2009)(Dobney *et al.*, 2010). Effects of the same magnitude, but of the opposite sign, are expected for cold-related delays in the UK (costing 500 k£ in the baseline) due to milder winters. Efficient adaptation comprises proper maintenance of track and track bed and proper setting of the stress-free rail temperature. As for sea level rise, under current defence levels the wave overtopping in UK coastal railway was estimated to increase by 50% in the 2020s and more than 200% in the 2080s compared to 2006 under the median (W5B-029/TR) estimates for sea level rise (RSSB, 2008).

Regarding *inland waterways*, the navigability of important rivers (Rhine, Danube, and Elbe) is expected to be affected through changed water levels. In Rhine, 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). The need of transport blockage for safety reasons during future high water levels has not been assessed yet. Low water levels imply restrictions on the load factor of inland ships, increasing transport prices. In the summer of 2003, a good proxy for future summers (Beniston, 2004), transport prices increased by more than 75% resulting in a welfare loss of about €90 million (compared to €28 million in a normal year) for a part of the Rhine market (Jonkeren *et al.*, 2007). Extending this to the total Rhine market leads to a loss of €194-263 million (Jonkeren, 2009). Adaptation is possible through modal shift, which could reach 2-10% of the annual cargo volume (Jonkeren *et al.*, 2011; Krekt *et al.*, 2011; Krekt *et al.*, 2011), although this may create infrastructure capacity problems for rail and road transport. Increasing the number of navigational hours per day in periods with low water levels is also found to be cost-efficient (Krekt *et al.*, 2011). Using smaller ships is not an option since most ships of the current fleet of barges are still considerably below the optimal size (Demirel, 2011). Ignoring environmental costs, which may be substantial, the adaptation of the waterway infrastructure itself (e.g.

canalization of the downstream part of the river Rhine) has also been deemed to be economically profitable (Krekt *et al.*, 2011).

Regarding *long range ocean transport* between Europe and Asia or North America, the economic attractiveness of the Northwest Passage and the Northern Sea Route, opened to cargo ships in 2008-2009 as a result of higher temperatures (Parker and Madjd-Sadjadi, 2010)(Lasserre and Pelletier, 2011)(Ho, 2010), is not yet clear as it depends also on non-climatic factors (Verny and Grigentin, 2009)(Liu and Kronbak, 2010)(Lasserre and Pelletier, 2011).

On *air transport*, estimates on climate change impacts are few. A study for London's Heathrow Airport (Pejovic *et al.*, 2009) found that, under the A1B, A2 and B1 emission scenarios and by using the results of seven different climate models, the net combined effect of on-site minimum temperature, wind speed, headwind-tailwind and crosswind would cause a small (less than 1%) net annual change on the cost of weather-related delays, despite much larger seasonal variations. However, changes in air traffic volume, airport capacity, air traffic demand, and weather at the airports of origin and final destination were not examined. In the same study, the statistical analysis of historic data showed also that thunderstorms, snow and fog increase the probability of weather-related delays by more than 25%.

23.3.4. Energy Production, Distribution, and Use

On *wind energy*, recent studies conclude that under the A1B, A2 and B1 emission scenarios and 3 different climate models no significant changes in wind resources are expected before 2050 in Northern, part of the Alpine and upper Continental Europe (Pryor *et al.*, 2006)(Pryor and Schoof, 2010); (Pryor and Barthelmie, 2010). Afterwards, in line with AR4, sites in these regions and to some extent in Atlantic Europe may experience a small (<10-15%) increase in energy density (expressed in W/m^2) during winter and a decrease in summer (Pryor *et al.*, 2005)(Harrison *et al.*, 2008). In the Mediterranean, the energy density during 2071-2100 under the A2 emissions scenario may decrease during winter, while in summer and spring estimations are uncertain and diverse, with potential increases in some areas (e.g. Aegean Sea) and decreases in others such as southern France and the Tyrrhenian Sea (Rockel and Woth, 2007)(Bloom *et al.*, 2008)(Najac *et al.*, 2011). The inter-annual variability of energy density may increase, at least in some locations in the north (Pryor *et al.*, 2006)(Pryor and Barthelmie, 2010). As for extreme wind speeds and gusts, although there are some indications for increased magnitude of extremes in Northern and Continental Europe for the period 2071-2100 (Pryor *et al.*, 2012)(MacKinnon *et al.*, 2007)(Rocked and With, 2007)(Gateman and Weise, 2008)(Leckebusch *et al.*, 2008)(Leckebusch *et al.*, 2007)(Pinto *et al.*, 2010)(Pinto *et al.*, 2007a; Pinto *et al.*, 2007b), extreme wind direction changes and the overall effect of extremes on wind farms' operation and maintenance remain to a large extent unknown. For *hydropower*, most studies since AR4 examine the hydrological response at basin scale rather than impacts on socio-economic activities, especially within an integrated framework incorporating competing water uses. Impact studies after AR4 are region or case-specific; for Scandinavia, different climate models under the A2, A1 and B1 emission scenarios showed for most locations an increase of hydropower during 2071-2100 at the order of 5-14% compared to 1961-1990 levels, and a smaller increase (4-8.5%) for 2021-2050 (Haddeland *et al.*, 2011); (Bergström *et al.*, 2007). For Swiss Alps, (Schaefli *et al.*, 2007) estimated a 36% lower production of a reservoir plant by 2070-2099 compared to 1961-1990 for a +3.4°C mean daily temperature and increased evapotranspiration due to severely reduced glaciation. For the Upper Danube, which currently feeds around 140 run-off and reservoir plants, a decrease by 46% of the annual low flow by 2060 compared to 1971-2003 is expected for the A1B scenario (Mauser and Bach, 2009). In Austria, a reduced hydropower production by 6-15% compared to 1961-1990 is estimated for the period 2025-2075 and for the A1B, A2 and B1 emission scenarios (Stanzel and Nachtnebel, 2010). In Northern Greece, the operational risk of production stoppage of a reservoir plant may increase from a current range of 0-30% (for an annual production range of 180 to 420 GWh) to 0-54% by 2050 for the HadCM2 scenario (Baltas and Karaliolidou, 2010). Improved water management 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).

Warmer than average summers in 2003 and 2007 resulted at reductions/ interruption of production in several *nuclear plants* located mostly in France as well as at locations in rest Southern, Continental and Atlantic Europe because of cooling water shortages and limitations in discharging cooling water (Kopytko and Perkins, 2011)(Rübbelke and Vögele, 2011). In agreement with AR4, (Linnerud *et al.*, 2011) estimated that on the basis of actual data from various European plants, a 1 °C rise in ambient temperatures above 20 °C will reduce output by more than 2% because of loss of load. (Förster and Lilliestam, 2010) calculated load reductions of 1.6-11.8% for a typical plant in Continental Europe in the case of increased river temperatures by 0-5 °C and under no adaptation, leading to average annual income losses of up to 80-111 million €. Closed-cooling circuits are an efficient adaptation option (Gañán *et al.*, 2005)(Koch and Vögele, 2009) but are usually feasible only for new plants. The increased risk of premises' flooding as a result of storm events is also considered very important and is being assessed by some European utilities. As for transmission, impact estimates are scant and qualitative (Mideksa and Kallbekken, 2010).

The net effect of climate change on total annual *energy demand* in Europe as a whole during 2000-2100 may be positive (Isaac and van Vuuren, 2009), however expected impacts on regional and seasonal scale differ significantly, especially regarding the electricity use for cooling in the Mediterranean (Eskeland and Mideksa, 2010) (Mirasgedis *et al.*, 2007)(Zachariadis, 2010) and the energy use for space heating in the Continental, Atlantic and Northern Europe. Expected seasonal changes in electricity use as a result of future climate change are prominent, especially in some regions, with increases in summer demand and a decrease in winter (see Figure 23-5). Energy use for domestic space heating under a +3.7 °C scenario by the end of the century is expected to decrease by 3% in Russia and by 25% in Continental and part of the Atlantic Europe between 2000 and 2050, and remain practically stable at the rest of Europe, while decreases of 18-43% are expected for 2050-2100 (Isaac and van Vuuren, 2009). When only climate change is considered, heating degree days are expected to decrease by 11% in Russia and 18-20% for the rest of Europe between 2000 and 2050, while similar changes are estimated also during 2050-2100. As for cooling, the same authors estimate an increase by 260% in Continental and part of the Atlantic Europe between 2000 and 2050 and by more than 4000% in Russia and the rest of Europe under the combined effect of climatic and non-climatic drivers (i.e. income growth). Between 2050 and 2100, the increase of energy use for cooling relative to 2050 values falls to 74%-118%.Changes of a similar order of magnitude were estimated for Slovenia (Dolinar *et al.*, 2010). In the Mediterranean, cooling degree days by 2060 will increase throughout the region, while heating degree days will decrease but with substantial spatial variations (Giannakopoulos *et al.*, 2009). For Greece, under the SRES A2 and B2 and for three alternative economic scenarios, electricity consumption during summer in 2071-2100 is expected to increase by 14-22% compared to future scenarios with historic (1961-1990) climatic conditions, leading to an additional net annual generation cost of 170-770 million € (Mirasgedis *et al.*, 2007). (Zachariadis, 2010) estimated an additional cumulative generation cost due to climate change at 239 million € for Cyprus for the period 2008-2030 and for a +1 °C scenario. Passive-cooling alone seems not to be enough for adaptation, while energy increases can be mitigated and even offset (in some cases) by using more efficient buildings and cooling systems, as well as demand-side management (Artmann *et al.*, 2008; Breesch and Janssens, 2010; Chow and Levermore, 2010; Day *et al.*, 2009; Jenkins *et al.*, 2008).

[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

Available literature on the way climate change affects industries is scant. Several studies examine the impacts on some raw materials (mainly crops) used, but there is no consideration how these impacts may influence the industrial process. Wine production is more studied than other products. Apart from impacts on grapevine yield, higher temperatures are expected to affect also wine quality in some regions/ varieties by changing the ratio between sugar and acids (Bock *et al.*, 2011)(Santos *et al.*, 2011) (Duchêne *et al.*, 2010). Replacing existing varieties in some regions with others more tolerant to climate change may affect traditional local wine quality, resulting possibly in lower demand and consequently wine prices (Metzger and Rounsevell, 2011).

Significant gaps of knowledge exist on how climate change affects the consumption patterns of some industrial products (e.g. soft drinks), as well as the supply chains, utilities and transport infrastructure utilized by industries. Higher temperatures may also alter the products' quality and safety (Jacxsens *et al.*, 2010; Popov Janevska *et al.*, 2010).

23.3.6. Tourism

Since AR4, a significant amount of research has been carried out. New approaches combining meteorological and tourism related components have been developed (Endler *et al.*, 2010); (Endler and Matzarakis, 2011a; Endler and Matzarakis, 2011b; Endler and Matzarakis, 2011c; Matzarakis and Endler, 2010). Tourists' preferences or visitation data, necessary for the validation of Tourism Climate Index (TCI) studies, have been explored through questionnaires or other empirical techniques (De Freitas *et al.*, 2008)(Rutty and Scott, 2010)(Moreno, 2010) (Denstadli *et al.*, 2011) (Moreno *et al.*, 2008; Moreno and Amelung, 2009). In line with AR4, index-based studies show that in northern areas of Continental Europe, as well as Finland, southern Scandinavia and southern England, climate conditions for tourism after 2050 and especially after 2070 are expected to improve remarkably during summer and to a smaller extent during autumn and spring under the A1F, B1A, B2 and A2 emission scenarios (Amelung and Viner, 2006)(Amelung and Moreno, 2011); (Amelung *et al.*, 2007); (Nicholls and Amelung, 2008). For many destinations in the Mediterranean, climatic conditions for light outdoor tourist activities are expected to deteriorate significantly in summer mainly after 2050 and to improve during spring and autumn (Amelung and Viner, 2006); (Amelung and Moreno, 2009); (Hein *et al.*, 2009); (Perch-Nielsen *et al.*, 2010)(Amelung *et al.*, 2007)(Giannakopoulos *et al.*, 2011). However, especially for beach tourism, studies incorporating empirical techniques found no evidence that the Mediterranean as a whole will become exceedingly hot before 2030 or even 2060 (Moreno and Amelung, 2009)(Rutty and Scott, 2010). Interestingly, actual visitation data and questionnaires indicate that high beach visitation levels are associated with high temperatures, while the absence of precipitation plays a determinant role for summer tourism (De Freitas *et al.*, 2008)(Moreno, 2010)(Moreno and Amelung, 2009). Tourist arrivals at destinations also depend on parameters other than changes in climate comfort, including economic and environmental conditions (e.g. water stress), population and the capacity of tourist infrastructure (Hamilton and Tol, 2007)(Moreno and Amelung, 2009; Perch-Nielsen *et al.*, 2010).

Regarding ski tourism, in agreement with AR4, climate change affects snow reliability and consequently the ski season's length. In the Alps, by using the 100-day rule (Witmer, 1986) which requires that snow cover in a ski area should last at least 100 days per season for a successful operation, 69% of Alpine ski areas in Germany, 87% in Austria, 93% in Italy and 97% in France and Switzerland can be considered as naturally snow-reliable under the present climate (OECD, 2007). Still, in the record warm season 2006/2007 some low-altitude ski areas were not able to offer a continuous skiing season from December to April despite being equipped with artificial snowmaking, and in several others snow reliability would not have been maintained without this measure (Steiger, 2011)(Steiger, 2010b).

In a +2 ^{o}C scenario, Alpine naturally snow-reliable ski areas are expected to fall to 61% (OECD, 2007). In Sweden, a reduction of the current skiing season by 40-59% under the B2 and A2 emission scenarios was estimated (Moen and Fredman, 2007). Low-lying ski areas are most vulnerable (Falk, 2010; Serquet and Rebetez, 2011; Uhlmann *et al.*, 2009), as in the Black Forest area in Germany where a 30-50% reduction of snow days is expected by 2050 (Endler *et al.*, 2010; Endler and Matzarakis, 2011c). For some locations in Finland, extreme events such as high wind and frost were found to affect vulnerability much more than the shortening of the skiing season (Tervo, 2008). Artificial snowmaking is still the main adaptation option, covering 38% of the total skiing area in the European Alps and showing an increase by 48% since 2004 (Rixen *et al.*, 2011)(Hoy *et al.*, 2010)(Hoy *et al.*, 2010; OECD, 2007))(CIPRA, 2004). However, it has physical and economic limitations, especially in small and medium sized ski stations and stations located at low altitudes (Schönbein and Schneider, 2005)(Schönbein and Schneider, 2005) (OECD, 2007; Sauter *et al.*, 2010)(Steiger, 2010a; Steiger, 2010b)(Steiger and Mayer, 2008), and increases water consumption. Other options include shift to higher altitudes, operational changes, technical measures, use of weather derivatives, year-round tourist activities (Bank and Wiesner, 2011; OECD, 2007).The technical feasibility and economic viability of adaptation options are case-dependent, while existing diversification of tourist activities at a location affects significantly tourists' preferences and thus the efficiency of adaptation (Landauer *et al.*, 2012).

Notably, as shown by a survey of ski lift operators, the level of vulnerability does not always act as a motivation for adaptation (Gañán *et al.*, 2005).

Mountainous areas in Alpine and Continental Europe may experience a reduction in snow cover (Uhlmann *et al.*, 2009)(López-Moreno *et al.*, 2009), but improved climatic conditions for summer tourism (Endler *et al.*, 2010; Endler and Matzarakis, 2011c; Perch-Nielsen *et al.*, 2010; Serquet and Rebetez, 2011). Infrastructure capacity remains an important parameter to be considered.

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 also AR5 WG2 Section 10.7). The insurance and banking sector is affected by problems with accurate pricing of insurance, shortage of capital after large loss events, and by an increasing burden of losses that can affect markets and insurability, within but also outside the European region (Botzen *et al.*, 2010a; Botzen *et al.*, 2010b; CEA, 2007) (IPCC SREX). On the other hand, risk transfer mechanisms including insurance are also recognised as an important means to cover and reduce losses from extreme weather (Botzen and van den Bergh, 2008; CEA, 2009), and in addition, the sector could increasingly support the reduction of risks, notably through financial incentives, by fostering resilient practices and technologies, and by promoting risk awareness and education (Herweijer *et al.*, 2009).

Very few studies on financial services have assessed the risks of climate change to the European banking sector, with most studies focussing on the insurance sectors. 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. A large share of European banks are engaging in mitigation activities, but only a few of 100 surveyed banks have adopted comprehensive climate strategies that also address adaptation (Furrer *et al.*, 2009), and another survey of 40 large banks found that only few have specific activities such as funds in support of companies offering products for both mitigation and adaptation (Cogan, 2008).

Windstorm losses that are generally well covered in Europe by building and motor policies create a large exposure to the insurance sector. New studies have become available since AR4 that have coupled GCMs to damage models. All of these studies indicate an overall increase in future storm risk in Europe (see also Section 23.2.2.3), but the natural variations in storm frequency are large, and some European countries may see decreases in risks as storm tracks shift northward (Donat *et al.*, 2011)(Leckebusch *et al.*, 2007)(Narita *et al.*, 2010)(Pinto *et al.*, 2007a; Pinto *et al.*, 2007b)(Schwierz *et al.*, 2010) , see also Section 23.2; IPCC SREX Chapter 3; AR5 WG1 Chapter 3. There is no increase in historic European storm damages due to anthropogenic climate change, as the increasing number and value of buildings and infrastructure is a major driver at present (Barredo, 2010). The severe river flood events in 2000, 2007 and 2009 have put the insurance market in the UK, the largest private markets in Europe, under further pressure, with increasing need for the government to reduce risk in order to keep the market viable (e.g. (Ward *et al.*, 2008)(Lamond *et al.*, 2009). Other losses of concern to the European insurance industry are building subsidence losses related to drought, which may have been increasing in France (Corti *et al.*, 2009), insured hail damage to buildings which has increased over the past 20 years in some countries (Kunz *et al.*, 2009), and possible further increases in future hailstorm losses (Botzen *et al.*, 2010b).

The financial sector can adapt through adjustment of premiums, restricting or reduction of coverage, further risk spreading, and importantly risk reduction (e.g. Botzen et al., 2010). For instance, the insurance sector is helping to guide severely affected small businesses in the UK to their reduce risks (Clemo, 2008). More critical studies underpin the obstacles for actually incentivising risk reduction in Europe through insurance, a main problem being the lack of a legal requirement to minimise risks for new development (e.g. (Crichton, 2007)(Crichton, 2006)(Wamsler and Lawson, 2011)), although the sector is guiding constructors and policy makers (Surminski and Philp, 2010). Willingness-to-pay studies, for instance 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 risks (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.* (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. Food and Fibre 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 along the Mediterranean and in Southern and the eastern part of Continental Europe.

Climatic variability and the frequency and severity of climatic extremes affect agricultural systems (Tubiello *et al.*, 2007). Climate induced variability in maize and wheat production has increased in recent decades in France 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 summer since 1500 (Luterbacher *et al.*, 2004)(Barriopedro *et al.*, 2011). Grain-harvest losses in affected regions reached 20 and 30%, respectively (Aerts and Botzen, 2011; Aerts and Botzen, 2011; Ciais *et al.*, 2005)(Coumou and Rahmstorf, 2012). The 2004/2005 hydrological year was characterised by an intense drought throughout the Iberian Peninsula and cereals production fell on average by 40 % (EEA, 2010c). 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 many European countries, the last two decades are witnessing a decline in the growth trend of cereal yields (Olesen *et al.*, 2011) although national statistical yields do not reach the potential yield (Supit *et al.*, 2010). In France, genetic progress in wheat yields was partly counteracted from 1990 on by heat stress during grain filling and drought during stem elongation, as well as by agronomical factors (Brisson *et al.*, 2010). This is consistent: i) with statistical modelling showing that cereal yields have been negatively affected by warming in some European countries since 1980, e.g. in France by -5% for wheat and -4% for maize (Lobell *et al.*, 2011) and ii) with agro-climatic modelling showing over 1976-2005 a widespread decline of European potential crop yields, especially in Italy, central and eastern Europe, albeit increasing potential yields in the British Isles (Supit *et al.*, 2010)(Figure 23-6).

[INSERT FIGURE 23-6 HERE
Figure 23-6: Modelled changes in potential crop yield [a] and potential biomass production [b] in Europe over 1976-2005. The top figure shows regions where the potential yield decreases for one or more crops. The bottom figure shows regions where the potential yield increases for one or more crops. The following crops were simulated with the CropGrowth monitoring system: winter wheat, spring barley, maize, winter rapeseed, potato, sugar beet, pulses and sunflower. Source: 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).

The regional distribution of climate change impacts is *likely* to vary widely. 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 to 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. Following the B1 and A1B emission scenarios, detrimental impacts on wine growing in southern Europe are *likely* (Malheiro *et al.*, 2010). 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). 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). For Northern Europe, there are diverging views concerning future impacts. Positive yield changes and 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).

Ozone is the most important regional-scale air pollutant causing risks for agricultural production. For the European Union, ozone induced wheat and maize yield reduction was 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 to areas at higher latitudes where rapid warming is projected to occur in the absence of declining air and soil moisture (Fuhrer, 2009).

Climate change will probably influence the occurrence, prevalence and severity of plant diseases (Kersebaum *et al.*, 2008). 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 to tackle the expected yield loss in southern Europe as well as to exploit possible advantages in northern regions (Moriondo *et al.*, 2011; Moriondo *et al.*, 2010a). Further adaptation options include: changes in crop species, fertilization, irrigation, drainage, land allocation and farming system (Bindi and Olesen, 2011). In vineyards, some adaptation measures (vine management, technological measures, production control, and to a smaller extent relocation) are already in place (Battaglini *et al.*, 2009; Duarte Alonso and O’Neill, 2011; Holland and Smit, 2010; Malheiro *et al.*, 2010; Moriondo *et al.*, 2011; Santos *et al.*, 2011). At the high range of the projected temperature change, 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). 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), 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 climate variability and market risk (Howden *et al.*, 2007)(Knox *et al.*, 2010). The development of insurances against weather-related yield variations and the use of weather derivatives to safeguard against volumetric risks 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). Adaptation to increased climatic variability may imply an increased use of between and within species genetic diversity in farming systems (Smith and Olesen, 2010). By combining ecological and economic optimisation models at farm scale (Moriondo *et al.*, 2010b) the economic viability and the long term sustainability of farming systems in future scenarios may be approached.

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 daily dairy production above a threshold of 18 degrees C (André *et al.*, 2011). Pig performance decreases at an accelerating rate when temperature is increased above a critical threshold, which declines from 30 to 21°C for body weights between 10 and 90 kg (Renaudeau *et al.*, 2011). With dairy cattle in Italy, the mortality risk was increased by 60% as a result of exposure during breeding to a combination of high air temperature and air humidity, with a 4% increase in mortality rate for each degree above a threshold temperature-humidity index (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 2070's (Cantarel *et al.*, 2009). 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).

The spread of bluetongue virus (BTV) in sheep across Europe has been attributed to climate warming (Arzt *et al.*, 2010)(Guis *et al.*, 2012) and was caused by the distribution expansion of *Culicoides* vectors (Wilson and Mellor, 2009). Ticks, which are the primary arthropod vectors of zoonotic diseases in Europe, have *likely* changed distributions with climate warming (van Dijk *et al.*, 2010), see also 23.5), Climate warming may also increase the risk of fly strike incidence, which can however be managed through modest changes in husbandry practices (Wall and Ellse, 2011). For Europe, climate change is not predicted to increase in the 2080's 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 high flow threshold violation during winter, while in Central and Southern European basins the probability of low flow threshold violation 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).

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). 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). 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

Future responses of forests to climate change include changes in growth rates, phenology, species composition, increased fire damage, and increased insect and pathogen damage. In Europe, an increase in summer droughts will affect growth and regeneration of forest tree populations (E Silva *et al.*, 2012). Climate change is projected to have an overall positive effect on growing stocks in Northern Europe, negative effects are also projected in some regions (e.g. drought and fire pose an increasing risk to Mediterranean forests), making overall projections difficult (Lavalle et al., 2009).

In Northern and Atlantic Europe the increasing atmospheric CO2 content and warmer temperatures are expected to result in positive effects on forest growth and wood production, at least in the short–medium term. On the other hand, increasing drought and disturbance risks will cause adverse effects. From west to east, the drought risk increases. In the Mediterranean regions productivity is expected to decline due to strongly increased droughts and fire risks (Lindner *et al.*, 2010). In northern-central Italy, deciduous broadleaved forests (beech and oaks) at low elevation showed reductions up to 50% growth rate in 2000-2004, compared with 1997- 1999, due to a marked water deficit coupled to high air temperature, which resulted in a heavy water stress (Bertini *et al.*, 2011), while Italian mountain beech forest ecosystems increased their productivity since 1986 due to the increase of average temperatures (Rodolfi *et al.*, 2007). Repeated seasonal deviations in temperature and rainfall were recorded in the Alps in 2005-2009 causing a significant growth decrease within the coniferous spruce forests located at medium-high elevation (Bertini *et al.*, 2011). Climate change will substantially affect the growth of spruce and beech in Central Europe: growth rate in their upper distribution ranges is projected to improve, while drought-induced production decline was projected at the species' receding edges. However these forests are *likely* to remain net carbon dioxide sinks in the future, although the magnitude of their sequestration capacity will differ: increasing nitrogen deposition and atmospheric carbon dioxide concentration are projected to greatly affect the forest carbon cycle (Hlásny *et al.*, 2011).

Long-term phenological records from eight woody deciduous species from Southern and Central Finland show advancement in the bud burst and flowering time by 3.3 to 11 days during a century, in line with the temperature increase of 1.8 °C (Linkosaloa *et al.*, 2009). Despite such positive trends, droughts events had well documented effects on tree mortality and forest decline. During or just after the exceptional 2003 drought, mortality was observed on non favourable forest sites because of physiologic constraints, e.g. affecting pubescent oak on South-exposed sides in the Pre-alps in France (Giuggiola *et al.*, 2010; Nageleisen, 2008). The year after the drought, in 2004, a second mortality peak was observed due to insect outbreaks (Rouault et al. 2006) and 3 to 4 years later another wave of mortality was induced by a complex mix of biotic and non biotic factors (Nageleisen, 2008). Increased mortality due to severe drought events was also observed in southernmost populations of Scots pine forests in Mediterranean countries (Giuggiola *et al.*, 2010) and in dry inner-alpine valleys (Affolter *et al.*, 2010)(Bigler *et al.*, 2006; Raftoyannis *et al.*, 2008). In Cyprus the period 2005 - 2008 was extremely dry causing sudden dieback of both young and mature trees. Even drought adapted, typical Mediterranean species died on poor sites (ECHOES Country report, 2009)(ECHOES Country report, 2009). In Greece, intense crown discoloration, needle fall and mortality of fir trees have been observed throughout the country due to climate change (Raftoyannis *et al.*, 2008). In the Iberian Peninsula region, a generalized increase in crown defoliation was observed during 1987–2007, in response to increased water deficit and in relation to tree density and temperature effects (Carnicer *et al.*, 2011).

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 shift in suitable habitats for forest categories (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)(García-López and Alluéa, 2011)(Hemery *et al.*, 2010).

There is medium evidence that climate change together with socio-economic and technological drivers will influence future European land use change leading to declines in the agricultural area along with increases in forested and urban areas that would potentially reduce GHG emissions and enhance carbon sinks. These trends would be reinforced by small future changes in the climate. High-end climate scenarios indicate that net GHG fluxes to switch from being a sink to a source (Rounsevell and Reay, 2009).

In Southern Europe, especially in the Mediterranean Basin, fire incidence has increased dramatically during the past decades and fire is expected to become more prevalent also in the future due to climate change (Vilén and Fernandes, 2011). The incidence of forest fires increases substantially during extended droughts. During summer 2009 a series of Mediterranean wildfires broke out across France, Greece, Italy, Portugal, Spain, and Turkey. The most severe were associated with strong winds that spread the fire during a hot, dry period of weather (*see also (EEA, 2008)*). Results for Europe confirm a significant increase of fire potential, an enlargement of the fire-prone area and a lengthening of the fire season (Lavalle et al., 2009; (Albert and Schmidt, 2010; Flannigan *et al.*, 2006).

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 all 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. There is medium evidence that 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). Shortening frost periods as well as thawing permafrost may strongly reduce the accessibility of forests in the Boreal zone with implications for the timber supply to the forest industry (Keskitalo, 2008).

Many opportunist fungi and insects benefit from the 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). Higher temperatures can result in increased frequency and length of late summer warming events, producing a second generation of bark beetle in southern Scandinavia and a third generation in lowland parts of central Europe (Jönsson *et al.*, 2011). Model calculations suggest that the 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 (Jönsson *et al.*, 2009)(Jönsson *et al.*, 2009). In France, a development of diseases caused by thermophilous pathogens was observed (Marcais and Desprez-Loustau, 2007). In 2007, the highest peak in the annual average temperature ever recorded in the Czech Republic was followed by severe outbreaks of bark beetle in Norway spruce and Scots pine forests damaging almost 1.9 million m3 and similar was observed in 2008 (Knížek *et al.*, 2009). In some parts of the Temperate Continental Zone, fungi are even more problematic damage agents than insects. While some species benefit from milder winters, others spread during drought periods from south to north (Drenkhan *et al.*, 2006; Hanso and Drenkhan, 2007).

Tree growth is controlled by complex interactions between climate- and non-climate-related factors, with forest management also having a significant effect (Lavalle et al., 2009) and, on the other side, climate change will influence forest management, even if it is difficult to precisely quantify the overall effects. Increasing harvest level might lower the vulnerability through reduction of share of old and vulnerable stands. Ongoing changes in species composition from conifers to broadleaves could also reduce vulnerability (Schelhaas *et al.*, 2010). Adaptive capacity differs regionally, e.g. depending on the economic relevance of forest management. Fragmented small-scale forest ownership can also constrain adaptive capacity (Lindner *et al.*, 2010).

Possible response approaches include short-term and long-term strategies that focus on enhancing ecosystem resistance and resilience (Millar *et al.*, 2007). Forest management, in particular, thinning and shrub removal could decrease the intensity of drought stress by decreasing competition for water resources and thus increasing carbon uptake. For instance, the adaptive forest management will play an important role for maintaining Scots pine across southern regions of Europe (Giuggiola *et al.*, 2010). Strategies to anticipate severe forest mortality in the future may 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 be an adequate measure to 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 CO2 concentration can 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 CO2 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), although there is medium evidence that the northward expansion of SRC will erode the European terrestrial carbon sink (Liberloo *et al.*, 2010).

23.4.6. Fisheries and Aquaculture

Marine ecosystems, fisheries and aquaculture are being altered by direct effects of climate change including ocean warming, ocean acidification, rising sea level, changing circulation patterns, and changing freshwater influxes. As impacts of climate change strengthen they may exacerbate effects of existing stressors like overfishing and require new or modified management approaches. 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). 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, 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).

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. 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 demise of the sardine fishery and the potential threat to the mussel culture could have serious socio-economic consequences for the region (Perez *et al.*, 2010).

Climate change may 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).

A case study of fisheries in the Bay of Biscay concluded that 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 (Le Floc'h *et al.*, 2008). In the Baltic Sea, marine-tolerant species will be disadvantaged and their distributions will partially contract; conversely, habitats of freshwater species will likely expand (Mackenzie *et al.*, 2007). Although some new species can be expected to immigrate because of an expected increase in sea temperature, only a few of these species will be able to successfully colonize the Baltic because of its low salinity. Fishing fleets which presently target marine species (e.g. cod, herring, sprat, plaice, sole) in the Baltic will likely have to relocate to more marine areas or switch to other species which tolerate decreasing salinities. 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). A temporary marine reserve policy in the Eastern Baltic could postpone the negative effects of climate change on fish stocks (Rockmann *et al.*, 2009).

Integrative assessment can 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.*, 2011; Perry *et al.*, 2010).

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 wtih disabilities (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, and also will experience the highest heat exposures (Iñiguez *et al.*, 2010; Tobías *et al.*, 2010). However, elderly populations in central (Hertel *et al.*, 2009) and northern Europe (Rocklöv and Forsberg, 2010) are also vulnerable to hot weather and heat wave events, and are less likely to be prepared. Adaptation measures to heat include heat wave plans (EEA-JRC-WHO, 2008) and changes to housing and infrastructure (e.g. retrofitting houses, installing cool rooms in residential homes). 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 heat waves (see above) which are associated with significant impacts on mortality (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 in terms of the reduction of cold related mortality (Doyon *et al.*, 2008). A Europe-wide assessment, estimated that increase in heat-related mortality under a range of climate scenarios will only be equal or greater to the decrease in cold-related mortality at some point during the last third of the century (Ballester *et al.*, 2011). If the variance of the distribution of daily temperatures is increased, this is likely to increase the future mortality projected as due to climate change (Ballester *et al.*, 2011).

Mortality and morbidity associated with flooding is becoming better understood although the monitoing of health effects of disasters remains poor. The additional mortality associated with additional flooding has been estimated for some countries. Maaskant *et al.* (2009) estimated additional mortality in the Netherlands due to sea level rise; and for the UK, Hames and Vardoulakis (2012) estimated that climate change and population growth could lead to approximately 8-49 additional deaths per year in the 2050s.There is also more 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). Developments in mapping the current distribution of important vectors and vector-borne diseases in Europe have focussed on environmental factors such as land use cover. The Asian tiger mosquito (*Aedes albopictus*, a vector of dengue and other arboviruses) is currently present in many countries in southern and eastern Europe (ECDC, 2009). An assessment of the potential impact of climate change indicated the potential for eastward expansion in its distribution in Europe, with some areas in the Balkans becoming unsuitable (ECDC, 2009). A study in Italy also projected the potential for northward shift of the vector's distribution in that country (Roiz *et al.*, 2011). Visceral and cutaneous leishmaniasis are sandfly-borne diseases 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. 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 some key food pathogens is sensitive to temperature (e.g. salmonellas) although there is some evidence that this sensivity has declined in recent years (Lake *et al.*, 2009). Climate change may also have affects on food consumption patterns (the reduction in consumption of animal products can be a co-benefit of mitigation). Weather effects pre and post harvest mycotoxin production. Cold regions may become liable to temperate problems concerning ochratoxin *A*, *patulin* and *Fusarium* toxins. Warming may increase the risk of aflatoxin production. A control of the environment of storage facilities may avoid post-harvest problems but at high 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. persistant 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).

_____ START BOX 23-1 HERE _____

Box 23-1. Multiple Impacts of a Heat Wave Event

An extreme weather event occurred in the European part of the Russian Federation in [dates] 2010 when air temperatures exceeded the long-term averages by more than 10ºC (>4 standard deviations) (Barriopedro *et al.*, 2011). The heat wave was associated with impacts on human populations, the natural environmental and several economic sectors. The heat wave was associated with a local [define] increase in outdoor air pollution. Forest fires burned an area of over 2800 km^2. Concentrations of CO and PM_{10} in Moscow and surrounding area were 30 mg/m^3 and 1500 µg/m^3, respectively, and daily average PM_{10} levels varied between 431 and 906 µg/m^3 (WHO, 2010). It is estimated that the heat wave caused approximately 54,000 deaths in the Russian Federation (the excess relative to the same period in 2009). In Moscow, the estimate impact on mortality was approximately 5,950 deaths from cardiovascular disease and 339 additional from respiratory diseases (Revich and Shaposhnikov, 2010). A three-fold increase in deaths in bronchial asthma patients was reported (Zairatiants *et al.*, 2011). The annual crop failure was estimated to be 25%. The economic loss associated with the heat wave was estimated to be USD 15 billion (1% of gross domestic product) (cited in (Barriopedro *et al.*, 2011). The heat wave also affected tourism and energy sectors.

_____ END BOX 23-1 HERE _____

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 (UK Cabinet Office 2011). Extreme weather events, such as floods, heat waves and wild fires are known to damage critical infrastructure. Several countries have undertaken reviews of flood risks to hospitals, schools, water treatment/pumping stations. The UK found that 7% of schools were in flood risk zones (EEA, 2008). In 2007, a forest fire in Greece caused the closure of a major road and access to the international airport.

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. 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 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. A JRC report investigated the impacts of climate policies (mitigation) on employment by sector, but there has been no published synthesis of climate change impacts per se. However, the sector summaries above indicate 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 long term.

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, 2009). 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 (also called managed realignment) is one of the options to adapt in coastal areas (Rupp-Armstrong and Nicholls, 2007) (see section on integrated coastal management below). 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 highly vulnerable to climate change impacts on livelihoods and food sources (Arctic Climate Impact Assessment 2005) which are discussed in more detail in the Polar chapter. Research has focussed on indigenous knowledge, impacts on traditional food sources and community responses/adaptation, in the Saami in Finland (Mustonen and Mustonen, 2011a; Mustonen and Mustonen, 2011b) and Chukchi and Evenki peoples in Russian Federation.

23.5.4. Cultural Heritage and Landscapes

Climate change and sea-level rise will impact on cultural heritage within the built environment (Storm *et al.*, 2008) through both extreme events and chronic damage to materials (Brimblecombe *et al.*, 2006; Brimblecombe and Grossi, 2010; Brimblecombe, 2010a; Brimblecombe, 2010b; Grossi *et al.*, 2011). Water, as ice, liquid water and water vapour, all have important impacts on buildings (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)(Bonazza *et al.*, 2009a; Bonazza *et al.*, 2009b; Brimblecombe and Grossi, 2009; Brimblecombe and Grossi, 2010; Grossi *et al.*, 2008). Climate change may also affect indoor environments where most 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; Bonazza *et al.*, 2009b). Marble monuments located in the Mediterranean will continue to experience high levels of thermal stress (Bonazza *et al.*, 2009a; Bonazza *et al.*, 2009b). However damage from frost damage is likely to reduce across Europe, except in Northern and Alpine areas. The problem may increase in areas characterized by permafrost (Greenland, Iceland) and in wood (Grossi *et al.*, 2007; Sabbioni *et al.*, 2008). Damage to porous materials (sandstone, mortar and brick) due to salt crystallisation may increase all over Europe (Benavente *et al.*, 2008; Grossi *et al.*, 2011). As Northern and Eastern Europe become warmer, higher precipitation levels will require wood structures to be protected against the effects of rainwater. Damage from high winds may increase in the 2080s in northern Europe (Sabbioni *et al.*, 2010).

The culturally-significant city of Venice has implemented a sea level rise (flood) forecasting system, as well as the MOSE system of flood barriers (Keskitalo, 2010). AR4 indicated that Venice would be at higher risk from SLR with current flood defence schemes unable to cope with projected climate scenarios. However recent evidence suggests that Venice may be at less risk from climate change due to projected decreases in the frequency of extreme storm surges (Troccoli *et al.*, 2011 (in press)). Venice has also included adaptation in its municipal energy plan with projects that are designed to reduce the effects of increases in summer temperatures whilst simultaneously targeting air pollutants.

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 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. Because of their cultural importance, many such landscapes are protected through rural development and environmental policies.

In spite of their importance, however, cultural landscapes have been little researched in terms of climate change impacts and adaptation, with the exception of the economic consequences. 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).

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). Traditional wine producing regions are strongly influenced 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. Vineyards may be displaced geographically beyond their traditional boundaries, but in principle, wine producers can adapt to this problem by growing grape varieties that are more suited to warmer climates (see earlier discussion). 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 it is unlikely that consumers would 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. 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).

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). Other pollutants have been examined using other methods. [These modelling studies are reviewed in more detail in Chapter 1/21]. 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). The effect of future climate change alone on future concentrations of particulates, nitrogen oxides and volatile organic compounds is much more uncertain.

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. Climate change may also increase the risk of forest fires, which in turn will increase particulate exposures. For example, in Greece, forest fires were major contributors to PM concentrations (up to 50%) (Lazaridis *et al.*, 2008) (see also Box 23-1).

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 (García-Ruiz *et al.*, 2011)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). Erosion can further lead to supply of sediments to watersheds. 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 *et al.*, 2008; Thodsen, 2007).

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 mineral soil organic carbon stocks 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).

Direct effects of climate change have the potential of affecting the distribution and degradation of soil and sediment organic pollutants, including persistent organic pollutants. For example, climate change may reduce the environmental levels of these chemicals in the Venice Lagoon (Italy) but would also probably enhance their mobility and hence their potential for long range atmospheric transport (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 and fibre production (see also Section 23.4.3), ecosystem functioning, human and animal health, and compliance with European and national quality targets including those of the Water Framework Directive. Overall, because of 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) 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).

Studies have estimated future impacts attributable to climate change include increased nutrient fluxes (Delpla *et al.*, 2011); impacts from increasing water temperature and discharge reduction in the Seine river (Ducharne, 2008); nutrient loads in Danish water sheds (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); and adverse effect on nutrient flushing episodes and surface water quality in the UK (Whitehead *et al.*, 2006; Whitehead *et al.*, 2009; Wilby *et al.*, 2006). A modelling study on projected future water quality impacts for all EU27 indicated increased nutrient loadings in northern Europe (due to increased surface runoff) and increase nutrient loadings in southern Europe (due to increased evapotranspiration) (Jeppesen *et al.*, 2011).

23.6.4. Terrestrial and Freshwater Ecosystems

The observed change in suitable habitats, species distribution and biodiversity as well as the northward and uphill distribution shifts of many European plant and animal (birds, insects, fish, amphibians, reptiles, and mammals) species has been attributed to observed climate change.

23.6.4.1. Implication for Habitats

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, using a consensus across ensembles of forecasts 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). Projected habitat loss is greater for species distributed at higher elevations; depending on the climate scenario, up to 36–55% of alpine plant species, 31–51% of subalpine plant species and 19–46% of montane plant species lose more than 80% of their suitable habitat by 2070–2100. While high-resolution analyses consistently indicate marked levels of threat to cold-adapted mountain florae across Europe, they also reveal unequal distribution of this threat across the various mountain ranges (Engler *et al.*, 2011).

The projected climatic changes are *likely* to affect upland habitat composition, long-term soil carbon storage and wider ecosystem service provision. Mean altitude of the upland area is projected to increased by +11 to +86 m and +21 to +178 m respectively for high and low emissions scenarios by 2071–2100, assessing that low altitude areas in eastern and southern Great Britain will be the most vulnerable to change (Clark *et al.*, 2010a). Increasing summer temperature will be the main driver of a long-term decline in the distribution of actively growing blanket peat, although it is emphasised that existing peatlands may well persist for decades under a changing climate (Clark *et al.*, 2010b). Climate projections for the time periods 2011-2040, 2041-2070 and 2071-2100 predict a gradual retreat towards the north and the west of British blanket peatlands, with the blanket peatland bioclimatic space likely becoming 84% smaller than contemporary conditions (1961-1990); only parts of the west of Scotland remain inside this space (Gallego-Sala *et al.*, 2010).

With climate change, severe winters are predicted to become less frequent and the winters to be milder and shorter. This may lead to higher winter survival of fish, lower zooplankton grazing of phytoplankton the following summer and more turbid waters, particularly in shallow eutrophic lakes (Balayla *et al.*, 2010). In three natural shallow lakes located in the southwest of France, several planktonic species typically encountered in tropical areas were observed during 2006 and 2007 possibly as a result of minimum temperatures increases that were observed over the last 30 years and could have played a key role in algal survival through winter (Cellamare *et al.*, 2010). Across most of central, eastern and southern Europe, reduced hydroperiods and increased temperatures with parallel reduced oxygen in shallow waters and wetlands will very likely have profound impacts on the distribution of fish, amphibians and invertebrates. Habitat connectivity in river networks may become increasingly fragmented.

Protected areas are expected to play a key role in retain climatic suitability for species better than unprotected areas allowing a more effective conservation of biodiversity in plant and terrestrial vertebrate species under climate change. Europe has the world’s most extensive network of conservation areas (Araújo *et al.*, 2011). However, by 2080, 58 ± 2.6% of the species would lose suitable climate in protected areas, whereas losses affected 63 ± 2.1% of the species of European concern occurring in Natura 2000 areas. It has been hypothesised that conservation areas are selected without taking into account the effects of climate change and the risk is high that ongoing efforts to conserve Europe’s biodiversity are jeopardized by climate change (Araújo *et al.*, 2011).

23.6.4.2. Implications for Plant Species

The timing of seasonal events in plants is changing across Europe due to changes in climate conditions. Between 1971 and 2000, the average advance of spring and summer was 2.5 days per decade. The pollen season starts on average 10 days earlier and is longer than 50 years ago (Feehan *et al.*, 2009). Change in plant phenology are due not only to warming but also to change in precipitation: impacts on florae from regions projected to undergo increased warming accompanied by decreased precipitation, such as the Pyrenees and the Eastern Austrian Alps, will *likely* be greater than on florae in regions where the increase in temperature is less pronounced and rainfall increases concomitantly, such as in the Norwegian Scandes and the Scottish Highlands (Engler *et al.*, 2011). According to a combination of an integrated environmental model (IMAGE) and climate envelope models for Europe, 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 for that region, and in Southern Europe, where up to 25% of the species now present would disappear.

In European mountainous regions, the ongoing climate change gradually transforms mountain plant communities since climate warming is expected to shift species’ ranges to higher altitudes. Evidence for such shifts is provided by observed changes in vascular plant species richness in a standardized monitoring network across Europe’s major mountain ranges (Pauli *et al.*, 2012). In all major European mountain systems the more cold adapted species decline and the more warm-adapted species increase. In view of the projected climate change the observed transformation suggests a progressive decline of cold mountain habitats and their biota (Gottfried *et al.*, 2012). However, these shifts had opposite effects on the summit floras’ species richness in boreal-temperate mountain regions (+3.9 species on average) and Mediterranean mountain regions (–1.4 species), probably because recent climatic trends have decreased the availability of water in the European south (Pauli *et al.*, 2012).

In European lowlands, niche-based to process based models project on average large range contractions of temperate tree species due to climate change. Some tree species, vulnerable to climate change could see their suitable areas reduce up to 72% in 2080 for SRES-A2a scenarios (Casalegno et al., 2007). For the dominant Mediterranean tree species, Holm oak, all models foresee substantial range expansion (Cheaib *et al.*, 2012). The increase in climatic aridity may compromise the survival of several populations of Pinus sylvestris in the Mediterranean basin (Giuggiola *et al.*, 2010). Results from a phytoclimatic, correlative and niche-based model implemented for peninsular Spain (CLIMPAIR model) project a significant decrease in the versatility of forest tree formations at elevations of less than 1500 m (García-López J.M. and Alluéa, 2011). The scattered distributions of some broadleaved 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 (Hemery *et al.*, 2010).

23.6.4.3. Implications for Animal Species

Concerning animal phenology, climatic 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. Seasonal advancement is particularly strong and rapid in the Arctic. 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). For common European birds, species with the lowest thermal maxima showed the sharpest declines between 1980 and 2005(Jiguet *et al.*, 2010). However, climate cooling would be more deleterious for the persistence of amphibian and reptile species than warming. The ability of species to cope with climate warming may, however, be offset by projected decreases in the availability of water. This should be particularly true for amphibians (Araújo *et al.*, 2006). Northern European species appeared to be amongst the most vulnerable European butterflies. However, there is much species-to-species variation, and species appear to be threatened due to different combinations of critical characteristics, using the HadCM3-A2 climate scenario for 2051–2080 (Heikkinen *et al.*, 2010).

Climate change could lead to future changes in the co-occurrence of interacting species having significant implications on trophic interactions, as co-occurring species do not necessarily react in a similar manner to global change (Schweiger *et al.*, 2012). The monophagous butterfly (*Boloria titania*) may expand considerably its future range (by 124–258%) if the larval host plant (*Polygonum bistorta*) has unlimited dispersal, but it could lose 52–75% of its current range if the host plant is not able to fill its projected ecological niche space, and 79–88% if the butterfly also is assumed to be highly dispersal limited (Schweiger *et al.*, 2008). This may lead to novel emergent ecosystems composed of new species assemblages arising from differential rates of range shifts of species (Montoya and Raffaelli, 2010).

Range shifts of many animal species are documented as a response to global warming. The community temperature index (CTI) directly reflect, for a given species assemblage, the balance between low- and high-temperature dwelling species. The CTI for birds communities strongly increased in the last two decades revealing that birds are rapidly tracking climate warming generating a northward shift in bird community composition (Devictor *et al.*, 2008). 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). (Lemoine *et al.*, 2007a; Lemoine *et al.*, 2007b) showed that climate and land-use alteration in Central Europe cause impacts on the abundance of birds of different breeding habitat, latitudinal distribution, and migratory behaviour. Changes in the regional abundance of the 159 coexisting bird species from 1980-1981 to 2000-2002 were observed in the Lake Constance, which borders Germany, Switzerland, and Austria: farmland birds, species with northerly ranges and long-distance migrants declined whereas wetland birds and species with southerly ranges increased in abundance.

In migratory birds, climate change has been shown to result in both exchange of species and adaptation of migratory behaviour. Changes in winter and spring temperature are expected to cause mainly adaptation in migratory activity, while changes in spring precipitation may result in both changes in the proportion of potentially migratory species and adaptation of migratory activity. There is limited evidence that under current climate change forecasts, changes in the proportion of migratory species will be modest and the communities of migratory birds in Europe are projected to be altered through adaptation of migratory activity rather than through exchange of species. In contrast, phenotypic adaptation allows species to persist *in situ*, conserving community composition (Schaefer *et al.*, 2008).

Potential mammalian species richness is predicted to become dramatically reduced in the Mediterranean region but increase towards the northeast and for higher elevations and endemic species are predicted to be strongly negatively affected by future climatic changes, while widely distributed species would be more mildly affected. Projections for 120 native terrestrial non-volant European mammals suggest that up to 5-9% risk extinction during the 21st century, while 32-46% or 70-78% may be severely threatened (lose > 30% of their current distribution) using bioclimatic envelope models under two of IPCC's future climatic scenarios (Levinsky *et al.*, 2007).

23.6.4.4. Implications for Invasive Species

Climate change can exacerbate the threat posed by invasive species to biodiversity, both by direct and direct effects such as changes to farm practices and introductions of exotic material and effects of other environment changes such as elevated CO2 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; recent results showed a northward advancement of the upper physiological limit as a result of climate change, which might increase the strength of outbreaks at higher latitudes (Aragòn and Lobo, 2012). Lantana camara L. (lantana) is a woody shrub that is highly invasive in many countries of the world and some areas in Europe may become climatically suitable under future climates (Taylor *et al.*, 2012). Climate scenarios of milder conditions for Atlantic Europe could lead to Giant rhubarb and Brazilian giant rhubarb 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. These findings reveal that substantial niche shifts are rare in terrestrial plant invaders, providing support for an appropriate use of ecological niche models for the prediction of both biological invasions and responses to climate change (Petitpierre *et al.*, 2012).

23.6.5. Coastal and Marine Ecosystems

Europe’s coastal and marine ecosystems are likely to be affected by climate change, 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 invasives 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 likely to have more 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 is likely to 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, while this is less likely in 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 is considered part of the vulnerability and adaptation literature (V&A studies), and these have been discussed in previous sections of this chapter. However, there is an emerging literature that also describes the wider decision making framework, including actual adaptation efforts occurring throughout Europe at the local, regional, national and pan-European level. Many European countries have now developed a series of national plans and strategies to address adaptation (see Box 23-2). Since AR4, considerable progress has been made to advance planning and implementation of adaptation measures as well as the costing of adaptation.

_____ START BOX 23-2 HERE _____

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 (sectoral) research and/or preparations for future implementation. Actual implementation often relates to coastal zone and water resources management. Where planned adaptation has been achieved at the national level, this has been due to political will, as well as good financial and information capacities (Westerhoff *et al.*, 2011). (Biesbroek *et al.*, 2010) 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 (Finnish 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 (Swaney *et al.*, 2012), and ensure that climate change considerations are incorporated into marine strategies with mechanisms for regular updating to take account of new information (OSPAR, 2010; UNEP, 2010).

In the Dutch new 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 British government has developed extensive adaptation plans (TE2100) to adjust and improve flood defences for the protection the Thames estuary and the city of London from future storm surges and river 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 (see Figure 23-7), and this plan is now past the consultation phase.

[INSERT FIGURE 23-7 HERE
Figure 23-7: Decision pathway developed for Thames flood defence system in the UK. Source: adapted from Haigh and Fisher, 2010.]

23.7.2. Integrated Water Resource Management

Climate change concerns have been incorporated into water resources planning since the 1990s in the England and Wales but with only limited consideration of change to climate variability (Arnell, 2011) and changes in water resources in sub-regions (Charlton and Arnell, 2011). Traditionally, water resources management has been a technical and top-down organised approach to manage and allocate water resources. While first integrating different environmental and social concerns, this area is increasingly open to new developments. In the literature, a shift can be noticed in suggestions for water management approaches, specifically from “hard” to “soft” measures, battle versus accommodation. This is considered to allow for a more flexible and adaptive approach to an uncertain future (Pahl-Wostl, 2007). A number of approaches for flood control and water supply response options have been assessed for The Netherlands (de Graaff *et al.*, 2009). The robustness of adaptation strategies illustrated for a case study on water supply in East England was tested under a range of different scenarios (Dessai and Hulme, 2007). The concept of creating space for water and accommodating water and to integrate water management approaches with goals of environmental protection is an essential component of integrated water management (Wiering and Arts, 2006). Also, an increasing role is sought in Europe for public participation in decision making, exemplified in the consultation practices river basin management planning (Huntjens *et al.*, 2010), as well as for current adaptation plans (e.g. TE2100). An overview study found that various countries around southern Europe and the Mediterranean are in the process of developing drought contingency plans, with some adopting a high degree of public participation (Iglesias *et al.*, 2007).

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 (EC, 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). In response to the flooding in New Orleans during hurricane Katrina in 2005, 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). Also small businesses can contribute to reducing 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 and leads therefore to partial solutions (Mickwitz *et al.*, 2009)(Wilson, 2006)(Van Nieuwaal *et al.*, 2009). Even so, there is limited evidence that climate change is being considered in these aspects. 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, notably London and 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 (2009-2011) (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)(Baycan-Levent and Nijkamp, 2009). A study in Manchester showed that urban green space and green roofs can moderate temperature and decrease surface rainwater run-off. Increasing green space cover by 10% in high-density residential areas and town centres was shown to maintain surface temperatures at or below the baseline 1961-1990 level for most of the coming century, but removing 10% green cover from these areas would increase maximum surface temperatures by 7 to 8.2°C by the 2080s, for the highest emissions scenario (Gill *et al.*, 2007). Despite the benefits however of urban green space, conflict can occur between the use of land for green space or for new building developments (Wilson, 2008).

European policies for biodiversity (e.g. the European Biodiversity Strategy, CEC, 1998) 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, 2009) 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 is currently not being met by policy.

23.7.6. Economic Assessments of Adaptation

Increasingly, cost estimates for planned adaptation are being generated, often however in the grey literature domain (see (Watkiss and Hunt, 2010)). What is different from previous studies assessed in AR4 is that these costs estimates are not derived from global integrated assessment models, but from bottom-up sector studies specifically aimed at costing response measures. Adaptation cost studies for Europe can be broken down into pan-European, sectoral, and national studies. The evidence base is fragmented and incomplete. As for the sectoral studies, the coverage of the adaptation costs (and benefit estimates) is limited and varies considerably between the sectors covered. Studies on coastal zone management have most cost and benefit categories covered, while for energy, agriculture, infrastructure there is medium coverage of cost and benefit categories, and low coverage for other sectors, with most often benefit estimates lacking (Watkiss and Hunt, 2010). The costing studies use a range of methods and metrics and relate to different time periods and sectors, which renders robust comparison difficult. Table 23-3 summarises cost estimates for Europe for sectoral studies, and national studies.

[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 Earth's climate is a global public good. Therefore the protection benefits due to mitigation can only be compared with protection costs only at the global scale. No single country or region can justify mitigation measures on economic grounds, as benefits depend on what others do (or fail to do) (Zylicz, 2010). Adaptation policies are guided by different principles. Those who take adaptation measures are also usually their sole beneficiaries which make conventional economic analysis applicable, providing it includes non-markets costs and benefits (externalities). 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- but these will be included, where available.

23.8.1. Production and Infrastructure

Dwellings across Europe are likely to undergo radical, mitigation related, changes due to the implementation of decarbonisation strategies. It is vital that both appropriate mitigation and adaptation occur together if serious and widespread unintended consequences are to be avoided (Davies and Oreszczyn, 2011). Due to the need to decarbonise the built environment, energy efficiency interventions will be implemented at large-scale across Europe. Such interventions may have considerable impact on indoor summer temperatures, some acting to reduce temperatures and others acting to increase temperatures (Mavrogianni *et al.*, 2011).
As regards energy demand, local side-effects of mitigation measures in buildings under different climatic conditions have been analyzed (Jenkins *et al.*, 2008; Jenkins, 2009). In the case of UK, the reduction of internal heat gains in offices as a result of more energy efficient PCs, low energy LCD display technology, improved power management and energy efficient lighting can reduce cooling requirements by up to 48% even under a 2030 warming climate (+1 ^{o}C compared to 2005). However, as space heating requirements would increase, the location, type and dominant energy use of the building will determine its overall energy gain or loss to maintain comfort levels. 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).

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; Perch-Nielsen, 2008). 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 GHG emissions and operating costs. Interactions between adaptation and mitigation are also created by the link between tourist flows and transport.

23.8.2. Agriculture, Forestry, Fisheries, 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).

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).

23.8.3. Social and Health Impacts

Significant research has been undertaken since AR4 on the health co-benefits of mitigation policies (see WGIII chapter x 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 implications for human health. An increase in the cost of energy either for home heating or space cooling can limit an individual's capacity to cope with extreme weather events. Researches on the benefits of various housing options (including retrofitting) have been intensively addressed in the context of low energy, healthy and sustainable housing.

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 future land use demand for bioenergy production, food production, nature conservation and urbanisation. 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.*, 2010). Bioenergy crops could occupy significant areas of rural land within 20 years in the UK (Haughton *et al.*, 2009).

23.9. Intra-Regional and Inter-Regional Issues

The focus of this section is to analyze how climate change impacts and adaptation in different European sub-regions (intra-regional) or 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.

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

(Ciscar *et al.*, 2011) showed that if the climate of the 2080s were to occur today, the annual loss in household welfare in the European Union (EU) resulting from the four market impacts (agriculture, river floods, coastal areas, and tourism) would range between 0.2-1% using the computable general equilibrium (CGE) GEM-E3 model for Europe under four alternative scenarios of future climate change. The results show that there are large variations across European regions. Southern Europe, the British Isles, and Central Europe North appear most sensitive to climate change. Northern Europe, on the other hand, is the only region with net economic benefits, driven mainly by the positive effects on agriculture. Coastal systems, agriculture, and river flooding are the most important of the four market impacts assessed. Table 23-4 summarises the evidence regarding impacts by sector and by sub-region, discussed in more detail in the chapter above.

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

In northern Europe, increases in yield and expansion of climatically suitable areas are expected to dominate, whereas disadvantages from increases in water shortage and extreme weather events (heat, drought, storms) will dominate in southern Europe under four IPCC SRES-A1FI, A2, B1 and B2 emissions scenario. These effects may reinforce the current trends of intensification of agriculture in Northern and Atlantic Europe and extensification and abandonment in the Mediterranean and south-eastern parts of Europe (Bindi and Olesen, 2011).

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).

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 is included in two IPCC regions: Europe and Africa. The area is particularly vulnerable to climate change because of environmental and social changes. Warming in Mediterranean is in line with the global trends, whereas precipitation is decreasing over the region (Ulbrich *et al.*, 2012); (Mariotti *et al.*, 2008); (Navarra, 2012, In press.). Observed warming trends in annual mean and in summer are very likely caused by anthropogenic forcing (greenhouse and aereosol) and are consistent with model simulations, whereas no conclusion can be reached for changes in precipitation (Planton *et al.*, 2012). The new generation of regional and global climate models specifically including the MedSea confirm a very likely warming and drying trend under at least one emission scenarios for the region (Gualdi, S., Somot, S. *et al.*, 2012b; Gualdi *et al.*, 2012a). Sea level estimations have a strong spatial variance over the MedSea but there is high confidence that global average increase of the MedSea has been of the order of 15cm in the period 1987-2007 (Ulbrich *et al.*, 2012). The evaluation of projected sea level changes with multiple models shows a likely average increase estimated of about 10cm for the period up to 2050 and a chance of increasing to 15 in the average up to 2100, based on only one model (Gualdi *et al.*, 2012a). However, the local sea level change is still uncertain due to large spatial variability. There is robust evidence that salinity especially in the Eastern Mediterranean sea has been increasing in the recent period (Ulbrich *et al.*, 2012).

Mediterranean ecosystems have been strongly modified from millennia of human occupation and use. Therefore, there is no “natural baseline”. Climate change is only one driver of the observed trend of increasing water scarcity. Water, agriculture and “natural ecosystems” in the Mediterranean are strongly affected by the combination of drivers, with different expressions in the northern and south-eastern Mediterranean. It is very likely that vulnerability is going to increase (Hoff, 2012). It is very likely that water resources will be affected with increasing competition for access (Iglesias *et al.*, 2012). It is uncertain if tourism flows will decline in the Mediterranean countries (Magnan *et al.*, 2012). 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 exotic vectors of human and animal infectious diseases. In addition, transport of animals and products of animal origin has caused the spread of animal diseases, notably of Rift Valley Fever from Africa to the Arabic peninsula and of African Swine Fever from East Africa into the Caucasus region (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 above).

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).

23.10. Synthesis of Key Findings

23.10.1. Key Vulnerabilities

We have reviewed evidence regarding capacity to adapt today (from surveys, observational evidence), and resilience to extreme events, particularly major events such as heat waves. We also reviewed the evidence from modelling studies of future impacts that have estimated the benefits and/or limits of specific adaptation measures.

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 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 an 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 exposure to overheating and damage from subsidence and flooding. Passive cooling measures alone are not enough for adaptation
- Housing will be affected- the risk of overheating, and damage from subsidence and flooding. Passive cooling measures are unlikely to be sufficient to address adaptation but retrofitting current housing stock is likely to 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.

- 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, i.e. people are already adapting.
- 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 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 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 local climate warming. The attribution of local warming to anthropogenic climate change is less certain (see Chapter 18 for a full discussion).

[INSERT TABLE 23-6 HERE
Table 23-6: Impact of observed changes in key Indicators in ecological and human systems.]

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 and forest productivity.

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). Many impacts on health and welfare, and across multiple economic sectors have been observed due to the major heat wave events of 2003 and 2010 in Europe. The attribution of such events to anthropogenic climate change is discussed in WGI.

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:

- Observed long term trends in crop yields in European countries and the characterization of the determinants of changes in yield.
- Research on the resilience of populations to extreme events, including responses to flood and heat wave risks.
- More research on the definition of climate comfort in tourism.
- More research is needed on adaptation options, especially modal shifts, and the effects of adaptation in one sector on other sectors in Europe.
- Synergies and trade-offs between mitigation and adaptation need to be further researched and incorporated into economic analyses of the mitigation costs.

Frequently Asked Questions

[forthcoming]

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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 Subregions. Numbers are based on 9 (indicated with *) and 20 (indicated with **) regional model simulations taken from EU-ENSEMBLES project[2]. The likely range defines the range of 66% of all projected changes around the ensemble median.

Szenario 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
	Frostdays (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
	Summerdays (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
	Tropicalnights (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	-11	-9	4	-7
		Likely in the range	5 to 12	-4 to 5	-1 to 5	13 to 21	-12 to -18
		Max	15	9	12	29	-25
	Annual total Precipitation where RR>99p of 1971/2000 (26) in %	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

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

[2] Based on CMIP3 data. Data will be replaced by CMIP5 CORDEX data in SOD.

Table 23-2: Impacts of climate change on ecosystem services.

Ecosystem Service	**Alpine**	**Southern**	**Northern**	**Continental**	**Atlantic**
Food and fibre production	↑	↓	↑	↑	↑
Carbon sequestration	↓?	↓	↑	↑	↑
Water quality	-	-	↓	-	↓
Biodiversity Local loss of native species and extinction of species	↓ Loss of alpine species	↓	↓	↓	↓
Cultural services - Loss in cultural landscapes	Yes	Yes	Yes	↓	↔ (changes in terroir)

Key: ↑ improvement in ecosystem service; ↓ loss or reduction of ecosystem service, - = no information; ↔ increases and decreases in ecosystem service (no net change).* includes shifts in native species

Table 23-3: Adaptation cost estimates for European countries.

Population	**Cost estimate**	**Time period**	**Sectors/Outcomes**	**Reference**
Netherlands	€1.2–1.6 billion/a	up to 2050	Protection from flooding	Delta Committee, 2008
Netherlands	€0.9–1.5 billion/a	2050–2100	Protection from 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 in order to cover the higher summer energy demand for cooling	Mirasgedis et al., 2007
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).

Sector	Regions in Europe					AR5 Sections
	Alpine	**Southern**	**Northern**	**Continental**	**Atlantic**	
Infrastructure						
Wind energy	0	?[1]	0	0	?[1]	23.3.3
Hydropower	–/+[2]	–	+/0	–	–	23.3.3
Thermal production	0	–/0	0	–/0	–/0	23.3.3, 8.2.3.2
Energy use (net annual change)	+	–	+	+/?	+/–	23.3.6, 23.9.4
Road transport	+	+	+	+/–	+/–	23.3.2
Rail transport		?	?	?	–/?[3]	23.3.2, 8.3.3.6
Inland waterways			?	–		23.3.2
Skiing tourism	–/0	?	–/?	–/0		23.3.4, 3.5.7
Summer tourism[6]	+	–/0[7]	0/+/?[8]	0/+/–	0/+	23.3.4, 10.6.1.1., 18.3.1.2
Spring/fall tourism[6]	+/0	+	+/0/?[8]	+/0	+/0	23.3.4, 18.3.3.5
Industry	?	–/?[9]	?	–/+/?[9]	–/+/?[9]	23.3.5, 18.3.3.1, 23.4.1
Food and Fibre production						
Arable yields	-/0	–	+	–	?	23.4.1
Livestock production	?	–				23.4.2
Dairy production		–	–			
Water availability for agriculture	–/0	–	+	–	?	23.4.3
Forest productivity	?	–	+			23.4.4
Seasonality activity of pest and plant diseases	?	?	–	?	?	23.4.1, 23.4.4
Bioenergy production	+	–	+	+	+	23.4.5
Health and Social Impacts						
Heat wave mortality	–	–	–/0	–	–	23.5.1
Flood related mortality		–			–	23.5.1
Cultural buildings	+	–	+	+	+	23.5.4
Cultural landscapes	–	–	–	–	–	23.5.4

Footnote. + positive impact, - negative impact

[1] Simulations have been performed, but only for the period after 2070; [2] '+' is for Norway; [3] Impacts have been studied and quantified for UK only, thus '?' is for the rest of the region; [4] '+' is for Russia; [5] Impact refers mostly to the Northern sea route. The '+' sign, although attributed to Atlantic Europe only, can be applicable also to other regions where countries use ports in Continental Europe for their exports; [6] 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 tis may not be the case); [7] '0' stands for the beach tourism in the Mediterranean, where some studies estimate no changes at least until 2030 or even 2060; [8] '?' is for Russia; [9] '-', '+' refer to wine industry only, as impacts on other sectors have not been yet assessed.

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**	**Agriculture, Fisheries, Forestry, and Bioenergy Production**	**Health and Social Welfare**	**Protection of Environmental Quality and Biological Conservation**
2003	Europe	Hottest summer in at least 500 years[1]	Damage to road and rail transport systems. Risk to nuclear power generation in France.	Grain harvest losses of 20% [2]	Approx 35,000 deaths in August in Central and Western Europe[3]	
2004/ 2005	Iberian Peninsula	Hydrological drought		Grain harvest losses of 40%[4]		
2007/ 2008	England and Wales Southern Europe	May–July wettest since records began in 1766 [6] Hottest summer on record in Greece since 1891 [5]	Major flooding causing ~£3 billion damage	Devastating wildfires		
2010	Western Russia	Hottest summer since 1500[7]		500 wildfires around Moscow, grain-harvest losses of 30% [5]	High outdoor pollution levels. Heat mortality in Moscow region[8]	

* based on Coumou and Rahmstorf, 2012.

References: [1]Luterbacher *et al.*, 2004; [2]Aerts and Botzen, 2011, Ciais *et al.*, 2005; [3]Robine *et al.* 2008; [4]EEA, 2010c; [5]Founda & Giannakopoulos 2009; [6]WMO 2009; [7]Barriopedro *et al.*, 2011; [8] Revich and Shaposhnikov, 2010.

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

Sector	*Change in indicator*	*Formal attribution to anthropogenic CC?*	*Key references*	*Sections*	*Type***
Transport					
Inland waterways	restricted load of ships leading to increase of transport prices during 2003 heatwave	No	Jonkeren *et al.* , 2007, 2011	23.3.2	A
Long range transport	opening of the Northwest passage in 2008	No	Borgerson, 2008	23.3.2 18.3.3.3.5	A
Rail	Increased capacity of the London Tube's underground cooling	No	Arkell, *et al.*, 2006	10.4.2	P
Tourism					
Snow cover in ski resorts	Decrease of snow reliability in low elevation stations	No	Steiger, 2010b, 2011	23.3.4	I
Settlements and housing					
Storm losses	Increase in Europe since 1970s	No (attributed to ocio economic changes)	Barredo, 2010	23.3.7	I
Hail losses	Increase in parts of Germany		Kunz *et al.*, 2009	23.3.7	I
Agriculture					
	CO2 induced positive contribution to yeld since preindustrial for C3 crops	High confidence (high agreement, robust evidence)	Amthor, 2001; Long *et al.*, 2006; McGrath and Lobell, 2011	7.2.1	A
	Earlier greening, Earlier leaf emergence and fruit set in temperate and boreal climate,	High confidence (high agreement, robust evidence)	Menzel *et al.*, 2006	4.4.1.1	A
	Change in cereal yields (negative trend)	Low confidence	Lobell *et al.* 2011		
Fisheries					
	Increased phytoplankton activity in NE. Atlantic, decrease in warmer regions, due to warming trend and hydroclimatic variations	High confidence	Edwards *et al.*, 2001; Beaugrand *et al.*, 2002; Edwards and Richardson, 2004	6.3.1.1	A
	Northward movement of species and increased Species richness due to warming trend	High confidence	Philippart *et al.* , 2011	6.3.1.2 and 7.2.1	A
Forestry					
	increase in growth rate and total carbon stock due to climatic and non climatic factors	Low agreement	Boisvenue and Running, 2006	4.3.4.1.2	A
Health and Social Welfare					
	Increased allergic sensitization to pollens	Very low confidence (single study)	Ariano *et al.* 2010	11.4	I
Biological conservation					
	Increased number of colonization events by alien plant species in Europe	Medium confidence (high agreement, medium evidence)	Walther *et al.*, 2009	4.2.4.7	A
	Earlier arrival of migratory birds in Europe over the 1970/2000 period	Medium confidence (medium agreement, medium evidence)	Moller *et al.*, 2008	4.4.1.1	A
	Upward shift in tree line and plan species optima in Europe	Medium evidence (medium agreement, high evidence)	Gehrig-Fasel *et al.*, 2007, Lenoir *et al.*, 2008	18.3.2.1,	A

** I =impact, A = Adaptive response to warming, P = planned response to warming

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

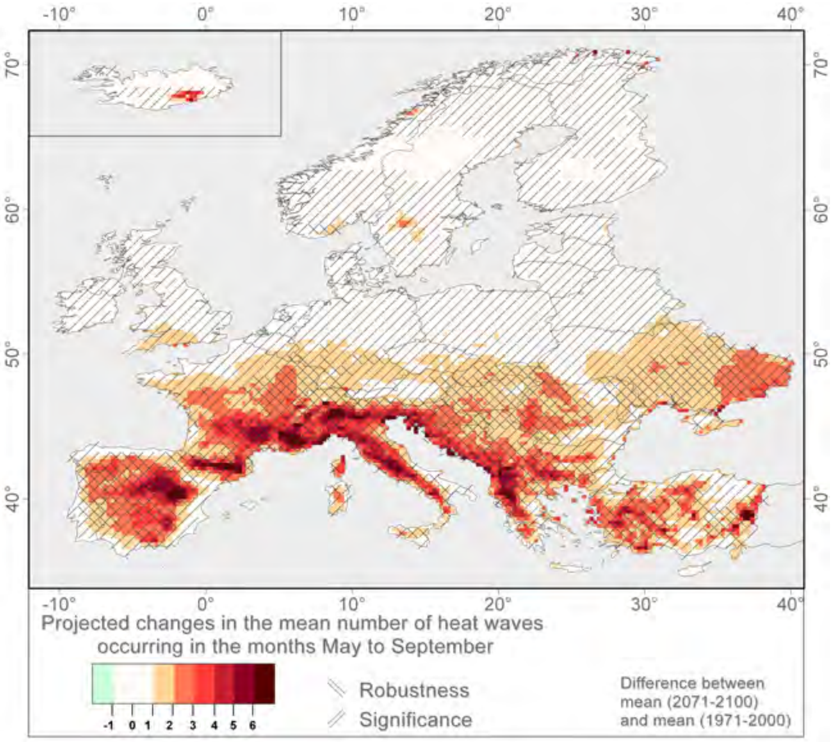

Figure 23-2: Projected changes in the mean number of heat waves occurring in the months May to September for the period 2071-2100 compared to 1971-2000 (number per season). Heat waves are defined as periods of at least 5 consecutive days with daily maximum temperature exceeding the normal daily maximum temperature of the May to September season of the control period (1971-2000) by at least 5°C. Changes represent average over 9 regional model simulations taken from the EU-ENSEMBLES project. 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. Based on CMIP3 data, will be substituted by CMIP5 CORDEX data.

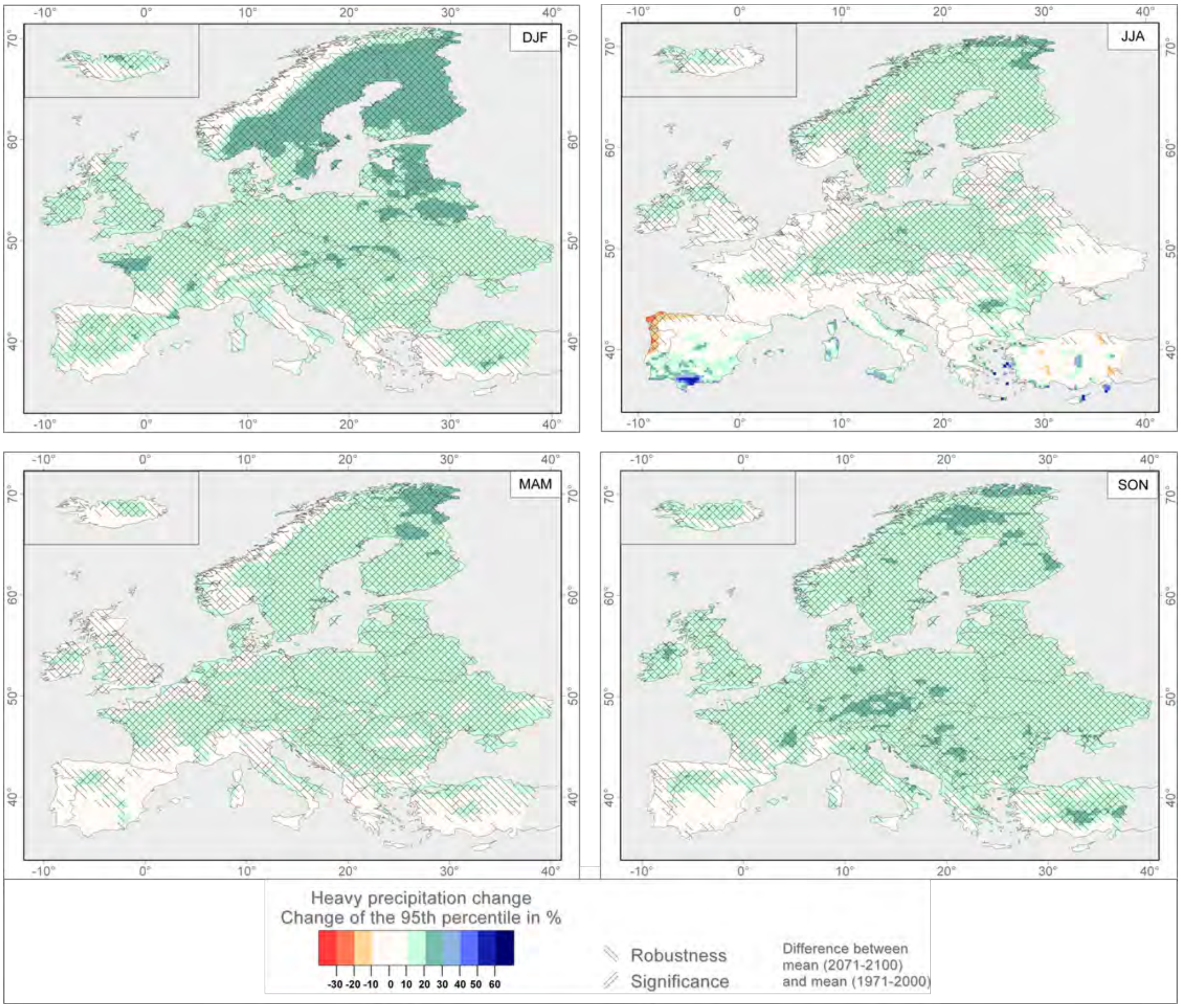

Figure 23-3: Projected seasonal changes of heavy precipitation defined as the 95th percentile of daily precipitation (only days with precipitation > 1mm/day are considered) for the period 2071-2100 compared to 1971-2000 (%). Changes represent average over 20 regional model simulations taken from the EU-ENSEMBLES project. 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). The figures are sorted as follows: top row: DJF, JJA; bottom row: MAM, SON. For the eastern part of Turkey, unfortunately no regional climate model projections are available. Based on CMIP3 data; will be substituted by CMIP5 CORDEX data.

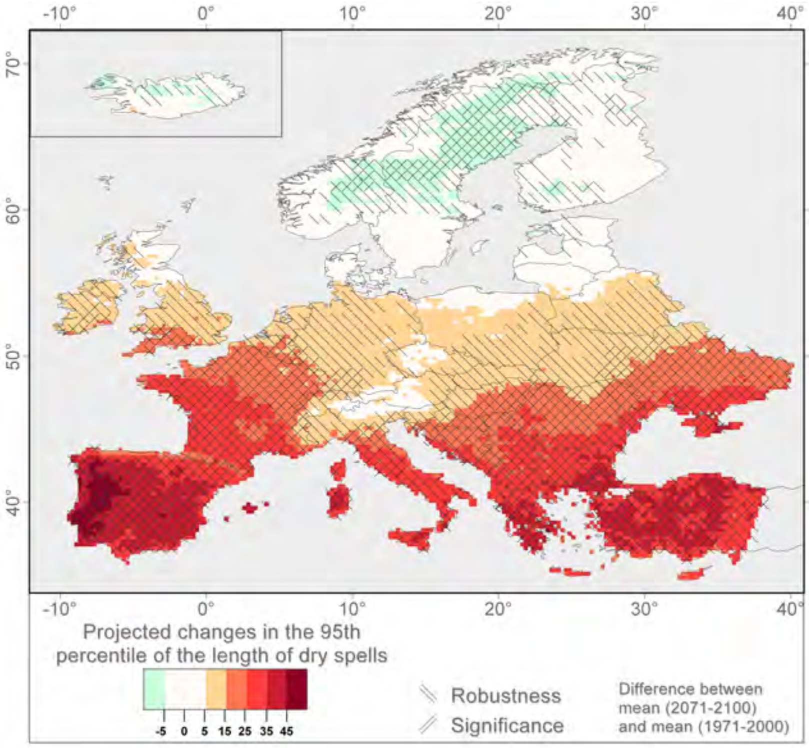

Figure 23-4: Projected changes in the 95th percentile of the length of dry spells for the period 2071-2100 compared to 1971-2000 (in days). Dry spells are defined as periods of at least 5 consecutive days with daily precipitation below 1mm. Changes represent average over 20 regional model simulations taken from EU-ENSEMBLES project. 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. Based on CMIP3 data, will be substituted by CMIP5 CORDEX data.

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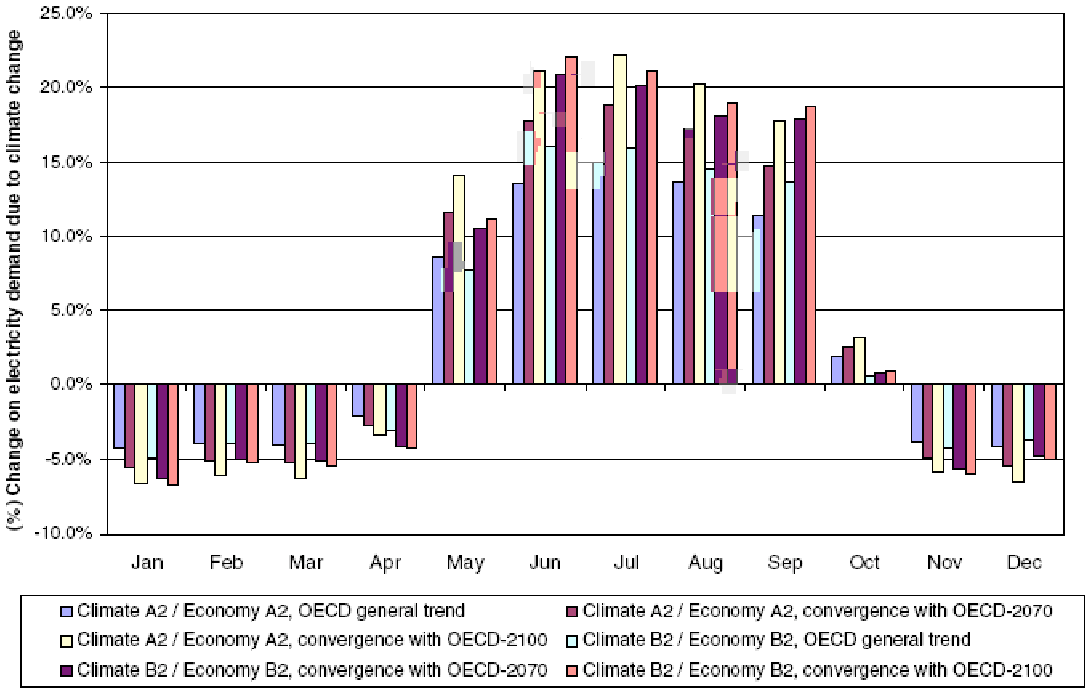

Figure 23-5: Percentage change in electricity demand in Greece attributable to climate change, under a range of climate scenarios and economic assumptions. Source: Mirasgedis et al., 2007.

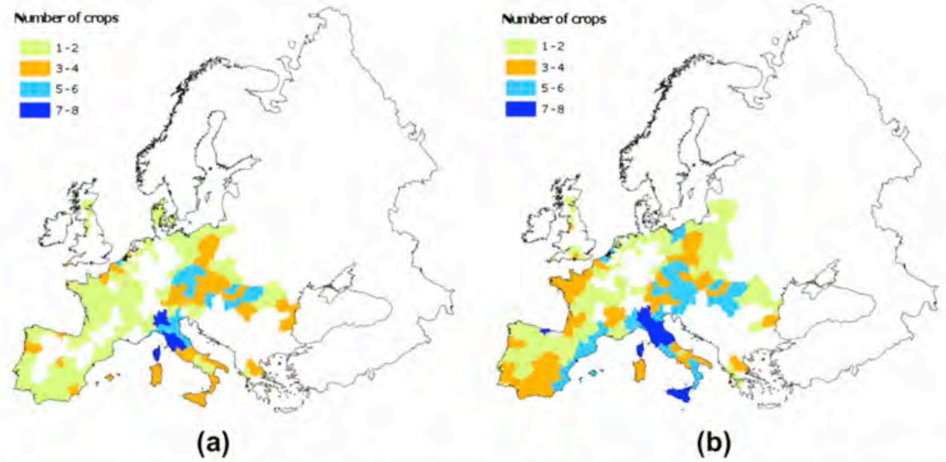

Fig. 2. NUTS2 regions where the potential yield: (a) and potential biomass production (b) decreases for one or more crops. Period 1976–2005.

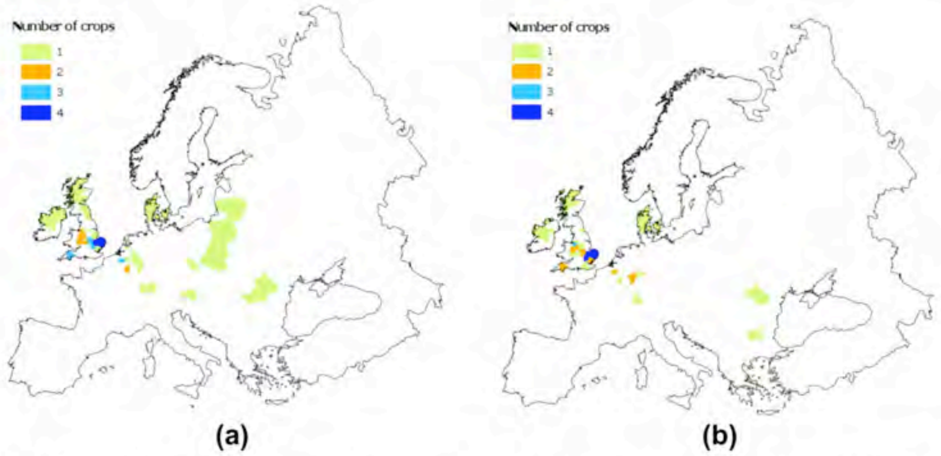

Fig. 3. NUTS2 regions where the potential yield: (a) and potential biomass production (b) increases for one or more crops. Period 1976–2005.

Figure 23-6: Modelled changes in potential crop yield [a] and potential biomass production [b] in Europe over 1976-2005. The top figure shows regions where the potential yield decreases for one or more crops. The bottom figure shows regions where the potential yield increases for one or more crops. The following crops were simulated with the CropGrowth monitoring system: winter wheat, spring barley, maize, winter rapeseed, potato, sugar beet, pulses and sunflower. Source: Supit et al., 2010.

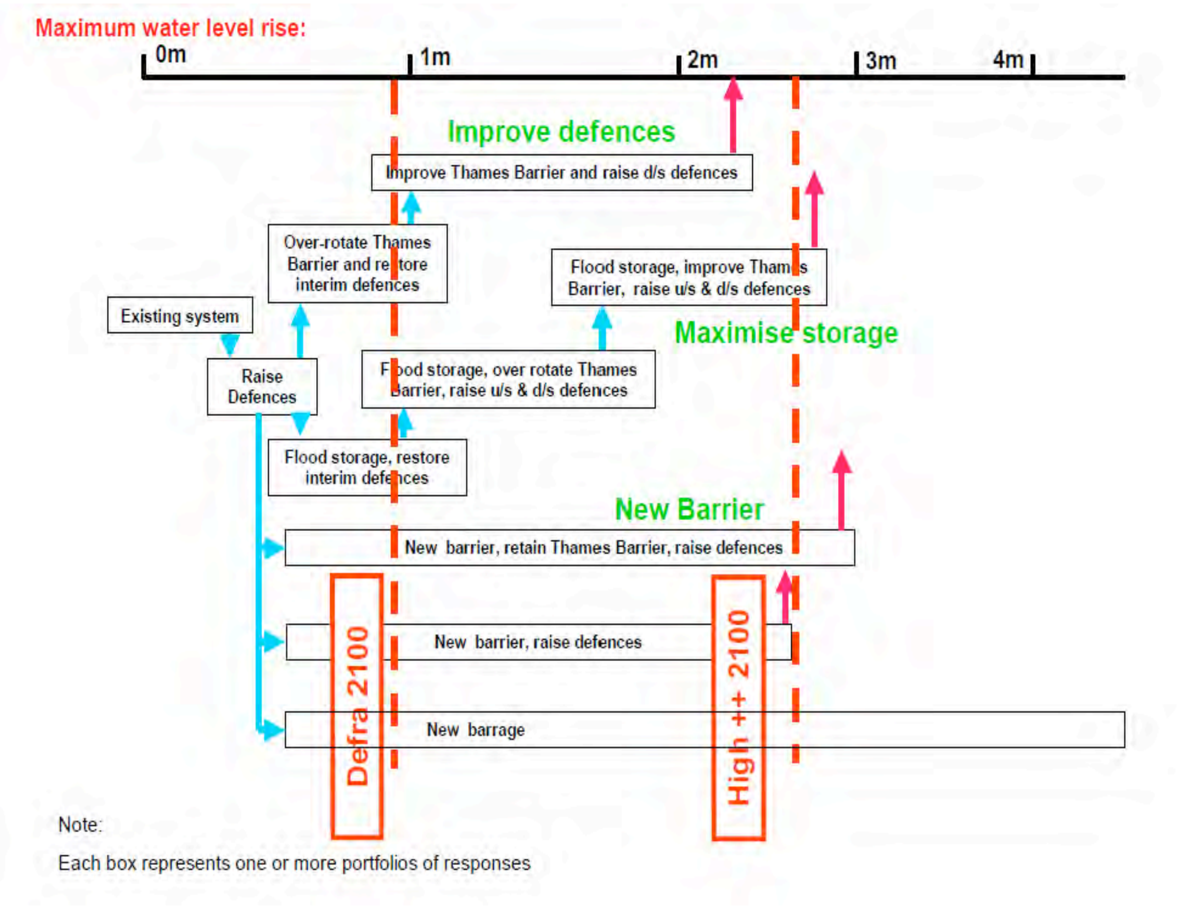

Figure 23-7: Decision pathway developed for Thames flood defence system in the UK. Source: adapted from Haigh and Fisher, 2010.

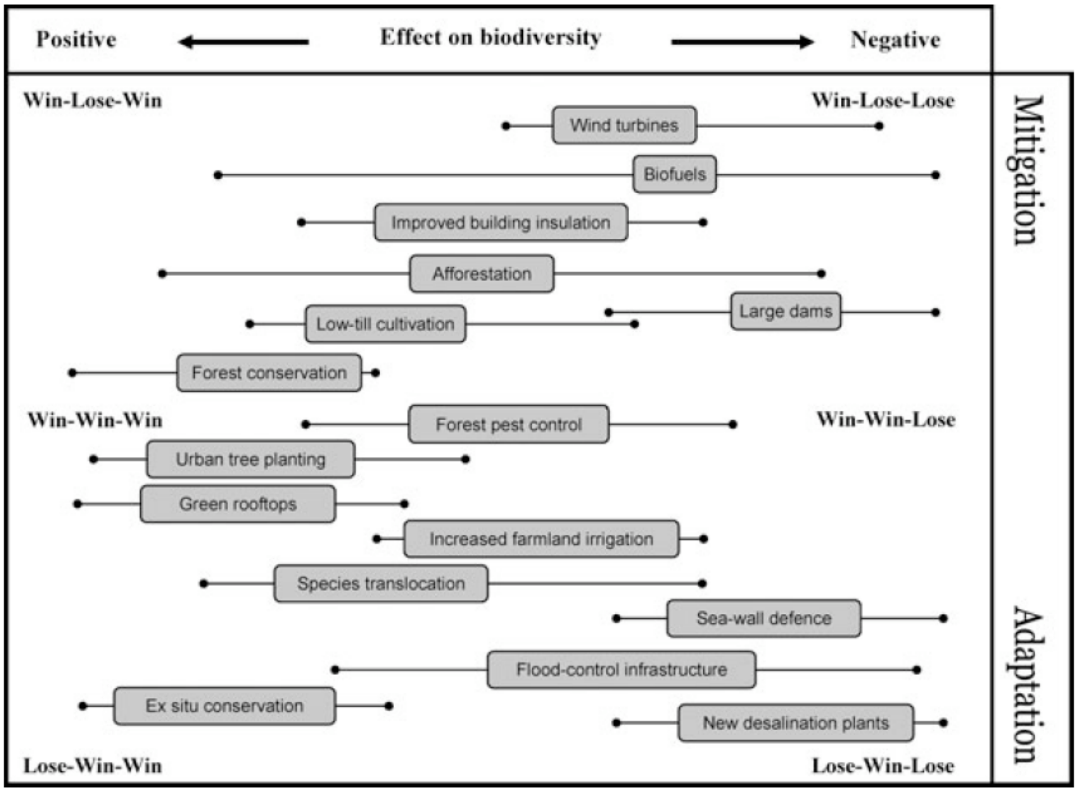

Figure 23-8: Adaptation and mitigation options and their effects on biodiversity. Based on Paterson et al., 2009.