Chapter 23. Europe

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Executive Summary

Observed climate change is affecting a wide range of flora and fauna, including health relevant exposures (pollen), food crops (cereals), and the vectors of animal diseases. Shifts in distribution of flora and fauna across Europe and from neighbouring continents are observed. Climate change is adversely affecting marine ecosystems especially in the Mediterranean. Climate change has already affected the distribution of invasive species.

Climate models project significant changes in rainfall in Europe, and increases in the frequency/intensity of extreme weather events. Observed climate trends and future projections are broadly the same as in the previous assessment. There is a clear indication that there will be a marked increase in many types of extremes, in particular

heat waves, droughts and heavy precipitation. Changes in wind extremes are less clear. No changes in hail are anticipated (low confidence). There will be strong regional differences in sub-regions in Europe.

Climate change has implications for the distribution of economic activity and welfare within European region. Climate change will affect key economic sectors in Europe with a strong diversification across sub-regions according to climate and institutional settings. There will be adverse affects of climate change on winter/ski tourism although significant impacts are unlikely before 2050 for other tourism sectors. Changes in travel patterns from southern to northern/central Europe are expected. Shifts in agriculture production across sub-regions may occur. Climate change is likely to have impacts on food safety.

Adaptation is a trans-national and a cross-sectoral issue. More research is needed on adaptation options, especially modal shifts, and the effects of adaptation in one sector on other sectors in Europe. Some evidence that adaptation is already occurring in Europe, such as upstream/downstream links in large catchments, especially for water resources. Policy makers are responding to the need to develop climate adaptation strategies.

There are important synergies and trade-offs between adaptation and mitigation. Adaptation measures for housing – retrofitting, etc, are well described and have been evaluated in the context of other policy requirements, especially energy efficiency (mitigation) and healthy housing. The main adaptation options to maintain winter tourism (i.e. artificial snowmaking) are energy intensive.

Climate change has implications for infrastructure. Climate change is likely to affect rail, road and river transport and have implications for economic sectors (e.g. delays associated with extreme weather events). Climate change is unlikely to significantly affect transport safety, with very local exceptions (soil destabilization in high mountains, coastal erosion). The impacts on transport will affect future adaptation options. Climate change will decrease hydropower production from reductions in rainfall in all sub-regions, but only in parts of Scandinavia. Impacts of climate change on wind energy are anticipated mainly after 2050, including increased opportunities for wind energy in parts of southern Europe. Climate change may have serious adverse impacts on thermal power production. Integrated analysis of water is needed because of competing demands with agriculture and other sectors.

Climate change is likely to affect energy demand. Climate warming will decrease space heating energy consumption, but will significantly increase cooling energy consumption in urban areas. More efficient buildings and demand-side management are main adaptation options, although passive cooling alone may be insufficient. Increasing demand of bioenergy may have potential negative effects on food crop production and forest carbon sink mitigation potential.

Climate change may have significant impacts on health and welfare, with some groups at particular risk. Climate change will increase heat load in urban areas. There will be an increased risk of heat-related mortality and morbidity unless adaptive actions are undertaken. Risks of emerging infections, including those transmitted by arthropods, may be affected by climate change but other factors (travel, land use change) are more important in near term. Climate change will affect cultural heritage, including iconic buildings and places.

Climate change is already affecting crop yields in Europe. The observed trend/stagnation in cereal yields is, in part, due to observed climate change. Compared to AR4, the evidence no longer supports assessment that climate change will cause a benefit [in cereal yields] at high latitudes, due to the high climate variability. Such benefits may not become apparent until after mid-century. Plant and animal diseases-control will require more knowledge on climate risks that need to be managed by adaptation measures. Need to preserve genetic diversity to help adaptation. Adaptation of crops is needed especially in regions with water resources shortage. Irrigation is not enough to prevent damage from heat waves to crops. System costs will increase under all climate scenarios. There are negative impacts of warming on crops and livestock production that are independent of other factors. Climate change will influence the occurrence, prevalence and severity of plant diseases.

Climate change will have negative impacts on forestry. There is new evidence of forest pests and diseases – possible evidence of observed impacts due to recent warming. New developments in adaptation in forest management and in tree plantation. Climate change is likely to increase the risk of wild fires (boreal and Mediterranean).

It will be more difficult to maintain environmental quality and conservation of threatened species under climate change. Climate change likely to affect air quality (specifically tropospheric ozone) and water quality. Habitat of alpine plant will be significantly reduced and phenological mismatch is likely to constrain both terrestrial and marine ecosystem functioning under climate change, with possible reduction in ecosystem services.

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. Polar issues are addressed in Chapter 28 and the Baltic Sea is addressed in the Open Oceans Chapter 30.

The European region has been divided into 5 sub-regions in order to describe intra-regional climate change vulnerability (see Figure 23-1). This map is based on climate zones developed by Metzger *et al*. (2005), and therefore the sub-regions are largely defined by geography and represent broad ecological zones.

[INSERT FIGURE 23-1 HERE
Figure 23-1: Sub-regions within Europe.]

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 with respect to specific sectors: production systems and physical infrastructure; agriculture, fisheries, forestry and bioenergy production; health and social welfare and; the protection of environmental quality and biological conservation. The second half of the chapter addresses cross-sectoral decision making. The chapter includes several sections that were not in AR4. Because adaptation and mitigation policies are now in place in many countries in Europe, a section on issue where there are significant conflicts and synergies between adaptation and mitigation strategies is included (Section 23.9). The implications of climate change for the distribution of economic activity within European region is discussed in Section 23.10. Section 23.7 synthesises the evidence for observed impacts and responses to climate changed, including an assessment of whether adaptation is already occurring in Europe (for more detailed discussions see Chapter 18).

23.1.2. Policy Frameworks

Since AR4, there have been significant changes in European countries in responses to climate change. Many countries now have policies in place on adaptation and mitigation. 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 implemented at the international, national and local levels. For example, in 2011, the Russian Federation approved a Climate Action Plan that includes both mitigation and adaptation policies. 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. Box 23-1 provides a briefly overview of key national adaptation policies in the region. EU policy makers are currently developing an EU adaptation strategy to be implemented for 2014 to 2020.

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Box 23-1. Integrated Assessment of the Impact of the Russian 2010 Heat Wave and Wildfires

A blocking anti-cyclone brought extreme heat to the European part of the Russian Federation in 2010. Air temperatures exceeded the long-term averages by more than 10ºC (>4 standard deviations) (Barriopedro *et al.*, 2011). Moscow experienced temperatures as high as 38.2ºC.

The heat wave was associated with forest fires over a 2800 km^2 area. 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 fires and meteorological conditions caused high levels of outdoor air pollution. Concentrations of CO and PM_{10} were 30 mg/m^3 and 1500 $\mu g/m^3$, respectively, and daily average PM_{10} levels varied between 431 and 906 $\mu g/m^3$ [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). An analysis of respiratory mortality revealed a three-fold increase in deaths from asthmatic status among bronchial asthma patients (Zairatiants *et al.*, 2011).

_____ END BOX 23-1 HERE _____

23.1.3. Conclusions from Previous Assessments

AR4 highlighted for the first time that a wide range of impacts from the climate change had already occurred in Europe. A key conclusion of the assessment was that climate change is expected to magnify regional differences within Europe for natural resources and assets (particularly for agriculture and forestry) driven by increases in water stress over central and southern Europe (Alcamo *et al.*, 2007). Most climate-related hazards were expected to increase (with significant regional variations). Adaptation will be difficult for many species and ecosystems. Adaptation was also expected to pose challenges to many European economic sectors because few governments had systematically examined a comprehensive set of measures for adaptation. Uncertainties in climate impact assessments were noted in association 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 the associated costs and accounting for regional differences in adaptive capacity) 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. For the EU27 countries (Member states of the European Union), there is general increase in population, primarily due to net immigration. Some countries, including the Russian Federation, have shown a decreasing population size since the 1990s. The ageing of the population is a significant trend in Europe, and Eurostat projections show 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 countries in Europe. The longer term implications of the financial crisis are unclear. Overall, there is some modification of the economic outlook in Europe but other trends are broadly the same as described in the previous assessment.

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 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. Agriculture accounts for 22 % of total national freshwater abstraction in Europe as a whole and more than 80 % in some southern Europe countries (EEA, 2010b). 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 a potential for a future increases in irrigated agriculture and water use efficiency (EEA, 2010b). Water allocation between upstream and downstream countries is challenging in regions exposed to prolonged droughts like in the Euphrates-Tigris river basin, where Turkey plans to more than double water demand by 2023 (EEA, 2010b).

Forested area in Europe accounts for approximately 35 % of land area (EEA, 2010b). The majority of forests are now growing 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 reduction of air pollution (SO_2) have had a positive effect on forest growth. The occurrence of forest fires in Europe is due mainly to causes of an anthropogenic nature, the total burned area changes significantly from year to year largely because of weather conditions (Lavalle *et al*., 2009b).

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 only in Eastern Europe, with the magnitude of these increases depending on population growth, GDP growth and land use planning policy. Other important environmental trends include improvements in outdoor air quality and declines in water quality (eutrofication) in some areas (ELME project).

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)(Nicholls *et al*., 2008). Detailed national socio-economic scenarios have also been produced (e.g. Dutch WLO 2006).

23.2.2. Observed and Projected Climate Change

This section will be consistent with Chapter 21 (and WGI). For the part of projected climate change it largely depends on new findings from the global and regional simulations for CMPI5 and CORDEX, which are being carried out in 2011. The results will not be published before 2012.

23.2.2.1. Observed Climate Changes

The average temperature for the European land area for the last decade (2001 - 2010) was 1.2 °C above the 1850 - 1899 average, and 1.0 °C for the combined land and ocean area. Considering the land area, 8 out of the last 13 years were among the warmest years since 1850.

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)(KNMI) 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 scale of the continent, the winter snow cover extent presents a high variability, with a non significant negative tendency over the period 1967-2007(Henderson and Leathers, 2010). At the scale of the continent, the winter snow cover extent presents a high variability, with a non significant negative tendency over the period 1967-2007 (Henderson and Leathers, 2010).

Extreme sea levels in the past [cross ref SREX Chapters 3 and 4].

23.2.2.2. Projected Climate Changes

There is now more knowledge about the range of possible climates, including high levels of warming and more local information on climate change (high resolution output and downscaling). Although limits to climate projections are recognized, inter-model comparisons provide more robustness/confidence in the range of future climates. Climate impact assessment (and therefore adaptation planning) will increasingly rely on the range of temperature and rainfall changes rather a single average measure (ensemble mean). Overall, Europe is fortunate to have access to better climate projections for decision making than other regions.

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, Ensembles final report). [Update awaiting CMPI5- CORDEX results].Models show significant agreement in warming all over Europe, with strongest warming in Southern Europe (Kjellström *et al*., 2011)(Goddess et al., in ENSEMBLES Final Report). Less warming in spring is projected, with the largest warming in the winter months.

Precipitation signal is regionally and seasonally very different (see Figure 23-2). Trends are less clear, but agreement in precipitation increase in Northern Europe and decrease in Southern Europe, the zone inbetween has less clear sign of change (Kjellström *et al*., 2011). Changes in annual cycle with decrease in precipitation in summer months up to Southern Sweden. Decrease of long term mean snow pack, but still snow-rich winters possible (Räisänen and Eklund, 2011). There is some evidence for changes in convection and hail storm activity in Europe. Changes in circulation pattern and winds are less clear (e.g. (Beck *et al*., 2007; Kjellström *et al*., 2011; Rockel and Woth, 2007)(Ulbrich *et al*., 2009)(Pryor *et al*., 2010).

[INSERT FIGURE 23-2 HERE
Figure 23-2: Horizontal maps of seasonal precipitation changes (%) covering all sub regions including robustness measure (e.g. stippled for large number of model in trend agreement). [Notes: Figure under development. Further, if not covered in Chapter 21, would generate a like graphic for temperature to include standard deviation as robustness measure.]]

23.2.2.3. Projected Changes in Extremes

In Europe, as in many mid-latitude regions of the world, there will be a marked increase in many types of extremes, in particular heat waves, droughts and heavy precipitation. Investigating the statistics of anomalously warm seasons in a recent record, it is possible to quantify the increase in frequency of, for example, extremes such as the 2003 European heat wave (Schär and Jendritzky, 2004), or other anomalously warm seasons such as the winter of 2006/2007 or spring of 2007 in Europe (Beniston, 2009).

The future course of mid-latitude (winter) windstorms is less clear, as different causal mechanisms can enhance or counteract the intensity and frequency of storms in a warmer climate (Goyette, 2011; Ulbrich *et al*., 2009).

Some high-end estimates of extreme sea-level rise projections have been made for The Netherlands (Katsman *et al.*, 2011 (in press)), indicating that sea-level could rise globally between 0.55 and 1.15 m, and locally (The Netherlands) by 0.40 to 1.05 m. More on European regional sea-level projections to be added (e.g. (Slangen *et al.*, 2011))

Storm surges: some model studies indicate increasing near-surface wind speeds over Europe (Pinto *et al.*, 2007a; Pinto *et al.*, 2007b)(Donat *et al.*, 2010; Donat *et al.*, 2011; Pinto *et al.*, 2010; Schwierz *et al.*, 2010). Some studies project increasing surge levels. Significant increases in wave height and storm surge levels are projected in northern North Sea (Boldingh and Rÿed, 2008). Wang *et al.* (2008) show potential increases in the frequency of storm surges around the coast of Ireland. Other studies however indicate little or no effect on extreme surge levels for the Adriatic Sea (Lionello *et al.*,) or the North Sea, even when sea-level rise is included (Sterl *et al.*, 2009).

[INSERT TABLE 23-1 HERE
Table 23-1: Changes in key parameters for all sub-regions and relevant sectors projected/expected changes including changes in extremes - if possible. Identification of possible range of changes. [forthcoming]]

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

23.3.1. Flood Risk

Europe has a high flood risk that threatens production systems and physical infrastructure (and people, see section below), due to the presence of many highly urbanised areas in river basins and on coastlines. Past flood events have lead to the highest share of economic losses from weather-related hazards in Europe, totalling more than 100 billion Euros over the period 1980-2009 (EEA, 2010c), of which only about a third was insured. New studies since AR4 indicate that flooding remains a significant problem, despite increasing efforts aimed at protecting urban areas. A major improvement is that many more studies now include estimates of potential future damages, resulting from a combination of scenarios for the hazard (flood occurrence) and vulnerability (socioeconomic scenarios). Some studies now also include indirect economic costs and non-market impacts.

Coastal flood risk

Coastal flooding is relatively rare in Europe. Surge from storm Xynthia caused breaching of dikes in France in 2010, leading to several deaths. Extreme sea-levels and floods are projected to increase in Europe [Section 23.2.2, SREX report, AR5 WG2 Chapter 5]. A widely applied model to assess future coastal impacts is the DIVA model (Vafeidis *et al.*, 2008). The model shows that impacts from seal level rise around Europe could reach a total cost of some 17 billion Euros per year by 2100 (without adaptation), but that adaptation can substantially reduce impacts (Hinkel *et al.*, 2010).

Studies on future local potential flood losses on the coast include estimates for the City of Copenhagen (Hallegatte *et al.*, 2011), the UK coast (Mokrech *et al.*, 2008)(Purvis *et al.*, 2008)(Dawson *et al.*, 2009), 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). One study specifically addressed future risk of loss of life due to flooding (Maaskant *et al.*, 2009). These studies indicate potentially substantial impacts, but that these can be avoided by coastal protection measures. [to be added: Baltic Sea example. Netherlands new Deltaplan]

River flood risk

Research since AR4 shows some cases of increases in seasonal river discharges (Shiklomanov *et al.*, 2007) as well as extreme discharges, notably 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 differentiated pattern fits in wider scale analyses at the European level, that high variability of extreme discharges driven by atmospheric circulation variations (Bouwer *et al.*, 2008), and some observed increases in extreme discharges in some parts of Europe, as well as decreases, e.g. (Kundzewicz *et al.*, 2010a)(Kundzewicz *et al.*, 2010b) [see also SREX report, AR5 WG2 Chapter 4]. One study has indicated that due to anthropogenic climate change the probability of an event similar to the summer 2000 flood in the UK has increased by between 20-90% (Pall *et al.*, 2011).

New studies have become available since AR4 that analyse potential future impacts on the hydrology of river basins, and the occurrence of floods [SREX report, AR5 WG2 Chapter 4]. A Europe wide analysis of extreme discharges on the basis of GCM-hydrological model coupling indicates increases in the occurrence of extreme river discharges in west and parts of eastern Europe, but decreases in northeast, central and southern Europe (Dankers and Feyen, 2008). Recent studies on individual countries and basins indicate increases in occurrence of extreme discharges, to varying degrees, across many countries, including 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.*, 2010), the Meuse basin (Leander *et al.*, 2008);(Ward *et al.*, 2011), the Danube basin (Dankers *et al.*, 2007), and French Mediterranean basins (Quintana-Segui *et al.*, 2011).

There is no apparent increase in European river flood damages due to observed climate change, as increasing exposure is a major driver (Barredo, 2009). Many advances have been made since AR4 in analysing future flood risk and new studies provide estimates of the impact of climate change on the economic losses from river flooding (Feyen *et al.*, 2009)(Lugeri *et al.*, 2010)(Mechler *et al.*, 2010). A European-wide analysis from the PESETA project indicates 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 (Ciscar, 2009)(Ciscar *et al.*, 2011). Local and national scale studies have focussed on river flood risks 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 important driver of increasing exposure to future flood risk (Feyen *et al.*, 2009)(Maaskant *et al.*, 2009)(Bouwer *et al.*, 2010)(Te Linde *et al.*, 2011). One study has assessed the increase in potential damages from intense rainfall for the Netherlands (Hoes, 2006).

Some studies have assessed the effectiveness of structural measures, including 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). Although many flood protection plans are now implemented across Europe, some studies show that current plans may be insufficient to cope with increasing risks, for instance for the Rhine river basin (te Linde *et al.*, 2010; Te Linde *et al.*, 2010).

Landslides

Quantification of trends in landslides at the scale of Europe is difficult due to incomplete documentation of past events. Landslides are strongly connected to intense precipitations and the local conditions of slope stability. In mountains, glacier retreat and permafrost thawing tend to create favourable conditions. In the European Alps an apparent increase in large rock slides was documented by Fischer et al. (2011), while Jomelli et al. (2007) found a complex response to climate trends. Some land use practices changes during the 20th century 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).

Very few studies are available on the landslides evolutions during the 21th century, because of large uncertainties in extreme events projections and the importance of local factors (Crozier, 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 an increase in stability towards 2100 (Dixon and Brook, 2007).

23.3.2. 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).

Studies of climate change and *road transport* have examined the effects on traffic safety and congestion. In line with AR4, an increase in precipitation frequency and duration is estimated to increase collisions but decrease their severity due to reduced speed (Brijs *et al.*, 2008)(Kilpeläinen and Summala, 2007)(Chung *et al.*, 2005). Regarding the effects of snow and ice, 12-43% less accidents as a result of fewer frost days under a future climate are estimated by Andersson and Chapman (Andersson and Chapman, 2011a), lowering the cost of salt usage, although there are indications that drivers may become more complacent when the risk of slippery roads is reduced (Andersson and Chapman, 2011a)(Brijs *et al.*, 2008) also found that the relationship between temperature and car crashes may be more complex. During evening peak hours and congestion in the Netherlands, a 7-12% lower traffic speed was found because of rain, causing an additional welfare loss of around € 0.50 per commuting trip (Sabir *et al.*, 2010). Regarding direct damages, increased temperatures, excess and more frequent precipitation, storms and thawing of permafrost are likely to reduce the lifetime of roads and could increase infrastructure costs by 10-20% at 2080 even under design adaptation (Larsen *et al.*, 2008)(Carrera *et al.*, 2010). In complex terrain, such as mountain forests, forest functions are dependent on an adequate forest road network (Brang *et al.*, 2006)(Woltjer *et al.*, 2008).

For *rail*, insights remain limited. Lindgren et al. (Lindgren *et al.*, 2009) assessed in qualitative terms rail vulnerability in Sweden. In line with AR4, increased buckling problems due to higher temperatures are estimated to increase the average annual cost for heat-related delays in the UK (9.2 million £ in the baseline, excluding the cost of damage repair) by 10-13% in 2020, 18-27% in 2050 and 25-41% in 2080 depending on the climate scenario (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 million £ 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 is estimated to increase by 50% in the 2020s and more than 200% in the 2080s compared to 2006 (RSSB, 2008).

Regarding *inland waterways*, the navigability of important rivers (Rhine, Danube, and Elbe) is likely to be affected through changed water levels, while impacts are to a large extent transnational considering the geography of these waterways. In Rhine, high water levels in winter will occur more frequently, while in summer days with low water levels will probably increase (Te Linde, 2007). The need of transport blockage for safety reasons during future high water levels is not known (Krekt *et al.*, 2011). 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 in the coming decades according to 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 2-8% of the annual cargo volume (Jonkeren *et al.*, 2009 (in press); 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 a cost efficient measure (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, adapting 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).

On *air transport*, estimates on climate change impacts are few. A study for London's Heathrow Airport (Pejovic *et al.*, 2009) found that the net combined effect of on-site minimum temperature, wind speed, headwind-tailwind and crosswind would result in an increase of weather-related delays by up to 7% during winter in the 2050s, and in a decrease of 12-15% of summer delays. However, the overall increase of the annual cost of weather-related delays would be small. The first findings of a EUROCONTROL commissioned set of impact studies indicate major shifts in tourist demand after 2030 in the Mediterranean, increased vulnerability of several European airports to sea level rise, storm surges and flooding by 2100, and reduced performance due to storminess for the period 2020-2050 (Burbidge *et al.*, 2010).

23.3.3. Energy Production

On wind energy, recent studies conclude that no significant changes in wind resources are expected before 2050 (Pryor *et al*., 2006)(Pryor and Schoof, 2010). Afterwards, in line with AR4, sites in Northern, Continental and to some extent Atlantic Europe may experience a small (<10-15%) increase in energy density during winter and a decrease in summer (Pryor *et al*., 2005)(Harrison *et al*., 2008). In the Mediterranean, the energy density 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 some evidence exists for increased magnitude of extremes in Northern and Continental Europe for the period 2071-2100 (Makkonen *et al*., 2007)(Rockel and Woth, 2007)(Grabemann and Weisse, 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 unknown (Pryor and Barthelmie, 2010). New areas in Alpine and Northern Europe, especially at the coastal area of the Baltic Sea, may become suitable for wind energy development due to significantly less frequent icing events under a future climate (Clausen *et al*., 2007).

For hydropower, most studies since AR4 examine the hydrological response at the basin scale rather than impacts on socio-economic activities, especially within an integrated framework incorporating competing water uses. For the vulnerable area of Swiss Alps (Beniston, 2011), Schaefli et al. (2007) estimate a 36% lower production of a reservoir plant by 2070-2099 for +3.4ºC mean daily temperature and 88% increase of evapotranspiration due to severely reduced glaciation. For the Upper Danube, feeding around 140 run-off and reservoir plants, a decrease by 46% of the annual low flow by 2060 is expected for the SRES A1B scenario (Mauser and Bach, 2009). In Austria, a reduced hydropower production by 6-15% is estimated for the period 2025-2075 (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 (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 productions was found (since AR4).

Warmer than average summers in 2003-2006 and 2009 resulted at reductions/ interruption of production in several nuclear plants in because of cooling water shortages and limitations in discharging cooling water (Kopytko and Perkins, 2011) (Rübbelke and Vögele, 2010). In agreement with AR4, Linnerud et al. (2011) estimated that on the basis of actual data from various European plants, a 1 ºC rise in ambient temperatures above 20 ºC 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 under a future climate, 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 important and is being assessed by European utilities (ASN, 2008). As for impacts on transmission losses, estimates are scant and qualitative (Mideksa and Kallbekken, 2010).

Climate change impacts on energy use is now included under the section on Housing, Urban Climates, Planning (23.3.6).

23.3.4. Tourism

Since AR4, a significant amount of research has been carried out on the effects of climate change on tourism in Europe. Most studies continue to assess climatic comfort in European destinations utilizing the Tourism Climate Index (TCI), either in its original form or modified in order to use daily values or to adapt to specific activities such as beach tourism (Moreno and Amelung, 2009)(Amelung and Moreno, 2009)(Hein *et al*., 2009) (Perch-Nielsen *et al*., 2010)(Amelung *et al*., 2007b)(Nicholls and Amelung, 2008). New approaches combining meteorological and tourism related components have also been developed (Matzarakis, 2007)(Endler *et al*., 2011). Tourists' preferences have also been explored through empirical studies using questionnaires (De Freitas *et al*., 2007)(Rutty and Scott, 2010)(Moreno, 2010)(Denstadli *et al*., 2011 (in press)) or techniques such as webcam technologies (Moreno and Amelung, 2009; Moreno *et al*., 2009).

In line with AR4, index-based studies show that in Northern Europe and in northern areas of the Atlantic and Continental Europe, in particular at the North Sea and Baltic Sea coastline, 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 (Amelung and Viner, 2006)(Amelung and Moreno, 2009)(Amelung *et al*., 2007a; Amelung *et al*., 2007b); (Nicholls and Amelung, 2008). Sea water temperature is estimated to increase in at least some areas of the Baltic, lengthening the swimming season by 25% and 60% in 2050 and 2100 respectively (Matzarakis and Tinz, 2008). For the Mediterranean, most studies estimate that climatic conditions for light outdoor tourist activities will deteriorate significantly in many destinations during summer mainly after 2050 and will 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*., 2007a; Amelung *et al*., 2007b); (Nicholls and Amelung, 2008). However, especially for beach tourism, recent studies that exploited also empirical techniques on assessing climatic comfort 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, the analysis of actual visitation data and questionnaires indicate that high beach visitation levels are associated with high temperatures, while precipitation plays a determinant role for summer tourism (De Freitas *et al*., 2007)(Moreno, 2010)(Moreno and Amelung, 2009). The level of climate comfort felt by tourists has been found to be affected also by tourists' weather expectations prior to the trip, as well as by their country of origin (Eugenio-Martin and Campos-Soria, 2010)(Denstadli *et al*., 2011 (in press)). The determination of climate comfort in tourism is identified by many authors as a main area for further research.

Tourist arrivals at destinations also depend on parameters other than changes in climate comfort, including economic and environmental conditions, population and the capacity of tourist infrastructure (Hamilton and Tol, 2007)(Moreno and Amelung, 2009; Perch-Nielsen *et al*., 2010). Significant knowledge gaps exist on the effects of increased water stress at destinations under a future climate. Global simulation models incorporating some of these parameters found that in large European countries with a non-uniform warming pattern, the general south-to-north shift of tourist demand may not hold (Hamilton and Tol, 2007).

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), 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 present climate (OECD, 2007). Still, Alpine ski areas have already experienced significant demand losses during the past three decades, while in the record warm season 2006/2007 some ski areas were not able to offer a continuous season from December to April despite being equipped with artificial snowmaking (Steiger, 2011)(Steiger, 2010b). In a +2 ^{o}C scenario, snow reliability in the Alps is expected to fall to 61% (OECD, 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 40% reduction of skiing season is expected (Endler and Matzarakis, 2011; Endler *et al*., 2011). Artificial snowmaking, although still the main adaptation option (Hoy *et al*., 2010 (in press); OECD, 2007)(Wolfsegger *et al*., 2008), has physical and economic limitations, especially in small and medium sized ski stations (Schönbein and Schneider, 2005)(OECD, 2007; Sauter *et al*., 2010)(Schneider and Schönbein, 2006)(Schneider *et al*., 2006)(Steiger, 2010a; Steiger, 2010b), and increases water consumption. Other options may include shift to higher altitudes, operational changes, use of weather derivatives (Bank and Wiesner, 2011; OECD, 2007) and provision of non-snow offers which however cannot replace entirely snow-related activities (OECD, 2007).

Mountainous areas though offer tourist activities beyond winter skiing. Low-lying regions in the Alpine and Continental Europe are expected to experience improved climatic conditions for summer tourism (Endler and Matzarakis, 2011; Endler *et al*., 2011; Perch-Nielsen *et al*., 2010; Serquet and Rebetez, 2011). However, infrastructure capacity remains an important parameter to be considered.

23.3.5. Industry and Manufacturing

Available literature on the way climate change affects industrial sectors is scant. Several studies examine the impacts on crops used as inputs by the agro-food and beverage industry, the assessment is not extended to the industrial production chain by considering also alternative/ complementary supplies and non-climatic factors (Holland and Smit, 2010). Wine production is more studied than other sectors; risks and opportunities have been associated to different regions and cultivars, while some adaptation measures (e.g. changes in management practices, 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.*, 2010a; Santos *et al.*, 2011). Significant gaps of knowledge exist on indirect impacts (i.e. on supply chains, utilities and transport infrastructure utilized by industries), which affect resilience to climatic changes and in particular extreme weather events (Beermann, 2011; Wedawatta *et al.*, 2010). Noteworthy, climate change impacts may also extend to the distribution chains of manufactured food products by altering the products' quality (Jacxsens *et al.*, 2010; Popov Janevska *et al.*, 2010), highlighting implications with food waste and sustainability in food chains. Small-and-medium scale enterprises are considered to be particularly vulnerable to climate change (Crichton, 2006).

23.3.6. Housing, Urban Climates, Planning

The impact of climate change on the outdoor environment, particularly, its interactions with urban heat islands, indicates that urban areas will have an increased heat load. Effects of climate change on local urban environment (e.g. air quality, pluvial flood risks) are less clear.

Energy use for domestic space heating under a +3.7 ºC 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 in 2000-2050, remaining practically stable at the rest of Europe, while decreases of 18-43% are expected for 2050-2100 (Isaac and van Vuuren, 2009). As for cooling, the same authors estimate an increase by 260% in Continental and part of the Atlantic Europe during 2000-2050 and by more than 4000% in Russia and the rest of Europe. After that, the increase 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, electricity consumption for cooling during summer is expected to increase by 28-128% for the SRES A2 and B2, leading to an additional net annual generation cost of 170-770 million € (Mirasgedis *et al.*, 2007). Zachariadis (2010) estimated this additional cost at 239 million € for Cyprus by 2030 and for a +1 ºC scenario. Passive-cooling alone seems not to be enough, 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).

Annual total electricity consumption would increase by 3-10% in the Mediterranean (except Portugal) and decrease by 3-21% in the rest EU member states if the present climate were as in SRES A1B (Eskeland and Mideksa, 2010). Mirasgedis *et al.* (2007) estimated a net increase by 3-6% (but with a large seasonal variation) for Greece by 2071-2100 and for the SRES A2 and B2, while Pilli-Sihlova *et al.* (2010) obtained lower figures (-0.4-1.3%) for Finland, Germany and France, and +0.6-1% in Spain by 2050 for the SRES A2, A1B and B1.

23.3.7. Insurance and Banking

The financial sector has a large base in Europe, and its activities are potentially affected by climate change. First, the insurance sector is potentially affected by increasing losses from extreme weather, through problems with accurate pricing of insurance, shortage of capital after large loss events, and by an increasing burden of losses from natural disasters that can affect markets and insurability, within but also outside the European region (Botzen *et al.*, 2010a; Botzen *et al.*, 2010b; CEA, 2007)(Botzen *et al.*, 2010a)(IPCC SREX). On the other hand, insurance is also recognised as a means to cover and reduce losses from extreme weather (Botzen and van den Bergh, 2008; CEA, 2009).

Most important to the insurance sector are storm losses that are generally well covered in Europe by building and motor policies. 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, but the uncertainties are large, and some regions may see decreases in risks (Donat *et al*., 2011; Leckebusch *et al*., 2007; Narita *et al*., 2010; Pinto *et al*., 2007a; Pinto *et al*., 2007b; Schwierz *et al*., 2010). There is no increase in historic European storm damages due to anthropogenic climate change, but increasing exposure is a major driver at present (Barredo, 2010). One study indicates a possible increase in economic losses from storm surges on the North Sea (Gaslikova *et al*., 2011). Other losses of concern to the insurance industry are building subsidence losses related to drought, which may have been increasing in France (Corti *et al*., 2009), and a possible increase in future hailstorm losses in the Netherlands (Botzen *et al*., 2010b).

As discussed in the AR4 (Alcamo *et al*., 2007), the financial sector has a number of approaches in dealing with increasing risks due to climate change, including adjustment of premiums, restricting or reduction of coverage, further risk spreading, and risk reduction. Although private sector activities can incentivise risk reduction, studies indicate that some government intervention is needed (such national insurance schemes, provision of compensation) (Aakre and Rübbelke, 2010; Aakre *et al*., 2010)(Aakre and Rübbelke, 2010). Hochrainer et al (2010) discuss options to improve the EU Solidarity Fund system, in particular, to incentivise risk reduction.

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

Terrestrial ecosystems provide a number of vital services for people and society, such as biodiversity, food, fibre, water resources, carbon sequestration and recreation (Metzger *et al*., 2006). Trends in use and status of ecosystem services in Europe assessed by a systematic review of the literature shows increases in demand of services for crops from agro-ecosystems, timber from forests, water flow regulation from rivers, wetlands and mountains, and recreation and ecotourism in most ecosystems, but decreases in services from livestock production, freshwater capture fisheries, wild foods and virtually all services associated with ecosystems which have considerably decreased in area (e.g. semi-natural grasslands) (Stoate *et al*., 2009)(Harrison *et al*., 2010). Under all scenarios, appropriate agricultural management practices are critical to realizing the benefits of ecosystem services and reducing disservices from agricultural activities (Power, 2010). Despite many adjustments to agricultural policy, intensification of production in some regions and concurrent abandonment in others remain the major threat to the ecology of agro-ecosystems impairing the state of soil, water and air and reducing biological diversity in agricultural landscapes (Stoate *et al*., 2009).

23.4.1. Food and Fibre Production

In 2008, Europe accounted for 19% of global meat production and 20% of global cereal production *(FAOSTATS)*. Current trends show an intensification of agriculture in northern and Western Europe and decline and abandonment in some parts of the Mediterranean and south-eastern regions of Europe (Stoate *et al*., 2009). Many animal production systems are increasing their efficiency and environmental sustainability (Thornton, 2010). AR4 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 South-eastern Europe.

Crop and pasture production is inherently sensitive to variability in climate. The last two decades are witnessing a decline in the growth trend of cereal yields in many European countries (Olesen *et al*., 2011). For instance, in France, genetic progress was partly counteracted, from 1990 on, by heat stress during grain filling and drought during stem elongation (Brisson *et al*., 2010). This is consistent with statistical modelling showing that cereal yields have been negatively affected by warming in Europe since 1980, e.g. in France by -5% for wheat and -4% for maize (Lobell *et al*., 2011). The climatic risk for corn and wheat production has increased between 1951 and 1990 in some

Hungarian regions (Ladanyi, 2008). In the northernmost agricultural areas of Europe, severity of overwintering damage, and associated cereal yield penalties, fluctuate considerably on a year-to-year basis and no consistent reduction in yield variability was recorded (Peltonen-Sainio *al*., 2010). Grassland productivity has increased in recent decades in Europe, but the average annual gain is greater in temporary (0.5%) than in permanent grassland (0.25%) and is less than the genetic gain (+3.5%) reported for forage species (Smit *et al*., 2008).

Climate change impacts on the European agricultural ecosystems are likely to vary widely. 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 (Bindi and Olesen, 2011). In the southern Mediterranean, the likelihood of crop failure would rise sharply to more than 60%, and even in wet years, yields are likely to decrease under climate change in elevated spots (Ferrara *et al*., 2010). Although in the UK for the 2050s, wheat will mature earlier in a warmer climate and avoid severe summer drought, the probability of heat stress around flowering that might result in considerable yield losses is predicted to increase significantly (Semenov, 2009). In the northernmost agricultural areas of Europe, climate change is projected to result in milder winters, which may enable cultivation of winter crops to a greater extent. However, fluctuating conditions that currently hamper wheat overwintering, may be exacerbated in the future by increased climatic variability and extreme weather events (Peltonen-Sainio *et al*., 2010). This could delay the adoption of winter-sown crops (cereals and rapeseed) for many decades. Nevertheless, spring crops from tropical origin like maize for silage could become cultivated in Finland by the end of this century despite a higher base temperature requirement (Peltonen-Sainio *et al*., 2009). Climate change is also projected to have a significant effect on European viticultural geography. Detrimental impacts on winegrowing are predicted in southern Europe, mainly due to increased dryness and cumulative thermal effects during the growing season. Conversely, in western and central Europe, projected future changes will benefit not only wine quality, but might also demarcate new potential areas for viticulture, despite some likely threats associated with diseases (Malheiro *et al*., 2010). *(Note: more on fruit trees and ozone is needed)*

Climate change will probably influence the occurrence, prevalence and severity of plant diseases (Kersebaum *et al*., 2008). Pathogenic fungi like fruit rots and cereal rots react differentially to climate change due to their complex infection biology. With fruit trees the appearance of a black rot fungus in Northwestern Europe is best explained by rising temperatures during the vegetation period, but this does not hold for other fruit rot species (Weber, 2009). With cereals, some pathogens like stem rot (e.g. *Puccinia striiformis*) will be limited by increasing temperatures. Nevertheless, earlier wheat anthesis dates and increasing atmospheric CO_2 may condition the extension of *Fusarium* ear blight (Luck *et al*., 2011) and lead to more severe blight epidemics in southern England by the 2050s (Madgwick *et al*., 2011). Under future climate conditions, there is a risk that the European corn borer (*Ostrinia nubilalis*) establishes permanent populations in Central Europe extending the climate niche to cover almost the entire area suitable for agriculture by 2040-2075 (Trnka *et al*., 2007). Cold winters and geographic isolation have hitherto protected the Nordic countries from many plant pathogens and insect pests, leading to a comparatively low input of pesticides. The changing climate is projected to lead to a greater rise in temperature in this region, compared to the global mean leading to opportunities for crop pests and pathogens, including new types of viruses and virus vectors to thrive in the absence of long cold periods (Hakala *et al*., 2011; Roos *et al*., 2011). A combination of climate scenarios and crop models predicted that climate change will increase yield of fungicide-treated oilseed rape crops in Scotland by up to 15%, but would increase yield losses from phoma stem canker epidemics to up to 50 per cent in South England and greatly decrease yield of untreated winter oilseed rape (Butterworth *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, GCMs and impact studies (Trnka *et al*., 2007)(Soussana *et al*., 2010).

Farmers across Europe are currently adapting to climate change. Simple, no-cost adaptation options such as advancement of sowing 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*., 2010a; Moriondo *et al*., 2010b). Local agricultural experts show a surprisingly high proportion of negative expectations concerning the impacts of climate change on crops and crop production throughout Europe, even in the cool temperate northern European countries (Olesen *et al*., 2011). Among the adaptation options include: changes in crop species, cultivar, sowing date, fertilization, irrigation, drainage, land allocation and farming system (Bindi and Olesen, 2011). 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). More efficient surveillance and control tools as well as coordinated regional monitoring and control programmes are needed for both plant and animal pests and diseases (Chevalier *et al*., 2010). The options available may, however, be limited by a lack of basic entomological data and limited epidemiological surveillance (Wilson and Mellor, 2009).

Achieving increased adaptation action will necessitate integration of climate change-related issues with other risk factors, such as climate variability and market risk, and with other policy domains, such as sustainable development. Adaptation assessment frameworks that are relevant, robust, and easily operated by all stakeholders, practitioners, and policymakers will be needed (Howden *et al*., 2007), as well as new investments in adaptive management and technology (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). By combining ecological and economic optimisation models at farm scale(Moriondo *et al*., 2010c) the economic viability and the long term sustainability of farming systems in future scenarios may be approached. Preserving genetic resources is a precondition for crop adaptation to changing environments (Jump et al. 2009). Climate change alters breeding targets. Increasing emphasis needs to be placed on 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) in order to provide starting lines for breeding programmes. In the same way, the option value provided by animal genetic diversity needs to be secured. Both for cultivated plants and domesticated animals improved mechanisms to monitor and respond to threats to genetic diversity; more effective *in situ* and *ex situ* conservation measures are required as well as genetic improvement programmes targeting adaptive traits in high-output and performance locally adapted seeds and breeds (Hoffmann 2010).

23.4.2. Water for Agriculture

Drought is a prominent limiting factor for agriculture at the scale of Europe, not only in the dryer zones, but also in mountain areas and wet zones in northern Europe. High frequency of rainy conditions complicates soil workability, sowing and harvest across most of the north-western zones, while flooding and stagnant surface water in agricultural fields is a persistent problem in parts of Central Europe (i.e. Hungary, Serbia, Bulgaria and Romania) (Olesen *et al*., 2011). In Mediterranean countries cereal yields are limited by water availability, heat stress and the short duration of the grain-filling period. The 2004/2005 hydrological year was characterised by an intense drought throughout the Iberian Peninsula and cereals production fell on average by 40 % (EEA, 2010b). The decline in maize yield and production during the 2003 heat wave and associated drought in France was only partly minimized by irrigation. Areas without irrigation infrastructure experienced high irrigation requirements during the extreme heat and drought conditions in 2003 (van *et al*., 2010).

Changes in climate, agricultural ecosystems and hydrometeorology depend on complex interactions between the atmosphere, biosphere and hydrological cycle and there is a need for more integrated approaches to climate impacts assessments (Falloon and Betts, 2010). Future projected trends in European agriculture may be accompanied by a widening of water resource differences between the North and South, and an increase in extreme rainfall events and droughts. Changes in future hydrology and water management practices will influence agricultural adaptation measures and alter the effectiveness of agricultural mitigation strategies (Falloon and Betts, 2010). Under economically focussed regional futures, water supply availability increases at the expense of the environment. Under environmentally focussed futures, irrigation demand restrictions are imposed. The effectiveness of water pricing for reducing irrigation demand is less in a global market-drive future, where irrigation demand is shown to be sensitive to the price of agricultural commodities (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). Even though the adoption of irrigation leads to higher and less variable crop (e.g. maize) yields in the future, economic benefits of this adoption decision are expected to be rather small. Thus, no adoption is expected in the future in countries like Switzerland, without changes in institutional and market conditions (Finger *et al*., 2011). Changes in agricultural intensity will have feedbacks on water quality. 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, increased yields and reduced growing cycles may lead to riverine and groundwater nitrate concentrations increase during the 21st century that would however not degrade severely water quality (Ducharne *et al.*, 2007).

For Northern Europe, agricultural adaptation may be shaped by increased water supply and flood hazards. Summer irrigation shortages may result from earlier spring runoff peaks leading to increased irrigation demand for instance in England and Ireland (Henriques *et al.*, 2008)(Holden and Brereton, 2006). The need for effective adaptation will be greatest in Southern and south-eastern regions 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). In the Guadalquivir river basin in Spain a significant increase in aridity and an increase of 15–20 % in seasonal irrigation need by the 2050s was highlighted (EEA, 2010b). An increase of the role of irrigation may, however, not be a viable option because of the reduction in total runoff in the Mediterranean area (Olesen *et al.*, 2011). Increasing flood and drought risks will further contribute to the need for robust management practices and adaptation strategies to cope with changes in future water reliability (Falloon and Betts, 2010). 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 through farming practices like organic farming 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 grain production (Wessolek and Asseng, 2006). 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). To sustain productive irrigated agriculture with limited water resources requires high water use efficiency. Alternative options such as the use of low-energy systems, improving irrigation efficiency, switching to deficit irrigation and changing cropping patterns can be used as adaptation pathways (Daccache and Lamaddalena, 2010). This can be achieved by the precise scheduling of deficit irrigation systems taking into account the crops' response to water stress at different stages of plant growth (Schutze and Schmitz, 2010).

23.4.3. Livestock Production

Livestock production may be impacted by climate change both directly through changes in animal voluntary intake and indirectly through changes in the amount, timing and quality of forage production (Tubiello *et al.*, 2007)(Soussana and Luscher, 2007). Grassland vegetation was highly resistant to experimental heating and water manipulation maintained over 13 yr in Northern England (Grime *et al.*, 2008). However, grassland production was significantly reduced by five years warming, elevated CO_2 and drought application in an extensive upland pasture in France (*Cantarel et al., Ecosystems, submitted*). In response to drought, a potential increase of weed pressure by tap rooted forbes (e.g. *Rumex obtusifolius*) may occur under future climatic conditions, demanding additional management measures to limit their success (Gilgen *et al.*, 2010). Significant reductions in summer-autumn milk production, in annual water drainage and in herbage protein content would occur by the end of the century in dairy systems in France, together with new opportunities for herbage production in early spring and in winter especially *(Graux et al., submitted)*. In Central Europe, dairy-oriented agriculture (based on permanent grassland production) could suffer through increased evapotranspiration demand combined with a decrease in precipitation, leading to higher water deficits and yield variations (Trnka *et al.*, 2009).

The spread bluetongue virus (BTV) in sheep across Europe has been attributed to climate warming (Arzt *et al.*, 2010). The spread of the disease was caused by the expansion of distribution of major vector, *Culicoides imicola*, and also the involvement of novel *Culicoides* vector(s) (Wilson and Mellor, 2009). The probability of introduction and large-scale spread of Rift Valley Fever in Europe is very low (Chevalier *et al.*, 2010). There is some evidence that climate change, especially elevated temperature, has changed the overall abundance, seasonality and spatial spread of endemic helminths in the UK affecting animal health and welfare (van Dijk *et al.*, 2010). In Europe, the primary arthropod vectors of zoonotic diseases are ticks, and there is good evidence that ticks distributions have changed associated with climate warming (see also section on human health). Tick distributions are determined by temperature, as well as the availability of hosts (Gilbert, 2010).

23.4.4. Forestry

European forest stands are often reaching the age and stem dimensions at which the accumulated biomass can be harvested. Thus, future routine harvesting may reduce the current forest carbon sink. The EU policy of fostering the use of biomass as an energy source may even lead to increased forest harvesting, perhaps to a level beyond the rate of wood growth, posing a serious threat to the forest carbon sink (Schulze *et al*., 2010), but also substituting fossil fuels or materials that demand more energy in their production. 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). Social attitudes like awareness of climate change were found to be major factors for explaining observed differences in adaptation among Swedish forest owners (Blennow and Persson, 2009).

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). The increase of average temperatures has positively affected productivity in Italian mountain beech forest ecosystems since 1986 (Rodolfi *et al*., 2007). 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)(Nageleisen, 2008). The year after the drought, in 2004, a second mortality peak was observed in several regions (Lorraine, Centre, Midi-Pyrénées) because of insect outbreaks (Rouault et al. 2006). Three-four years later another wave of mortality was induced by a complex mix of biotic and non biotic factors (Nageleisen, 2008). Increased mortality 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 Cyprus). In Greece, intense crown discoloration, needle fall and mortality of fir trees have been observed throughout the country (Raftoyannis *et al*., 2008). 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, 2010a*).

In 2007, the annual average temperature in the Czech Republic was the highest since the beginning of instrumental measurements and was followed by severe outbreaks of bark beetle in Norway spruce and Scots pine forests. In 2007, the damage in Norway spruce reached almost 1.9 mil. m^3 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). In France, the comparison between observations made in the seventies and the more recent national database shows a development of diseases caused by thermophilous pathogens (Marcais and Desprez-Loustau, 2007). 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) and may be directly related to increasing dry and warm spells frequency. Warming has also favoured exotic pathogens and pests disease.

AR4 reported that forests are projected to expand in the north and retreat in the south. Forest productivity and total biomass is likely to increase in the north and decrease in Central Europe, while tree mortality is likely to accelerate in the south. The northward expansion of forests is projected to reduce current tundra areas under some scenarios. A changing climate will favour certain species in some forest locations, while making conditions worse for others, leading to substantial shifts in vegetation distribution.

Some species, vulnerable to climate change could see their suitable areas reduce up to 72% in 2080 for SRES-A2a scenarios (Casalegno et al., 2010). The increase in climatic aridity may compromise the survival of several populations of *Pinus sylvestris* in the Mediterranean basin (Giuggiola *et al*., 2010). CLIMPAIR model results for peninsular Spain project a significant decrease in the versatility of forest tree formations at elevations of less than 1500 m (García-López and Alluéa, 2011). Potential impacts of climate change on scattered broadleaved tree species were recently reviewed by Hemery et al.(2010). Their scattered distributions, exacerbated in many cases by human activity, may make them more vulnerable to climate change. They are likely to have less ability to reproduce or adapt to shifting climate space than more widespread species. Tree growth is controlled by complex interactions between climate- and non-climate-related factors, with forest management also having a significant effect. Possible future responses of forests to climate change include increased growth rates, tree-line movements, changes to forest growth, phenology, species composition, increased fire incidence, more severe droughts in some areas, increased storm damage, and increased insect and pathogen damage. Taken together this is likely to lead to a changed pattern of forest cover. Simulation of the IPCC SRES A1B scenario for the period 2070–2100 shows a general trend of a south-west to north-east shift in suitable forest category habitat (Casalegno *et al*., 2007).

Although 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). Projections were derived for the IPCC SRES scenario A2, processing data from the PRUDENCE data archive, namely the daily-high resolution data (12 km) from the HIRHAM model run by DMI, for the time periods 1960–1990 (control) and 2070–2100 (projections). In agreement with a similar assessment performed for North America (Albert and Schmidt, 2010; Flannigan *et al*., 2006), the 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). The future storm tracks may also shift further north with the consequent possibility of increased risk of damage. Boreal forests are also likely to 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). Potential impacts of insect and pest damages were reviewed by Netherer and Schopf (2009). It is difficult to quantify precisely how the overall effects of climate change will influence forest management. Besides uncertainties of the climate scenarios as well as prediction errors in growth and yield models, there might be more serious implications on forests through extreme climate events that are not yet well understood (Albert and Schmidt, 2010).

Life cycle of forests ranges from decades to centuries. As the future climate cannot be predicted with certainty, decisions affecting the future forests have to be made in the face of uncertainty. 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). Climate adapted seed transfer for Scots pine (*P. sylvestris*) would need to be made over increasingly larger distances in the south and across narrower distances in the north (Reich and Oleksyn, 2008). There is a high demand for comprehensive planning systems which incorporate pest risk assessment and aim to improve forest health and stability (Moore and Allard, 2008; Netherer and Schopf, 2009). 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). In the boreal zone, thinning schedules should be adapted to the increased growth rates (Garcia-Gonzalo *et al*., 2007). A key approach in risk management is diversification of tree species mixtures and management approaches between neighbouring forest stands by improving the overall resilience of forests to climate change (Bodin and Wiman, 2007; Lindner, 2007). Stands mixed with species not equally susceptible to specific pest species remain less affected than monocultures, inter alia because pest population levels remain low due to limited food resources (Jactel *et al*., 2009). As there is uncertainty about the timing of changing species or provenances in forest regeneration, more conservative and more rapid adaptation strategies can be applied simultaneously in different forest stands of a management unit. Measures to successfully reduce vulnerability to climate change in the Austrian federal forests included the promotion of mixed stands of species well adapted to emerging environmental conditions, silvicultural techniques fostering complexity, and increased management intensity. Furthermore, timely adaptation to sustain forest goods and services was found to be crucial (Seidl *et al.*, 2011).

23.4.5. 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, increasing severity of storms, and changing freshwater influxes. As impacts of climate change strengthen they may exacerbate effects of existing stressors and require new or modified management approaches. AR4 reported that the recruitment and production of marine fisheries in the N Atlantic are likely to increase.

Warming induces a shift of species ranges toward higher altitudes and latitudes and seasonal shifts in life cycle events (Daufresne *et al.*, 2009). In European seas, warming causes a displacement to the north and/or in depth of fish populations, with more marked variations in abundance near the “cold” and “warm” boundaries of their distribution’s area. These displacements of species distribution areas have a direct impact on fisheries but also on the structure and functioning of marine ecosystems. A meta-analysis (Rosenzweig *et al.*, 2008) of the ecological consequences of changes in the sea surface temperature in the maritime zone of the North East Atlantic (Tasker, 2008) showed the magnitude of these displacements. Marked changes occurred within 30 years for the distribution of three species of the North Sea (Atlantic cod) a boreal species in the southern limit of distribution around the British Isles, the red mullet (*Mullus surmuletus*), a coastal Lusitanian species whose range extends from Norway to the northwest of Africa including the Mediterranean and Black Sea, and the anchovy, a pelagic species of subtropical affinities. An increased abundance of anchovy and red mullet in the northern part of their distribution area and a decrease of cod in the southern part of its range are noticeable. In the North Sea, over 30 benthic macrofaunal species have been newly recorded over the last 20 years, with a distinct shift towards southern species [Wiltshire.] In the Bay of Biscay, responses to climate change in 20 species of flatfish over 20 yrs show that expanding species have a lower latitude range (between 8 ° N and 46 ° N) than declining species (between 47 °N and 58 °N, chiefly dab, plaice and flounder). The decline of plaice and flounder is caused by deteriorating conditions for their development in the Bay of Biscay (Hermant *et al.*, 2010). In some freshwater lakes, rare fish that are adapted to cold temperatures are likely to lose a large part of their habitat volume under future climate scenarios (Elliott and Bell, 2011).

In the Mediterranean, a relatively high proportion of endemic species is associated to the arrival of alien species at the rate of one introduction every 4 or 5 weeks in recent years (Streftaris *et al.*, 2005). Out of 664 known species of fish (of which nearly 80 are endemic), 127 alien species have become established in the Mediterranean since the beginning of the twentieth century, of which 65 came through the Suez Canal (and 62 through the Strait of Gibraltar). The immigration influx of lessepsian species (from the Red Sea and Indo-Pacific) increases with warming, as well as the mean latitude of the distribution area of species of Atlantic origin decreases. While in the Mediterranean the endemic species distribution remained stable, that of most non-native species has spread northward by an average of 300 km since the 1980s. Therefore, the area of spatial overlap of the two categories of species has increased by nearly 25% in 20 years (Ben and Mouillot, 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). A typical example is the Atlantic cod, which commercial catches have declined in virtually all of its distribution area in the last decades. 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). It is worth noting that the analysis of the fish species richness of North Sea and Celtic Seas does not detect the impact of fisheries (ter Hofstede *et al*., 2010), because the arrival of Lusitanian species compensates for the steep decline in boreal species (Henderson, 2007), and further because the analysis was performed over a short time period (1997-2008). Nevertheless, temperature limited growth in eutrophic lakes would lead to ca. 3 weeks earlier onset of growth and larger sizes in bream as a result of warming (Mooij *et al*., 2008).

All components of a food chain cannot be expected to shift their phenology at the same rate, and thus are unlikely to remain synchronous (Durant *et al*., 2007). The food of North Sea cod larvae has become scarce through the size decrease (Beaugrand *et al*., 2010) and the replacement of copepod with one developing in late autumn rather than spring (Beaugrand and Kirby, 2010). Over the past decade, the cods'this stock has not been restored from its previous collapse (Mieszkowska *et al*., 2009)(ICES, 2010). Throughout the North Atlantic, different populations of shrimps (P. borealis) have adapted to local temperatures and phytoplankton bloom timing, matching egg hatching to food availability under average conditions. This matching is vulnerable to interannual oceanographic variability and long-term climatic changes (Koeller *et al*., 2009). In the North Sea, changes in the phenology of zooplankton groups raise concerns on the declining state of fish stocks, which could potentially be exacerbated by gelatinous zooplankton outbreaks. This may lead to trophic dead ends by channelling the flow of energy away from higher trophic levels. In the case of the Iberian upwelling, an observed weakening of upwelling in the inner shelf has slowed down the residual circulation that introduces nutrients. The phytoplankton community has responded to those environmental trends with changes that favour the proliferation of harmful algal blooms and reduce 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). In freshwater systems, shallow lakes have a higher potential for climate induced match-mismatches between zooplankton and algae during spring succession (Domis *et al*., 2007).

Climate change may impose severe risks for aquatic animal health if increasing water temperature leads to an increase in the incidence of parasitic diseases. Data for fish farms in Finland demonstrate the effect of increasing water temperature on aquatic disease dynamics, but also emphasise the importance of the biology of each disease (Karvonen *et al*., 2010) A number of endemic diseases of salmonids (e.g. enteric red mouth, furunculosis, proliferative kidney disease and white spot) will become more prevalent and difficult to control as water temperatures increase. Climate change also alters the threat level associated with exotic pathogens. The risk of some viral fish diseases declines as infection generally only establishes when water temperatures are less than 14 to 17 degrees C, but the risk of establishment of other exotic epizootic pathogens (haematopoietic necrosis and epizootic ulcerative syndrome) increases. Measures to reduce the threat of exotic pathogens need to be revised to account for the changing exotic diseases threat (Marcos-Lopez *et al*., 2010). Increasing water temperatures and the negative effects of extreme weather events (e.g. storms) are likely to alter the freshwater environment adversely for both wild and farmed salmonid populations, increasing their susceptibility to disease and the likelihood of disease emergence (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, dense surface blooms of toxic cyanobacteria in eutrophic lakes may lead to mass mortalities of fish and birds. High temperatures favour cyanobacteria directly, through increased growth rates. Moreover, high temperatures also increase the stability of the water column which shifts the competitive balance in favour of buoyant cyanobacteria. Through these direct and indirect temperature effects 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).

Non-climate change stresses such as overfishing may interact with climate change to produce surprises (Miller *et al*., 2010; Perry *et al*., 2011; Rijnsdorp *et al*., 2009). The NAOI (North Atlantic Oscillation Index) is likely to increase significantly with time which would lead to a decrease in size of the Atlantic salmon median population size (Boylan and Adams, 2006). However, a case study of fisheries in the Bay of Biscay concluded that a major part of the gross turnover associated would not be affected by long-term changes in climate (Le Floc'h *et al*., 2008). The Baltic situation illustrates some of the uncertainties and complexities associated with forecasting how fish populations, communities and industries dependent on an estuarine ecosystem might respond to future climate change (Mackenzie *et al*., 2007). Marine-tolerant species will be disadvantaged and their distributions will partially contract from the Baltic Sea; habitats of freshwater species will likely expand. 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).

Integrative assessment can help examine policy options (Miller *et al*., 2010). Experimentation and innovation at local to the 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). In the Eastern Baltic, a temporary marine reserve policy could postpone by 20 yrs the negative effects of climate change (Rockmann *et al*., 2009).

23.4.6. Bioenergy Production

The consumption of bioenergy in the European Union has grown, along with a concurrent growth in the trade of biomass for energy purposes. In 2009, the EU set a target that 20% of energy needs should be met by renewable energy by 2020, including 10% from biofuels for transportation (Capros *et al*., 2011). Bioenergy production and trade will likely continue to increase into the future, driven by emissions reduction targets and increasing concerns about domestic energy security (Bahadur Magara *et al*., 2011). The total area available for non-food crops in the EU27 (excluding Cyprus and Malta) is estimated to be 13.2 million ha. In scenarios 2020 and 2030, additional land would be released from food and fodder crops, resulting in total land potential of 20.5 million ha in 2020 and 26.2 million ha in 2030 (Krasuska *et al*., 2010). Certification of bioenergy is required to promote the sustainable use of biomass(Bahadur Magara *et al*., 2011). On the other hand according to (Junginger *et al*., 2011) results from an European survey show that import tariffs and the implementation of sustainability certification systems are perceived as (potentially) major barriers for the trade of bioethanol and biodiesel, while logistics are seen mainly as an obstacle for wood pellets. Development of technical standards was deemed more as an opportunity than a barrier for all commodities. (Swinbank, 2009) suggests that EU policy is unlikely in conflict with the WTO Agreement on Agriculture or that on Subsidies and Countervailing Measures, but its provisions on environmental sustainability criteria could be problematic

There is a growing recognition that the interrelations between agriculture, food, bioenergy, and climate change have to be better understood in order to derive more realistic estimates of future bioenergy potentials. In general bioenergy from lignocellulosic crops show positive effects on soil properties, biodiversity, energy balance, greenhouse gas mitigation, carbon footprint and visual impact when compared to arable crops. Compared to replacement of set-aside and permanent unimproved grassland, benefits are less apparent (Rowe *et al*., 2009). For hydrology, strict guidelines on catchment management must be enforced to ensure detrimental effects do not occur to hydrological resources (Rowe *et al*., 2009; Sevigne *et al*., 2011).

Poplar SRC system is energy efficient and produces more energy than required for coppice management. Even more, elevated CO2 will increase the net energy production and greenhouse gas balance of a SRC system with 18%. 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, although the northward expansion of SRC is likely to erode the European terrestrial carbon sink. (Hastings *et al*., 2008) showed that Miscanthus plantations could contribute to up to 17% of Europe's current primary energy consumption by the year 2080 but that inter-annual variation of crop yield can be more than 20%.

The potential distribution of temperate oilseeds, cereals, starch crops and solid biofuels is predicted to increase in northern Europe by the 2080s, due to increasing temperatures, and decrease in southern Europe (e.g. Spain, Portugal, southern France, Italy, and Greece) 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. Effects become more pronounced with time and are greatest under the A1FI scenario and for models predicting the greatest climate forcing. Different climate models produce different regional patterns. All models 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).

23.4.6.1. Forest Biomass

The quantity of wood directed from the forest industry to the energy sector would cover only around 8% of the European Union's RES target for 2020, and an even lower share for 2030. For some forest industry sectors like production of pulp and panels that would mean an important output reduction, around 20–25%. Additional felling could be an important source of wood for bioenergy in the near future, when utilization of the forest resource potential is still not very high. However, toward 2030, forest resource utilization is projected to increase and might become a limiting factor for additional biomass potentials. Given the relatively high economic growth assumed in the scenarios and the rather strong development in the demand for forest industry products, there is a considerable chance that the supply of wood biomass for energy will be largely limited to logging residues in the long run (Moiseyev *et al*., 2011). An analysis by (Verkerka *et al*., 2011) showed that it is possible to increase the availability of forest biomass significantly beyond the current level of resource use. Implementing these ambitious scenarios would imply quite drastic changes in forest resource management across Europe.

Considering a complete life cycle for forest residues, comparing the climate impacts from the recovery, transport and combustion of forest residues (harvest slash and stumps), versus the climate impacts that would have occurred if the residues were left in the forest and fossil fuels used instead, over a 240-year period, the cumulative radiative forcing is significantly reduced when forest residues are used instead of fossil fuels (Sathrea and Gustavsson, 2011).

23.4.6.2. Biofuel for Transport Sector

The use of biofuels can reduce greenhouse gas emissions from the transport sector, however, biofuel production and combustion also caused emissions directly (local air pollution) as well as indirectly. An explicit calculation of indirect land use change (ILUC) emissions from EU biofuel consumption shows that ILUC emissions alone could shift the CO2 balance for biofuels from reductions to more emissions relative to fossil fuels. However, some of the uncertainties remain (Overmars *et al*., 2011). A review of life-cycle studies of biodiesel in Europe compared in terms of non renewable primary energy requirement and GHG intensity of biodiesel shows a high variability of results, particularly for biodiesel GHG intensity, with emissions ranging from 15 to 170 g CO2eq MJ_f^{-1} (Malçaa and Freirea, 2011).

Current accounting method mainly promotes biofuel feedstock production on former cropland, thus increasing the competition between food and fuel production on the currently available cropland area. It is profitable to use degraded land for commercial bioenergy production as requested by the European Commission to avoid undesirable LUC but that the current regulation provides little incentive to use such land (Lange, 2010). Trade of bio-fuels in EU and Turkey has been become important in recent years. The most important exporters are Germany, Italy, Latvia and Poland and the most important importers are Germany, Italy, Belgium and UK. It is seen that Turkey has a low trade level (Akyüz and Yasin Balaban, 2011).

23.4.7. Rural Development

Rural development is one of the key policy areas for Europe, yet there is little or no discussion in the literature 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 in 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.

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 the older population (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) (Solymosi *et al.*, 2010). Several studies have estimated the impact of climate scenarios on future heat-related mortality at the city level. Baccini et al. (2011) estimated that greatest impacts were projected in Budapest and Athens under an A2 emissions scenario in 2030. The smallest impacts were projected in Dublin, Zurich and Ljubljana. For most countries in the 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).

There have been significant developments in mapping the current distribution of important vectors and vector-borne diseases in Europe, and describing the role of important environmental factors such as land use cover and climate factors. The Asian tiger mosquito (*Aedes albopictus*, a vector of dengue and other arboviruses) is currently present in many countries in southern and eastern Europe (Albania, Croatia, France, Greece, Monaco, Montenegro, Italy, Slovenia and Spain) (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.

Food safety

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 (and consumption of animal products is now seen as a mitigation issue). 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). 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).

23.5.2. Health Systems and 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 (EA 2008). Wildfires also represent a risk to infrastructure. In 2007, a forest fire in Greece caused the closure of a major road and access to the international airport.

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 during heat wave events (Ferron *et al*., 2006; Stafoggia *et al*., 2008). Further, higher temperatures have 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 no been overall 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.

23.5.3.1. Impacts of Extreme Weather Events/Disasters

The current burden for weather disasters is high and the risks are concentrated in certain geographical areas. Within Europe, projections to the end of this century show a significant increase in storm surge elevation for the continental North Sea and south east England. Populations at risk of increased winter river flooding are anticipated to be in central and northern Europe. The risk of increased flash flooding due to climate change may also increase. Flash floods are the most serious type of flood for mortality risk (drowning).

Little research has been carried out on the impact of extreme weather events such as heat waves and flooding on displacement in Europe (EC, 2009). Managed retreat (also called managed realignment) is one of the options to adapt to sea level rise in coastal areas (see Rupp-Armstrong and Nicholls 2007 and section on integrated coastal management below).

23.5.3.2. Impacts of Climate Change on Indigenous Populations in Europe

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)(see also the Polar chapter). Research has focuses 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

The impact of climate change on cultural heritage needs to consider both the consequence of extreme events and gradual damage on 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 interactions with heritage (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). The difference between atmospheric climate change and sea-level rise in its impact on heritage (Storm *et al.*, 2008). The impact of climate change in indoors environment where most of cultural heritage is preserved is important (Lankester and Brimblecombe, 2010). Climate change may affect visitor behaviour at heritage sites (Grossi *et al.*, 2010).

Surface recession on marble and compact limestone is predicted to change during the present century in Europe. In the 2080s, Central Europe, Norway, the northern UK and Spain will experience a surface recession ranging between 20 and 30 μm/y. Generally, a decrease in surface recession of about 1-4 μm/y in Southern Europe is predicted, indicating it to be an area of decreasing risk (Bonazza *et al.*, 2009a; Bonazza *et al.*, 2009b).Monuments in marble located in the Mediterranean Basin will generally continue to experience within this century the highest level of thermal stress (Bonazza *et al.*, 2009a; Bonazza *et al.*, 2009b). A general reduction in frost damage is forecast, with the exception of northern and mountain 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).

Biological weathering may increase in some areas by the 2080s due to climate change. Boreal areas such as northern Russia, Scandinavia and Scotland are expected to undergo a marked increase in biomass stock, with a pronounced decrease is predicted in western and southern Europe, except for the Alps. As Northern and Eastern Europe become warmer in the future, with high precipitation levels, greater attention will be required in the protection of wood structures against rainwater effect. Damage from high winds may increase in 2080s in northern areas of Europe (Sabbioni *et al.*, 2010).

Europe has many unique landscapes including, amongst other, the cork oak based Montado in Portugal, the Garrigue of southern France, Alpine meadows and the grouse moors of the UK. These landscapes reflect the cultural heritage of rural areas that have evolved from centuries of human intervention. Many, if not all, are sensitive to climate variables and even small changes in the climate could have significant impacts. Many such areas are also protected through rural development and environmental protection policy.

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

23.6.1. Terrestrial and Freshwater Ecosystems

The observed northward and uphill distribution shifts of many European plant and animal (birds, insects, and mammals) species has been attributed to observed climate change. Concerning plant phenology, 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. 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. Thermal maximum predicted recent trends independently of other potential predictors (Jiguet *et al*., 2010). Possible disruption of established biotic interactions (mismatchs) could benefit generalist species at the expense of specialists putting additional pressures on the capacity of ecosystems to provide certain services and on species of conservation importance (Biesmeijer *et al*., 2006).

By the late 21st century, according to climate envelope models, the most dramatic changes 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. The mean stable area of species decreases mostly in Mediterranean scrubland, grassland/steppe systems and warm mixed forests (Alkemade *et al*., 2011). Trends in seasonal events will continue to advance as climate warming increases in the years and decades to come. 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). Projections for 120 native European mammals suggest that up to 9% face extinction during the 21st century. Amphibian and reptiles because of low dispersal capacities will probably undergo a reduction of range (Hickling *et al*., 2006). These trends are projected to continue as climate warming increases in the decades to come. (Feehan *et al*., 2009).

Disruption of community interactions can arise when species differ in their sensitivity to rising temperature, leading to mismatched phenologies and/or dispersal patterns. A survey of published literature over a wide range of animal groups shows pronounced and consistent differences among trophic groups in thermal sensitivity of life-history traits and in dispersal distances (Berg *et al*., 2010). 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). Changes in genetic structure along migration fronts could nevertheless increase the adaptation of populations to climate change.

With climate change, higher winter survival of fish, lower zooplankton grazing of phytoplankton the following summer and more turbid waters, particularly in shallow eutrophic lakes are expected (Balayla *et al*., 2010). The projected increase of winter precipitation in southern Europe is likely to increase the nutrient loadings to lakes and contribute to their eutrophication. The impact is proportional to the runoff/in-lake concentration ratio of nutrients rather than to the retention time, and is more pronounced in lakes with lower trophy (Noges *et al*., 2011). 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 minimal 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).

It is suggested that more frequent extremes may have more severe consequences than progressive changes in means (Fuhrer *et al*., 2006). Floodpulses are expected to increase (including multi-annual flooding cycles) exposing lakes to changes in element cycles (Wantzen *et al*., 2008). More frequent heavy precipitation during winter in central Europe increasing the risk of large-scale flooding and loss of topsoil due to erosion. In summer, a decrease in the frequency of wet days and shorter return times of heat waves and droughts increasing the risk of crop yield and forage quality losses and in forests, the acceleration of the replacement of sensitive tree species therefore reduce carbon stocks. A modelling study shows that Mediterranean arid ecosystems could undergo discontinuous transitions to a desert state if increasing aridity is coupled to high grazing pressures (Kefi *et al*., 2007). Simulations suggest an overall increase in occurrence of summer wildfires because of increasing temperatures and decreased rainfall. Some management measure such as controlled burning, grazing or mowing to remove fuel may help lower effects of increased fires on ecosystem services (Albertson *et al*., 2010).

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. A first attempt on quantitative spatial vulnerability show that vulnerability to global change differs between sectors, regions and future scenarios, but that southern Europe has the lower adaptive capacity and is especially vulnerable (Metzger *et al*., 2008).

23.6.2. Coastal and Marine Ecosystems

Europe's coastal zones are of strategic importance to the European Union and beyond, as they support millions of people, provide major sources of food and raw materials and vital links for transport and trade, the location of some of our most valuable habitats, and the favoured destination for leisure time (CIESM, 2008; Ekeboom, 2007). However, due to climate impacts, these zones are facing increasing environmental, economic and social problems. There will be significant economic effects on water-dependent economic sectors and social effects resulting from the loss of provision. Fisheries biodiversity, productivity and catch options, as well as aquaculture will be affected by SLR, glacial melt and ocean acidification (Gambaiani *et al*., 2009; Philippart *et al*., 2011). Melting sea ice will open up shipping and oil exploration areas, but this may lead to detrimental development (HELCOM, 2007). Coastal tourism will be affected due to accelerated coastal erosion and changes in the marine environment and marine water quality, with less fish and more frequent jelly fish and algae blooms (HELCOM, 2009)(Lejeusne *et al*., 2009). SLR, storms and flooding will affect critical coastal infrastructure in particular communities situated close to the coast. Sea ports will be exposed to coastal flooding, and storms may provoke impacts on maritime transport and related infrastructure (Bulleri, F. and Chapman, M.G., 2010). 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).

The uncertain nature of the impact of climate change on coastal and marine ecosystems requires comprehensive and ongoing integration of adaptation options through a variety of measures, including policy instruments at national, regional, international scales, economic demand and supply-side measures, combining green infrastructure with supporting natural environmental processes as well as behavioural and attitudinal changes in how the environment is perceived and valued (Bulleri. and Chapman, 2010). Adapting to the challenges outlined above will require an integrated approach to the management of marine and coastal zones in particular foundational and catalytic policies, e.g. measures to mainstream adaptation into sectoral policies, early response measures for floods and coastal erosion, ensuring that climate change considerations are incorporated into marine strategies and by providing mechanisms for regular updating to take account of new information (OSPAR, 2010; UNEP, 2010). Providing for 'good ecological status' and preventing deterioration in the quality of the marine environment as a result of climate change will require policies that are flexible to the specific impacts of climate change at particular locations, integrate across sectors and levels of governance and account for the cross-border nature of many coastal processes (OSPAR, 2010).

23.6.3. 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 the 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 show that higher emissions controls will be required to maintain air quality below current European standards. Recent evidence has shown adverse impacts on agriculture from even low concentrations of ozone.

Climate change may 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 on heat wave and fires in 2010 in the Russian Federation).

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).

23.6.4. Soil Protection

Information on the impacts of climate change on soil and the various related feedbacks is very limited. Projected increased variations in rainfall pattern and intensity will make soils more susceptible to erosion. Projections show significant reductions in summer soil moisture in the Mediterranean region, and increases in the northeastern part of Europe (Calanca *et al.*, 2006). Climate change further alters the habitat of soil biota, which affects the diversity and structure of species and their abundance. Ecosystem functioning is modified consequently, but quantified knowledge of these impacts is limited. There is still a large uncertainty on the impacts of climate change on soil erosion. For the A2 scenario and a set of land use scenarios in Tuscany, even with a decline in precipitation volume until 2070, in some months higher erosion rates would occur due to higher rainfall erosivity (Marker *et al.*, 2008). However, a case study on sugar beet cultivation in Upper-Austria based on A2 emission scenario as simulated by the regional climate model HadRM3H predicted that annual average soil losses under climate change declined in all tillage systems by 11 to 24%. Such values are inside the margins of uncertainty typically attached to climate change impact studies. (Scholz *et al.*, 2008). Erosion can further lead to supply of sediments to watersheds. In Denmark for a future scenario period 2071-2100, climate-change-induced changes in suspended sediment transport can increase. For two Danish river catchments, mean annual suspended sediment transport is modelled to increase by 17 and 27% in alluvial and non-alluvial rivers, respectively, for steady-state land use scenarios (Thodsen *et al.*, 2008; Thodsen, 2007).

Direct effects of climate change, like temperature increase, modification of wind and precipitation patterns, sea level rise, snow and ice cover, have the potential of affecting the distribution and degradation of soil and sediment organic pollutants, including persistent organic pollutants. Different climate change scenarios were tested over the next 50 y in the Venice Lagoon (Italy), finding noticeable variations in persistent organic pollutants concentration even for minor environmental changes. Model results suggest that if climate change may have the potential of reducing the environmental levels of these chemicals, it would probably enhance their mobility and hence their potential for long range atmospheric transport (Valle *et al.*, 2007).

The current cost of erosion, organic matter decline, salinisation, landslides and contamination is estimated to be EUR 38 billion annually for the EU25. Evidence shows that the majority of the costs are borne by society in the form of damage to infrastructures due to sediment run off and landslides, increased health-care needs, 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). 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 key 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). In upland regions of England and Wales revegetation of bare soil was an important feature of upland sites, resulting in a net decrease in erosion area on 63% of sites (McHugh, 2007). By absorbing up to twenty times its weight in water, increased SOM 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. However, in this study, climate-induced changes in the frequency and intensity of heavy rainstorms were only considered in a limited way (Klik and Eitzinger, 2010).

23.6.5. Water Quality

Climate change may affect water quality in several ways, including increasing temperatures lead to less dissolved oxygen, and increasing the risk of algal blooms (Ulén and Weyhenmeyer, 2007), and less rainfall may lead to low flows which increase concentrations of biological and chemical contaminants. Several case studies on river catchments have been undertaken: Seine river (Ducharne, 2008); Danish water shed (Andersen *et al*., 2006) and the Meuse in Germany (van Vliet and Zwolsman, 2008). Climate change may have an adverse effect on river flows, yields from groundwater, nutrient flushing episodes, and surface water quality in the UK (Whitehead *et al*., 2006; Whitehead *et al*., 2009; Wilby *et al*., 2006). The implications for drinking water quality are less certain.

23.7. Synthesis of Observed Impacts and Adaptation to Climate Change

23.7.1. Observed Impacts

Newer findings strongly confirm AR4 findings of many European systems and sectors being particular sensitivity to recent trends in temperature and especially in the Mediterranean area to precipitation (Feehan *et al*., 2009)(see also sections above and Chapter 18). Based on a large number of observations, (Rosenzweig *et al*., 2008) could attribute this fingerprint in nature to recent climate change and found a discernible anthropogenic influence in changes of natural systems in Europe, similarly to Asia and North America. Equally, footprints of climate change were identified and attributed in the Arctic marine ecosystems, including many examples from the European Arctic (Wassmann *et al*., 2011). There is more evidence and it is more compelling of observed effects of climate change on a wide range of species types (including insects, mammals, fish, and birds) see Section 23.6.1 (Hickling *et al*., 2006).

[INSERT TABLE 23-2 HERE
Table 23-2: Observed changes in natural and managed systems to observed climate change (papers published since the AR4).]

There is evidence that since 1975 the length of the frost-free growing season of several agricultural crops in Europe has increased. Nevertheless, the opposite trend has been observed in the Mediterranean countries, in the Black Sea area and in parts of Russia, where risks from late winter-spring frosts have increased (Lavalle *et al*., 2009a). Earlier crop flowering and maturity have been observed and documented in recent decades, and these are often associated with warmer (spring) temperatures (Craufurd and Wheeler, 2009). For instance, the phenology of agricultural and horticultural events from a national survey in Germany shows a mean advance of 1.1-1.3 days per decade with more than 80% of this advance being caused by warming (Estrella *et al*., 2007). Warmer temperatures that shorten development stages of determinate crops tend to reduce the yield of a given variety (Craufurd and Wheeler, 2009). A study by (Lobell *et al*., 2011) found that climate warming was a contributory cause to the observed trends in crops since 1980.

Climate change will have an effect on invasive species, particularly those moving north into southern Europe. There is some evidence that this is already occurring. Increasing number of colonization events and subsequent establishment of species originating from regions with a warmer climate than in the area of establishment and spread in response to changed climatic conditions of the recent past (Walther *et al*., 2009).

[INSERT TABLE 23-3 HERE
Table 23-3: Observed impacts and responses (empirical studies post 2006, with criteria). [forthcoming]]

23.7.2. Adaptation is Already Occurring

There is less literature on the responses to climate change in the human systems in Europe. A literature review of published papers on adaptation indicated implementation was more advanced in agricultural and utility sectors (Berrang-Ford *et al*., 2011). Countries that are vulnerable to sea level rise investigate engineering options to protect their land. It is suggested that some countries have made changes in flood protection standards due to climate (Netherlands, Germany and the UK). In addition, some areas have adapted building (residential, commercial) standards /regulations to be responsive to future warming. [more to be added]. Plans are under way to invest in new municipal sewerage systems or to redesign nature protection networks. There is some evidence that adaptation is already occurring in water resource management in Europe, such as upstream/downstream links in large catchments.

23.8. Cross-Sectoral Adaptation Decisionmaking and Risk Management

23.8.1. Coastal Zone Management

The German government has developed a plan for coastal and flood protection of Mecklenburg-Vorpommern coastal zone, to address coastal erosion and retreat, and the protection of human interests. The materials used for coastal protection should be natural (sands, gravel, boulders, wood) and degradable (Ministerium 1993). The legislative regulation enforces that coastal protection is only permissible in connection with the built-up environment. In 2007 the "Action Plan on Climate Change for Mecklenburg-Vorpommern" includes recommendations on coastal protection (Ministerium für Wirtschaft, Arbeit und Tourismus, 2007): new buildings in potential flood prone areas shall be avoided by planning regulations, and those current coastal protection installations shall be adapted to the effects of climate change, including retreat options. However, there are limits to how far communities can adapt to rapid and large sea-level rise. Studies have examined such impacts in the UK (Lonsdale *et al.*, 2008) and the Netherlands (Olsthoorn *et al.*, 2008). There is no integrated coastal zone management or climate change adaptation for the Baltic Sea Region.

23.8.2. Integrated Water Resource Management

- Shift in water management approaches (e.g. "hard" versus "soft" measures, battle versus accommodation, role of participation) (Pahl-Wostl, 2007)(Wiering and Arts, 2006)
- Overview of adaptation strategies for water management in southern/Mediterranean countries (Iglesias *et al.*, 2007).
- Testing the robustness of adaptation decisions in water management (Dessai and Hulme, 2007)
- Adapting England and Wales water supply (Arnell and Delaney, 2006)

23.8.3. Disaster Risk Reduction and Risk Management

- Description of EU policies; flood risk, natural and technological hazards, civil protection
- Adaptation in urban areas and cities (review by (Hunt and Watkiss, 2011))
- Flood management (Petrow *et al.*, 2006) (2002 Elbe flood)
- Flood risk mapping activities in Europe: (Merz *et al.*, 2007); (de Moel *et al.*, 2009)
- Role of individuals (Terpstra and Gutteling, 2008)

23.8.4. Land Use Planning

The literature on land use planning as a means of adapting to climate change is sparse:

- The literature that does exist refers to flood risk aversion, coastal defence of urban areas, biological conservation, health implications of urban areas, agricultural and forest policy and city planning
- Flood risk studies tend to focus on engineering solutions to climate risks rather than the institutional, governance and policy strategies to implement risk reduction solutions (Coeur and Lang, 2008)
- Protection policy and planning can make a big difference to fluvial flood risk. For example, because of higher flood protection standards in the Netherlands compared with Germany, fluvial flood risk is greater in the Lower Rhine (Nordrhein-Westfalen) than in the Netherlands (Linde te, 2005).

- Furthermore, there is evidence to suggest that conventional fluvial flood protection measures are not providing sufficient protection level and are very cost intensive (Manojlovic and Pasche, 2008)
- Some studies refer to the systematic failure of planning policy to account for climate and other environmental changes (Branquart *et al*., 2008)
- Conservation planning in response to climate change impacts on species will involve several strategies: "(i) link isolated habitat that is within a new suitable climate zone to the nearest climate-proof network; (ii) increase colonizing capacity in the overlap zone, the part of a network that remains suitable in successive time frames; (iii) optimize sustainable networks in climate refugia, the part of a species' range where the climate remains stable." (Vos *et al*., 2008)
- A number of cities worldwide have started to create climate adaptation plans and in Europe this includes London and Rotterdam (Sanchez-Rodriguez, 2009). The European plans tend to be driven by the strong political leadership of mayors (Sanchez-Rodriguez, 2009).
- The literature on city governance and climate change is dominated by climate mitigation and energy consumptions issues rather than using land use planning to assist cities to adapt to climate change (Bulkeley, 2010).

23.8.5. Mountains

The delineation of mountain areas is variable depending on the system, the sector or the policy. EEA (2010a) considers that mountain areas cover 36% of the continent (Turkey included, Russia excluded). With respect to water, a snow cover decrease (Stewart, 2009)(Pons *et al*., 2010) and a glacier retreat already are visible (Huss *et al*., 2008; Nesje *et al*., 2008). This trend will continue during the 21st century (Haeberli and Hohmann, 2009a; Haeberli and Hohmann, 2009b; Lopez-Moreno *et al*., 2008) and will modify the water availability, both in quantity and in seasonality. Adaptation measures must be taken to limit enhanced natural hazard due to glacier retreat, (Frey *et al*., 2010), reduced soil cohesion by permafrost (Harris *et al*., 2009), slope denudation by forest fire. Mountain flora will be largely impacted in a contrasted manner. In general, the high elevation plants will suffer higher risks of habitat loss of endemic species (Dirnböck *et al*., 2011), but some regions, like the Spanish Pyrenees or the eastern Austrian Alps may be particularly affected, due to higher temperature and precipitation changes in these regions (Engler *et al*., 2011).

The most significant impacts of climate change for economic sectors in mountain regions will be the adverse effect on winter tourism (see also section 23.3.4 above), studies shows reduction in snow cover in. the Swiss Alps (Uhlmann *et al*., 2009) and the Spanish Pyrenees (López-Moreno *et al*., 2009) and increased variability (Beniston, 2011). The cost-effectiveness of snowmaking investments remains to be determined (Steiger and Mayer, 2008) as well as changes in demands and behavioural adaptation. Agriculture, forestry hydropower will be also affected by climate and water availability. Environmental changes may generate local conflicts of usage and modify the upstream-downstream links (Beniston *et al*., 2010; Beniston, 2010), introducing large changes even in low lying areas, especially for sectors relying on water, such as hydroelectricity, agriculture.

23.9. Interaction between Adaptation and Mitigation Options

Countries in Europe and the European Commission have emissions reduction strategies in place. The effectiveness of European mitigation policies varies by sector and by country. A major limitation has been to address emissions from European non-stationary sources (i.e. transport sector).

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.

23.9.1. Agriculture, Forestry, Fisheries, Bioenergy

Ecosystem services such as carbon sequestration, flood protection and protection from soil erosion, are directly linked to climate change, and healthy ecosystems are an essential defence against some of its most extreme impacts. But soils also have an important and untapped potential in terms of mitigation. As far as agricultural soils are concerned, it has been estimated that the technical potential for mitigation through optimized carbon management of agricultural soils at EU-15 level is between 60–70 million tonnes CO_2 per year (EC, 2009) or between 70-190 Tg C yr(-1) for continental Europe (Lal, 2008). While the level of implementation and mitigation potential of the soil and land management options varies considerably from country to country, overall they have the advantage of being readily available and relatively low-cost, and not requiring unproven technology. In addition, while the potential of individual measures may be limited, the combined effect of several practices can make a significant contribution to mitigation.

The European Commission's Thematic Strategy for Soil Protection recommends an indicator-based approach for monitoring soil erosion (Kibblewhite *et al*., 2008). Defined baseline and threshold values are essential for the evaluation of soil monitoring data. Natural rates of soil formation can be used as a basis for setting tolerable soil erosion rates, with soil formation consisting of mineral weathering as well as dust deposition (Verheijen *et al*., 2009). Different EU policies for water, waste, chemicals, industrial pollution prevention, nature protection, pesticides and agriculture are contributing to soil protection. However, as these policies have other aims and other scopes of action, they are not sufficient to ensure an adequate level of protection for all soil in Europe. The prevention of soil degradation is also limited by the scarcity of data. In this context, the European Commission adopted a Soil Thematic Strategy (COM(2006) 231) and a proposal for a Soil Framework Directive (COM(2006) 232) on 22 September 2006 with the objective to protect soils across the EU (EEA, 2010b). The European Commission has put forward legislation according to which Member States would have to identify the areas at risk of soil organic matter decline in their national territory. Such legislation should be would ensure a high level of soil protection across the Community. This development will have the potential to enable the kind of estimation, measurement or modelling of crop or grazing land management needed for accounting under Article 3.4 of the Kyoto Protocol (Marmo, 2008).

Human impact on land use and vegetation may alter expected effects (increased fire activity and post-wildfire erosion) arising from future climatic change. The EU Common Agricultural Policy encourages vineyard restructuring and conversion plans (Commission Regulation EC No 1227/2000 of 31 May 2000) by subsidizing up to 50% of the cost of soil preparation such as soil movement and land levelling. In North-East Spain, the soils of the vineyards are significantly altered by mechanical operations which also influence soil erosion and contribute to climate change effect through depletion of soil OM (Martinez-Casasnovas and Ramos, 2009).

23.9.2. 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).

23.9.3. Social and Health Impacts

The health co-benefits of mitigation policies are potentially large (see WGIII chapter x and WGII chapter 11). Several assessment have quantified benefits in terms of lives saved by reducing particulate air pollution, increasing housing energy efficiency and consuming less animal products.

As described above, there are several low energy housing options. Research on the benefits of various housing options (including retrofitting) have been intensively addressed in the context of low energy, healthy and sustainable housing.

23.9.4. Production and Infrastructure

National, regional or local strategies for greenhouse gas emission reductions typically do not take into consideration the technical and economic implications that a changing climate may have on the energy resources' potential. 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, 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.

23.10. 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) can redistribute economic activities and migration across the European landscape. The main sectors, impacted by climate change, that can redistribute economy and people across regions are: tourism, agriculture, forestry, floods and natural disasters, public health.

23.10.1. 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%. 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.

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. These effects may reinforce the current trends of intensification of agriculture in northern and western Europe and extensification and abandonment in the Mediterranean and south-eastern parts of Europe.(Bindi and Olesen, 2011).

An analysis of topoclimatic conditions for olive trees in Slovenia (Ogrin, 2007) shows that within the existing cultivated area, the capacities are sufficient to double at least the present-day olive groves, although expected extremes (including frosts) may decrease this capacity.

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).

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

In an increasingly globalised world, impacts of climate change in other countries are likely to effect countries within the Europe region. Further, the region is very closely linked to its near neighbours. Countries around the Mediterreanean share similar ecologies and therefore some vulnerabilities (see Box 23-2; see also Chapter 22).

_____ START BOX 23-2 HERE _____

Box 23-2. Climate Change Impacts in the Mediterranean
[to be expanded]

- Average temperature over the region is increasing in line with the global trends. Precipitation is decreasing over the region. The new generation of regional climate models (including MedSeas) confirm warming trend and drying trend under the climate scenarios for the region.
- Sea level estimation highly variable over the MedSea up to 15cm in the period 1987-2007. The evaluation of future sea level changes is in progress. Preliminary estimates indicate 15cm in the average but with significant variability by 2100.
- 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.
- Climate change is expected to trigger a more severe fire regime and more difficult conditions for ecosystem restoration after fire.
- Impacts of water resources is large and will require flexible management.

_____ END BOX 23-2 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), as result of a study in Germany, propose to stop using the term 'exotic' for these diseases, because infections which are today considered as 'exotic', may become established species. 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 [see chapter 12 on Human Security]. The majority of displaced persons are currently displaced either within country or in neighbouring countries. However, there is a need for some regulatory and institutional planning in EU regarding future migration (Kolmannskog and Myrstad, 2009).

23.11 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.

[to be developed]

_____ START BOX 23-3 HERE _____

Box 23-3. National Adaptation Strategies

Rapid changes in adaptation policy have occurred since the Fourth Assessment Report, including the implementation of national policies. This box will report the results of a comparative analysis of published adaptation strategies(Biesbroek *et al*., 2010).

- Comparison of adaptation plans in 29 European countries (Massey and Bergsma, 2008)
- Comparison of adaptation plans in Eastern Europe (Massey, 2009)
- Review current adaptation plans in developed countries (Berrang-Ford *et al*., 2011)
- Baltic sea approaches [ASTRA project] (Hilpert *et al*., 2007)

The progression of the Scottish adaptation strategy will be described in more detail. The Climate Change Adaptation Framework is a national, co-ordinated approach that aimed to lead planned adaptation across all sectors to increase the resilience of Scotland's communities. The Framework is based on three pillars:

- Improve the understanding of the consequences of a changing climate and both the challenges and opportunities it pretends;
- Equip stakeholders with the sills and tools needed to adapt to changing climate; and
- Integrate adaptation into wider regulation and public policy so that it is a help, not a hindrance, to addressing climate change issues.

_____ END BOX 23-3 HERE _____

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Table 23-1: Changes in key parameters for all sub-regions and relevant sectors projected/expected changes including changes in extremes - if possible. Identification of possible range of changes. [Forthcoming]]

Table 23-2: Observed changes in natural and managed systems to observed climate change (papers published since the AR4).

Region	**Observed change**	**References**
Coastal and marine systems		
Arctic marine biota (plankton, benthos, fish, birds, mammals)	Northward range shifts for various subarctic and temperate species, changes in growth/condition, in behaviour/phenology, and in abundance of key organisms, rearrangement of food webs and communities (mainly marine mammals and fish)	(Wassmann *et al.*, 2011)
North Atlantic Ocean	Rapid northward shifts of zooplankton (~ 23 km yr^{-1}) in response to rising sea surface temperatures, by far larger than for terrestrial ecosystems	(Beaugrand *et al.*, 2009)
Terrestrial ecosystems		
Altitudinal distribution of forest plant species in Western Europe and **alpine tree line in Switzerland**	Significant upward shift in plant species optima in France. 90% of the upward shifts in Switzerland represent ingrowth related both to land use and climate change, however below the potential regional tree line land use is the most likely driver.	(Gehrig-Fasel *et al.*, 2007; Lenoir *et al.*, 2008)
Distribution of plant species across the British Isles	Strength of the flowering response of native plants to climate change is linked to the degree to which their relative distributions changed over the last 30yr. Alien species exhibit stronger advances in phenology and increases in distribution, however unrelated.	(Hulme, 2011)
Spread of alien species (worldwide, Europe)	Increasing number of colonization events and subsequent establishment of species originating from regions with a warmer climate than in the area of establishment and spread in response to changed climatic conditions of the recent past	(Walther *et al.*, 2009)
Community composition in an arctic mountainside in northern Sweden	Arctic alpine vegetation changed over 20 years by an increase in shrub cover and a loss of species richness	(Wilson and Nilsson, 2009)
Geographical range of an insect in north-central France and northern Italy (Alps)	Northwards and upwards expansion of the distribution of pine processionary moth linked to increased winter survival over the past three decades	(Battisti *et al.*, 2005)
Distribution and abundance of birds species in western Europe	Populations of seven wader species show substantial shifts of up to 115 km northeast with abundance positively influenced by winter temperatures	(Maclean *et al.*, 2008)
Phenology in Central Europe	Widespread advances in spring and summer phenology with new evidence for (1) non-linear temperature responses, (2) marked spatial variability, e.g. pronounced changes in maritime Western and Central Europe, (3) predominantly non-linear phenological changes, especially in the north-western part	(Schleip *et al.*, 2009; Sparks *et al.*, 2009)

Phenology in Mediterranean ecosystems	Warm and dry springs advance flowering, leaf unfolding and fruiting dates and lengthen the growing season	(Gordo and Sanz, 2010)
Phenology of aphids in Europe	Earlier flight phenology of aphids related to spring temperatures	(Harrington *et al*., 2007)
Mistiming of plant-pollinator interactions	Considerable variation in the magnitude of plant and pollinator responses to warming may generate temporal mismatches among mutual partners, however overall structure of pollination networks is probably more robust	(Hegland *et al*., 2009)
Phenology of UK terrestrial, freshwater and marine taxa	Majority of spring and summer events advanced more rapidly than previously documented, however with a strong asynchrony in rates of change across trophic levels, slowest for secondary consumers	(Thackeray *et al*., 2010)
Mistiming in bird migration in the Netherlands	Population declines in a long-distance migratory bird linked to a too early peak in food in respect to arrival times	(Both *et al*., 2006)
Fish communities of large rivers in France	Changes in total abundance, structures and diversity of fish communities, significantly linked to temperature during reproduction, e.g. increasing abundance and proportion of warm-water species	(Daufresne and Boet, 2007)
Agriculture		
Plant phenology in Germany / Europe	Significant advance of agricultural and horticultural phenology related to warming; the average temperature response of annual crops being smaller than of perennial plants	(Estrella *et al*., 2007; Estrella *et al*., 2009)
Mushrooms in Norway	Mean autumnal fruiting dates of mushrooms delayed by 12.9 days since 1980	(Kauserud *et al*., 2008)
Human health		
Pollen season in Europe, Switzerland and Southern Spain	Earlier onset of Birch pollen season with higher annual birch pollen quantities, increase of the highest daily mean pollen concentrations in Basel. Early onset and peak of grass pollen season in Spain.	(D'Amato *et al*., 2007; Frei and Gassner, 2008; Garcia-Mozo *et al*., 2010)
Animal health		
Emergence of blue tongue disease	Northern extension of disease distribution, expansion of distribution of major vector, *Culicoides imicola*, and involvement of novel *Culicoides* vector(s)	(Mellor *et al*., 2008; Purse *et al*., 2006; Wilson and Mellor, 2009)

Table 23-3: Observed impacts and responses (empirical studies post 2006, with criteria). [forthcoming]

Figure 23-1: Sub-regions within Europe.

Figure 23-2: Horizontal maps of seasonal precipitation changes (%) covering all sub regions including robustness measure (e.g. stippled for large number of model in trend agreement). [Notes: Figure under development. Further, if not covered in Chapter 21, would generate a like graphic for temperature to include standard deviation as robustness measure.]]