6.5 Vulnerability to climate change in European macro-regions

Key messages

- Under continued climate change, the Arctic environment will, owing to the faster than average rising air and sea temperatures, undergo major changes affecting both ecosystems and human activities. Many traditional livelihoods are likely to suffer, but conditions for exploiting in particular non-renewable natural sources may become more favourable.
- The Baltic Sea region, in particular its southern part, is expected to experience an increased risk of storm surges owing to sea level rise, changing precipitation and run-off regimes, and biota shifts as a result of warmer coastal sea waters.
- All mountain regions are expected to be negatively affected in relation to their water resources and ecosystems in the next decades. Changing river flow regimes are expected to increasingly affect hydropower production capacities in most mountain regions, winter tourism is projected to be negatively affected by a reduced snowfall period, and increased slope instabilities may affect infrastructure and settlements.
- The Mediterranean region is projected to be increasingly affected by severe impacts on several sectors, in particular water resources, agriculture, forestry, biodiversity, tourism and energy.
- The European Union outermost regions and the overseas countries and territories, which are characterised by very rich biodiversity and high concentrations of endemic species, are recognised as particularly vulnerable to climate change impacts mainly because of sea level rise and extreme weather and climate events.

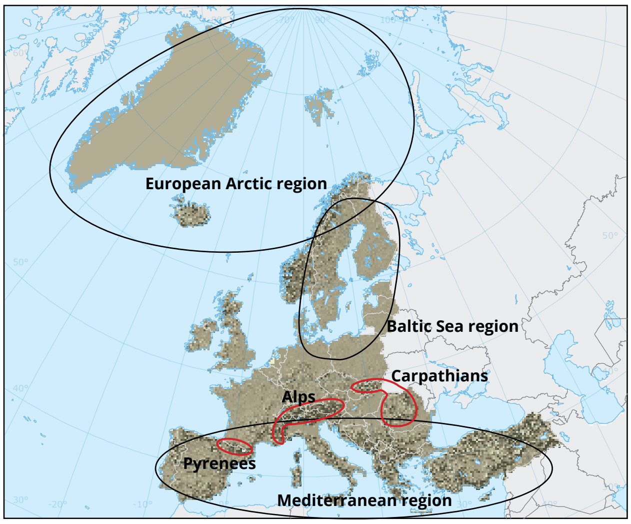
6.5.1 Introduction

This section reviews recent and projected climate change impacts and vulnerabilities for selected European macro-regions. A macro-region in this context is understood broadly to be a transnational region crossing administrative boundaries with common biogeographical characteristics, thus exhibiting particular climate change impacts and vulnerabilities. Only the macro-regions for which comprehensive assessments of climate change impacts and vulnerabilities are available have been considered.

The purpose of this section is to give a synthesis of the most recent regional assessments available for these macro-regions. As a result, there are some differences in the presentation of the various regions. In particular, some assessments focused on climatic and environmental changes, whereas others gave more attention to social and economic vulnerability. For an overview of adaptation policy development in European macro-regions, see Section 2.5.

The following macro-regions will be covered: the European Arctic, the Baltic Sea region, three mountain regions (the Pyrenees, the Alps and the Carpathians), the Mediterranean and the EU overseas entities (EU outermost regions and the overseas countries and territories) (see Map 6.6). For the Arctic region, the following text mainly addresses Arctic regions within (or associated with) EEA member and collaborating countries, i.e. Greenland, Iceland, Svalbard and the northern parts of Norway, Sweden and Finland. Furthermore, this section addresses only the northern part of the Mediterranean region that is within EEA member and cooperating countries.

Map 6.6 Overview of macro-regions in Europe



Note: The map broadly delineates various macro-regions in Europe that are covered by climate change impact assessments in this section. The map is provided for illustrative purposes only, and it does not intend to provide a legal definition of any of these regions.

Source: EEA.

6.5.2 The Arctic region

The Arctic is commonly defined as the region above the Arctic Circle (approximately 66 °N), but other definitions exist, such as 60 °N or using temperature or biological thresholds. The Arctic hosts a set of unique ecosystems and also plays an important role in the global climate system. Politically, the Arctic has been defined through the Arctic Council, whose members are Canada, Denmark (including Greenland and the Faroe Islands), Finland, Iceland, Norway, the Russian Federation, Sweden and the United States of America (see Section 2.5).

Temperatures have increased about twice as fast in the Arctic as in the mid-latitudes in an 'Arctic amplification' (Overland et al., 2014). In the absence of a strong reduction in the Atlantic Meridional Overturning, the Arctic region is also projected to continue to warm more than other regions (Collins et al., 2013) (see Section 3.2.2). The faster than average increase in temperatures is a strong driver of climate-related changes in the Arctic. The Arctic is vulnerable to these temperature increases because they affect key features, such as sea ice extent and seasonal variation in ice and snow, the ice sheet mass balance, glaciers and permafrost, and snow cover (see Section 3.3) with knock-on effects on the hydrology of Arctic waters (AMAP, 2011). The dynamics of the freshwater systems with increasing precipitation and thawing permafrost will be reflected in water courses and altered patterns of lakes and wetlands and the ecosystems they support (CliC et al., 2016). Research furthermore suggests that there are strong positive ice–temperature feedbacks in the Arctic, and thus the rapid warming and reduction in sea ice are likely to continue (Screen and Simmonds, 2010). Overall, the Arctic is becoming warmer and wetter (Boisvert and Stroeve, 2015).

The physical changes will in turn affect Arctic aquatic and terrestrial ecosystems, and a wide range of human activities, ranging from the exploitation of fossil fuel reserves, transportation and the building of infrastructure to reindeer herding (Arctic Council, 2013). For example, the loss of permafrost increases the risk of damage to infrastructure. At the same time, longer ice-free seasons and shorter periods of snow cover provide new opportunities for the use of natural resources and for sea transportation (see Section 5.5).

The Arctic Monitoring and Assessment Programme has produced an overview of key issues related to climate change in the Arctic (AMAP, 2013). Human development, biodiversity and oceans are directly vulnerable to the consequences of climate change, but, as the Arctic is a complex socio-ecological system, there are also many interactions between human activities, biodiversity and oceans (Arctic Council, 2013).

Arctic ecosystems have evolved under climatic conditions that have been characterised by long periods of sub-zero temperatures, snow, ice and permafrost and are, therefore, sensitive to an increased duration of above-zero temperatures. With progressing climate change, winters will become shorter and permafrost will thaw. The thawing of permafrost may also accelerate climate change (Schuur et al., 2015).

In the Arctic, specific habitats for flora and fauna (including sea ice, tundra and permafrost peatlands) have been partially lost over recent decades. Arctic vegetation zones are likely to shift, causing wide-ranging secondary impacts. Some species of importance to Arctic people as well as species of global significance are declining. Climate change is emerging as the most far-reaching and significant stressor on Arctic biodiversity (Meltofte, 2013). Moreover, marine ecosystem acidification may become a serious threat, as acidification can progress more rapidly in Arctic oceans owing to low temperatures and considerable influx of freshwater (Chierici and Fransson, 2009; AMAP, 2014). Hitherto unexpected consequences such as mixing of Pacific and Atlantic fish species may also be a result of warming (Wisz et al., 2015).

The Arctic differs from many other parts of Europe by having a relatively large proportion of indigenous people. Livelihoods that depend directly on ecosystem services are still common. Consequently, a range of climate change impacts have already been experienced by local residents in different communities of the Arctic (Gofman and Smith, 2009). Although some communities lack the appropriate resources for effectively adapting to the projected changes, it is also known that many Arctic communities have, because of the naturally harsh and variable conditions, developed a considerable capacity to deal with climatic variability (Stepien et al., 2014). Climate change is, however, not an isolated phenomenon, and the traditional livelihoods, such as reindeer herding, that are under pressure from a range of socio-economic and political developments may suffer (Pape and Löffler, 2012).

The Arctic has abundant renewable and non-renewable natural resources that hitherto have been difficult to exploit. Progressing climate change with shifts in the distribution and seasonal occurrence of snow and ice cover affect transport options and infrastructure, and thus access to resources (CliC et al., 2016). Climate change may therefore increase pressures on fragile Arctic environments but also on traditional livelihoods of indigenous people through competition for space or through environmental impacts caused by the exploitation of natural resources (AMAP, 2013). The changing socio-economic landscape interacts with climate change impacts and can erode cultural traditions, have an impact on food sources and influence migration, leading to shifts in the demography in the Arctic (UNESCO, 2009).

Climate change both offers opportunities for and threatens human use of Arctic ecosystem services and the exploitation of Arctic natural resources. However, for the unique ecosystems and species that are adapted to long periods of sub-zero temperatures, global warming is exclusively a threat, which can be reduced only by mitigating climate change.

6.5.3 The Baltic Sea region

This section is based on the Second assessment of climate change in the Baltic Sea basin (The BACC II Author Team, 2015), which describes observed and projected climatic changes in the atmosphere, on land and in the sea, and their observed and projected impacts.

Despite large multi-decadal variations, there has been a clear increase in surface air temperature in the Baltic Sea basin since the beginning of the observational record in the region in 1871. Linear trends in the annual mean temperature anomalies from 1871 to 2011 were 0.11 °C per decade north of 60 °N and 0.08 °C per decade south of 60 °N in the Baltic Sea basin. No long-term precipitation trend was observed for the whole region, but there is some indication that there was a tendency towards increasing precipitation in winter and spring during the latter half of the 20th century. No long-term trend has been observed in annual wind statistics since the 19th century, but there have been considerable variations on (multi-)decadal time scales. A northwards shift in storm tracks and increased cyclonic activity have been observed in recent decades, with an increased persistence of weather types.

No statistically significant long-term change has been detected in total river run-off to the Baltic Sea during the past 500 years. However, increased annual, winter and spring stream flow values, as well as earlier snowmelt floods, were observed in the northern regions, whereas a decrease in annual discharge from southern catchments of the Baltic Sea of about 10 % has been observed over the past century. For river ice, a decreasing trend was observed over the past 150 years, with an even clearer trend for the past 30 years, indicating a reduction of ice cover duration and a shift to earlier ice break-up. Decreasing trends have also been observed for snow cover and frozen ground.

The annual mean sea surface temperature of the Baltic Sea increased by up to 1 °C per decade in the period 1990–2008, with the greatest increase in the northern Bothnian Bay. Overall, a clear trend in salinity cannot be detected. Sea ice shows large interannual variability, but a change towards milder ice winters has been observed over the past 100 years. Both the annual maximum ice extent and the length of the ice season have decreased.

Sea level rise of around 1.5 mm/year, comparable to the global sea level rise, has been measured in the Baltic Sea. However, recent data have indicated a rise of around 5 mm/year (± 3 mm/year) with the central estimate thus higher than the recent global mean of 3.2 mm/year (The BACC II Author Team, 2015). There is some evidence that the intensity of storm surges may have increased in recent decades in some parts of the Baltic Sea, and this has been attributed to long-term shifts in the tracks of some types of cyclone rather than to long-term change in the intensity of storminess.

Future climate change in the Baltic Sea region has been assessed by means of dynamic downscaling (results from 13 RCM simulations of the ENSEMBLES project) and of statistical downscaling studies (The BACC II Author Team, 2015). Air temperatures in the Baltic Sea area are projected to increase further for all seasons under all of the different SRES levels, with a warming rate generally greater than the corresponding global one. The greatest level of warming is projected for the northern part of the region in winter. Under all SRES levels, winter precipitation is projected to increase across the entire Baltic Sea region, while summer precipitation is projected to increase only in the northern half of the basin and to change very little in the southern part of the region. Extremes of precipitation are also projected to increase. Model projections for wind diverge so there is no robust evidence on the direction of future changes.

Snow cover extent, duration and amount have been observed to be decreasing in the region, although with large interannual and regional variation. The amount of snow is projected to decrease considerably in the southern half of the Baltic Sea region, with median reductions at the end of the century of about 75 % with respect to the period 1961–1990 (as simulated by RCMs using the SRES A1B scenario) (The BACC II Author Team, 2015, Chapter 6, 11). A decrease in river run-off is possible, even in areas with increased precipitation, if it is overcompensated for by increasing evaporation (The BACC II Author Team, 2015, Chapter 21).

The water temperature of the Baltic Sea is projected to increase significantly, and sea ice cover is projected to decrease significantly under all of the greenhouse gas emissions scenarios used (covering the range between SRES B1 and A2) (The BACC II Author Team, 2015, Chapter 13). Sea level in the Baltic Sea may rise at a similar rate as is projected globally (The BACC II Author Team, 2015, Chapter 14). Sea level rise also has a greater potential to increase storm surge levels in the Baltic Sea than increased wind speed (Gräwe and Burchard, 2012).

The projected warming may affect the northwards migration of terrestrial and aquatic species resulting in longer reproductive periods for coastal fauna and flora in the Baltic Sea region and a northwards shift of the hemiboreal and temperate mixed forests. The effects of climate change facilitate invasions by non-indigenous aquatic bird species, such as cormorants (Herrmann et al., 2014), as well as mammalian predators, which could cause major changes in coastal communities (Nordström et al., 2003). There are indications that the transport of dissolved organic matter and total nitrogen fluxes to the Baltic Sea may increase considerably (Omstedt et al., 2012).

In the deep waters of the Baltic Sea, increasing areas of hypoxia and anoxia are anticipated owing to the increased nutrient inputs due to increased run-off, reduced oxygen flux caused by higher air temperatures, and intensified biogeochemical cycling, including mineralisation of organic matter. Cyanobacteria (blue-green algae) blooms are expected to start earlier in summer (Neumann, 2010; Meier et al., 2012; Neumann et al., 2012). A change in seasonal succession and dominance shifts in primary producers in spring is projected, as well as a general shift towards smaller sized organisms. A potential climate-induced decrease in salinity, together with poor oxygen conditions in the deep basins, could negatively influence Baltic cod and may lead to a reduction of marine fauna (Hinrichsen et al., 2011). A reduced duration and spatial extent of sea ice may cause habitat loss for ice-dwelling organisms and may induce changes in nutrient dynamics within and under the sea ice. A model simulation of future marine acidification in the Baltic Sea implies that rising atmospheric CO_2 levels dominate future pH changes in sea surface water, whereas eutrophication and enhanced biological production are not affecting the mean pH value. The projected decrease in pH of surface water by 2100 ranges from about 0.26 (best scenario) to about 0.40 (worst scenario) (Omstedt et al., 2012). In addition, overfishing and eutrophication may erode the resilience of the ecosystem, making it more vulnerable to climatic variations.

Climate change impacts on forestry and agriculture differ with location. Growing conditions tend to improve in the northern boreal zone owing to higher temperatures, increased CO_2 and increased water availability, while reduced precipitation (in the growing season) and higher temperatures would lead to deteriorating growing conditions in the southern temperate zone.

In general, the southern part of the Baltic Sea basin, with its low-lying coasts and higher anthropogenic pressure than the northern part, is expected to be more vulnerable to the above-mentioned impacts of climate change: an increased risk of storm surges owing to sea level rise, droughts in the summer as a result of a potential change in the precipitation and run-off regime, and possibly more frequent extreme precipitation events.

6.5.4 Mountain regions: the Pyrenees

This section is based on recent assessments by the Pyrenees Climate Change Observatory (OPCC) (OPCC and CTP, 2013; OPCC, 2015).

In the whole Pyrenees region, an increase of the mean surface air temperature of the mountain range of 0.21 °C per decade and a decrease in precipitation by 2.5 % per decade have been observed in the period 1950–2010 (OPCC, 2015). Climate projections indicate that the mean air temperature across the mountain range of this region will increase in the range of 1–2 °C by 2030 and 2.5–5 °C by 2100 compared with the current situation. Furthermore, the frequency and intensity of heat waves is projected to increase, in particular in the north-western and south-eastern parts of the region (AEMET, 2008; López-Moreno et al., 2008). These changes will have an impact on spatial expansion, persistence and thickness of snow cover. Projections according to the SRES A1B scenario suggest a reduction in snow cover of about 1.5 months at an altitude of 1 800 m in the south-western part by 2030, with respect to the reference period 1961–1990 (Déqué, 2012).

A reduction of 10–20 % of accumulated annual precipitation is projected by 2100, with the largest decline (about 40 %) in summer and largely unchanged precipitation patterns in winter (AEMET, 2008; López-Moreno and Beniston, 2009). Moreover, more frequent and intense droughts are projected owing to the reduction in summer precipitation and temperature rise, causing an increase in evapotranspiration (EEA, 2012).

The major river basins (the largest of which are the Ebre, the Garonne and the Adour), situated downstream of the region, are supplied from the

Pyrenees water resources. Reductions of up to 40 % of the flow of the Garonne river (MEDDE, 2013), 0–35 % of the flows of the Catalan rivers (ACA, 2009) and 20 % of the flow of the Ebre river in the summer season are projected for 2060 (Confederación Hidrográfica del Ebro, 2005). On the other hand, climate change is projected to lead to increased water demand (e.g. increase in irrigation needs and in drinking water demand in hot periods), which could further amplify the pressure on the water sector (SOGREAH, 2011).

Climate change is also projected to have an impact on forests — particularly conifers, as they are less adaptable to dry conditions — and agriculture, potentially leading to a decrease in average yields close to 12 % by 2025 (see Sections 4.4 and 5.3). On the other hand, the foothill grasslands and mountain summer pastures are expected to increase their biomass production in spring (maximum production period) and autumn, and to lengthen their production period, which will increase their exploitation possibilities (hay or pasture) (Felten, 2010; Brisson and Levrault, 2012). The risk of forest fires is expected to increase, especially in the summer, as temperature rises and precipitation declines.

Hydroelectric power generation in the Catalan Pyrenees has already decreased by 40 % in the 2003–2007 period, compared with average generation, and a further decrease in hydraulic power potential of 20–50 % is projected by 2070 (CTP and OPCC, 2012).

Tourism, which is a major economic sector for the Pyrenees, will be affected by future climate change (see Section 5.6). In particular, winter tourism is projected to be affected by a reduction in the length of the snowfall period (see Section 3.3.5), ranging between 40 and 55 days in 2030 at an altitude of 1 800 m and between 50 and 85 days in 2100 (for scenario A1B with respect to the period 1961–1990) (CTP and OPCC, 2012). This reduction of the snowfall period will be the result of a large decrease in snowfall and higher air temperatures, which will also move the altitude at which snow is stable from 1 800 m to 2 200 m in the region. This might lead to a potential reduction of the snow cover area by more than 50 % on the southern slopes of the Pyrenees region (ACA, 2009). Even though there will be a high local variability on the level of the impacts, an overall decrease of the season length and an increase of the snowmaking necessity is projected for most of the Pyrenean ski resorts (Pons et al., 2014, 2015). Finally, in the future, increases in the frequency and intensity of heat waves are expected to lead to increased health risks for the Pyrenees population, owing not only to heat but also to heat waves increasing peak air pollution in the main urban areas of the Pyrenees (CTP and OPCC, 2012).

6.5.5 Mountain regions: the Alps

Analysing the climate change impacts and vulnerabilities of this region is particularly relevant, as the Alps are the living and working space for more than 14 million people and are characterised by fragile ecosystems and specific topographical conditions, which determine not only climate sensitivities, but also non-climatic aspects such as settlement practices (Permanent Secretariat of the Alpine Convention, 2011).

The main climatic drivers of vulnerability to climate change in the Alps can be summarised by an increase in temperature higher than the global average, an observed increase in annual precipitation in the north-west and a decrease in the south-east of the Alps (Auer et al., 2005, 2007, 2014), a past and present decrease in seasonal precipitation during summer over all of the Alps and an increase in precipitation in winter in the north-west, as well as a pronounced variability in precipitation patterns, and an expected change in the intensity of extreme weather events.

From the late 19th century until the end of the 20th century, the Alpine region experienced a total annual mean temperature increase of about 2 °C, nearly twice the average in the northern hemisphere (Auer et al., 2014; Gobiet et al., 2014). As regards precipitation, despite the differences deriving from seasonal and geographical conditions (Gobiet et al., 2014), a general shift in precipitation peaks from summer to winter is projected for most of the Alps (BMU, 2008; Schöner et al., 2010), while the south and south-east will become significantly drier in all seasons (EEA, 2009; Haslinger et al., 2015). Owing to warmer temperatures, winter precipitation is projected to fall more frequently as rain. Moreover, an increase in the intensity and frequency of extreme weather events (heavy rainfall, drought periods, heat waves and possibly also storms) is expected in the whole Alpine region.

Since 1900, the Alpine glaciers decreased in their ice mass by about 50 % (Zemp et al., 2008; Huss, 2012) and a recent study (Radić et al., 2013) has estimated a loss between 84 % and more than 90 % of their current volume by 2100 under RCP4.5 and RCP8.5 scenarios, respectively (see Section 3.3.4).

The main non-climatic drivers of vulnerability derive from the specificities of the Alpine topographical conditions, and are, in particular, the limited settlement space available and the subsequent intensification of land use. The ongoing development of settlements — including their expansion into hazard zones — enlarges the surface area, population and material assets exposed to risk and hazards, resulting in the need for ad hoc planning and building practices, such as densification (Permanent Secretariat of the Alpine Convention, 2015). This can aggravate the pressure on the territory and can lead to adverse spill-over effects on environmental quality. Owing to the subsequent fragmentation of habitats, this can also have an impact on biodiversity and species distribution, which are likely to be adversely affected by climate change.

Decreasing water availability in the dry period — as a consequence of expected changes in the precipitation patterns and the melting of the glaciers — will reinforce the competition between different water usages, such as drinking water, irrigation, energy production and tourism-related uses, as well as between upstream and downstream territories (see Section 4.3). Moreover, the hydrological system is projected to become more sensitive to extreme weather events. The impacts of changing river flow regimes on hydropower production capacities are a key issue for energy production in the Alpine region, in particular in the longer term (Ballarin-Denti et al., 2014) (see Section 5.4). The development of new renewable energy production units will be the key adaptation measure, but could face possible conflicts with nature and landscape protection and with other activities such as tourism, agriculture and forestry.

The Alpine region is regarded as highly susceptible to mountain-specific climate-related hazards, such as gravitational mass movements (e.g. debris flows and landslides), torrential processes and floods (Gobiet et al., 2014). These risks from natural hazards are likely to increase as a consequence of different effects, such as changes in precipitation patterns, increased soil erosion, permafrost degradation and the destabilisation of mountain slopes. This reduces the suitable areas for settlement, reinforcing the competition between the different forms of land use and directly affecting infrastructures for transport and energy distribution.

Global climate change causes additional threats to Alpine biodiversity (EEA, 2010; Engler et al., 2011; Dullinger et al., 2012; Gottfried et al., 2012). Their high degree of specialisation makes Alpine species less tolerant and more vulnerable to changes in ecological conditions. Owing to shifting climatic zones, many plant and animal species face extinction risks because upwards or northwards migration is not possible, especially for high-altitude species. Observations show that the specialised species growing at high altitudes are replaced by more competitive species from lower regions (see Section 4.4).

Forest ecosystems are already affected and are expected to face increased losses and damage costs from multiple climate-induced effects, e.g. higher tree mortality, more pest species calamities, higher water stress and greater forest fire frequency. This will have a negative impact on both the regulative ecosystem services of forests and the entire forest wood-production chain (Umweltbundesamt, 2007, 2013).

In the agriculture sector, the impact of climate change will vary in different parts of the Alps (Fuhrer et al., 2006; Tamme, 2012; Mitter et al., 2015). In some regions, the average yield potential will increase, and some crop species, such as grapevine, may find new opportunities in areas that were not suitable to them before. In the southern part of the Alps, the change in precipitation could increase the risk of droughts.

Tourism is another important sector in the Alps that, on the one hand, is likely to be subjected to pressures deriving from climate change, owing both to lower snow reliability in winter (see Section 3.3.5) and to an increase in risks from natural hazards. On the other hand, there may be a new touristic opportunity for the Alps in a revival of summer cool-seeking tourism (see Section 5.6).

6.5.6 Mountain regions: the Carpathians

This section is mainly based on the final report of the CARPIVA (123) project, in which the results of the CARPATCLIM (124) and CarpathCC (125) projects are integrated (Werners et al., 2014).

Rising temperatures have been observed in all seasons for the period 1961–2010, with the strongest warming of up to 2.4 °C (depending on location and altitude) in summer seasons. The lowest rates of warming have been measured in winter, with temperature increases mostly lower than 0.4 °C. Model projections according to the SRES A1B scenario suggest an increase in temperature of up to 1.8 °C for the period 2021–2050 compared with the reference period 1961–1990, with greater temperature increases in the southern parts of the region (see Section 3.2.2). Regarding precipitation patterns, observations have shown increasing annual precipitation in most of this region in the last 50 years, except for the western and south-eastern areas, where precipitation has been decreasing. Projections suggest

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(123) CARPIVIA: 'Carpathian integrated assessment of vulnerability to climate change and ecosystem-based adaptation measures'; see http://www.carpivia.eu.

(124) CARPATCLIM: 'Climate of the Carpathian Region'; see http://www.carpatclim-eu.org/pages/home.

(125) CarpathCC: 'Climate Change Framework Project'; see http://www.carpathcc.eu.

further precipitation increases (up to 10 %) in winter but a decrease of about 15 % in the summer period (Werners et al., 2014).

The Carpathians include eastern Europe's largest contiguous forest ecosystem, which provides habitat and refuge for many endangered species. The native flora of the Carpathians is among the richest on the European continent. It is composed of almost 4 000 species, representing approximately 30 % of the European flora. The Carpathians contain Europe's largest populations of brown bears, wolves, lynx, European bison and rare bird species. The promotion of sustainable agriculture, forestry and tourism are crucial for safeguarding the diversity, continuity and robustness of these ecosystems, allowing species to migrate under changing climatic conditions to areas that better meet their living conditions. The seven countries with a share of the Carpathian territory are characterised by large socio-economic differences, which in turn shape climate change vulnerability and response capacities (Werners et al., 2014).

The factors projected to most affect the water sector are increasing temperatures, increasing winter precipitation and decreasing summer precipitation. Decreasing summer flows would have negative impacts on ecosystems and ecosystem services. Periods when ecological water demands will not be met are projected to increase, with potentially irreversible damage to aquatic and riparian ecosystems. Settlements, agriculture and industry are projected to be affected by more frequent periods of water shortages. At the same time, increasing wintertime flows are likely to exacerbate existing flood problems (see Section 4.3.3). The vulnerability of water resources shows a clear south–north gradient, with higher risks in the south, owing to a combination of climatic, topographical and economic factors (Werners et al., 2014).

In the context of the CarpathCC project, integrated forest vulnerability to climate change has been assessed on the basis of exposure and sensitivity components and adaptive capacity. This study shows that the vulnerability of forest ecosystems is highest in the southern and western parts of the Carpathian region (see Map 6.7). This is attributed to the fact that the condition of the trees has deteriorated and the composition of the forests has changed owing to increased drought events, with the result that pests can occur more easily (Werners et al., 2014).

The Carpathian wetlands and grasslands are also vulnerable to the combined pressure from climate change and human activities. The most vulnerable wetland habitats are peatlands, owing to their limited resilience to climate variability and human activities, such as changes in land use. Less vulnerable are halophytic habitats, steppes and marches. These habitats can adapt to climate fluctuations, yet are highly sensitive to human activities and changes in land use. The lowest vulnerability is found in habitats already subjected to regular flooding, such as subterranean wetlands and some riverbank and water habitats. Grasslands in the region have strong cultural associations, provide a wide range of ecosystem services and associated economic benefits, and are rich in wildlife and biodiversity. The species-rich *Nardus* grasslands in (sub-)mountain areas, where management possibilities exist, are less vulnerable, while the (sub-)Alpine grasslands on calcareous sites are more vulnerable to changing climatic conditions (Werners et al., 2014).

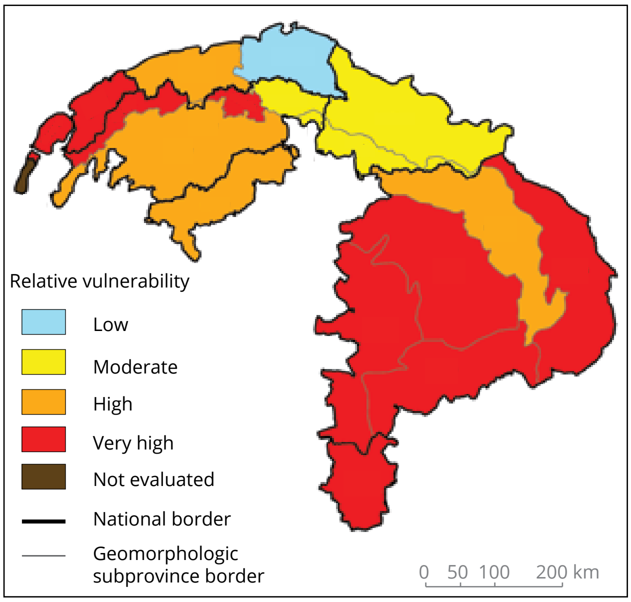
Currently, changes in the turnover of the tourism sector are much more dependent on general economic performance than on climate change. On the other hand, several tourism activities may potentially be positively affected by future climate change (e.g. ecotourism, summer tourism, health tourism, vocational tourism), while other activities such as fishing, hunting and winter sports are expected to be affected negatively (Werners et al., 2014).

6.5.7 The Mediterranean region

This section is mainly based on the first two volumes of the Regional Assessment of Climate Change in the Mediterranean (Navarra and Tubiana, 2013a, 2013b) as part of the FP6 CIRCE project. This is so far the only comprehensive regional assessment of climate change observations, projections, impacts and vulnerabilities for the Mediterranean region that applies an integrated interdisciplinary approach to assess how climate is expected to affect ecosystems, key economic sectors and societies.

The large environmental diversity and unique biotic and abiotic characteristics of the Mediterranean Sea, the largest of the semi-enclosed European seas, are undergoing rapid changes owing to increasing natural and human pressures (EEA, 2015). In particular, the physical dynamics and hydrological structure of the Mediterranean are influenced by climate change impacts and the increasing nutrient and pollutant loads discharged into several areas of the basin. Furthermore, the Mediterranean has been identified as one of the main climate change hotspots in Europe, where potential impacts may be particularly severe, with a large number of sectors affected (see also Section 6.2) (Giorgi, 2006).

Map 6.7 **Vulnerability of the forest sector in the Carpathian region**



Note: The map shows the vulnerability of forests in the Carpathian region (see Map 6.6 for the location) to climate change, evaluated in the frame of geomorphological units on the basis of several indicators of climatic exposure, forest climatic sensitivity and adaptive capacity.

Source: Adapted from Barcza et al., 2013.

Climate observations show that there has been a progressive and substantial drying of the Mediterranean land surface since 1900 (e.g. a change of the Palmer Drought Severity Index by – 0.2 units per decade), consistent with an increase in surface air temperatures and a decrease in precipitation. The analysed sea level data show a rise of about 150 mm in the last two centuries, and a 20-year-long reanalysis (1985–2007) of marine temperature and salinity detected long-term temperature variability and a positive salinity trend in the ocean layers from the surface to a depth of 1 500 m. Regarding extreme climate and weather events, heat wave durations and frequencies have been observed to have increased more than six-fold since the 1960s (Kuglitsch et al., 2010).

A significant surface warming of about 1.5 °C in winter and about 2 °C in summer and a decrease in mean annual precipitation (about 5 %) is projected in this region for the period 2021–2050 compared with the period 1961–1990 under SRES A1B emissions, with the largest changes projected for the summer months (Gualdi et al., 2013). Sea level rise in the Mediterranean Sea is expected to be in the range of 6.6–11.6 cm in the period 2021–2050 with respect to the reference period 1961–1990. Furthermore, more frequent very hot days and nights, longer warm spells and more intense and frequent heat waves are projected for the whole Mediterranean region (Navarra and Tubiana, 2013b) (see also Section 3.2.3).

Climate change also interacts with other non-climatic drivers in the Mediterranean (Navarra and Tubiana, 2013a, Chapter 2), such as urbanisation and other socio-economic modifications, land-use changes (Santini and Valentini, 2011) or changes in tourism flows. All these factors combined are likely to cause significantly increasing climate-related risks and vulnerabilities in the region (see also Section 6.2). Of the range of different climate impacts in the Mediterranean region, water availability is considered the most critical (EEA, 2012). The new expected climate regime, under the combined effects of precipitation decrease and near-surface air temperature increase, is expected to affect the hydrological cycle with a general decline in water availability in terms of groundwater recharge, superficial water flow and soil moisture (Santini et al., 2014). Furthermore, the decrease in water resource reliability is related to the increased variability of streamflow, including an earlier decline in high flows from snowmelt in spring, an intensification of low flows in summer, more irregular discharges in winter, and changes in reservoir inputs, including reduced availability of or less reliable discharges from dams to meet the water demand from irrigated and urban areas. These factors act in conjunction with other drivers such as changing patterns of land use, population increase, increasing water demands for agricultural, industrial, energy and domestic consumption, and inappropriate water management (García-Ruiz et al., 2011), all of which make the Mediterranean water sector highly vulnerable under future climate change (Navarra and Tubiana, 2013b).

The projected reduction in mean precipitation and the increase in interannual and intra-annual precipitation variability, alongside inefficient water resource management in some areas of this region, will negatively affect water availability for a large number of people. In particular, shortages of water resources are projected in some northern areas of Spain (Arias et al., 2014) and Italy (Senatore et al., 2011; Gunawardhana and Kazama, 2012), where some water production is currently non-sustainable (overexploitation of renewable and non-renewable water reserves) (Navarra and Tubiana, 2013b).

The Mediterranean region is projected to be affected by losses of agricultural yields and carbon storage potential, increased fire risks and biome shifts (Navarra and Tubiana, 2013a; Santini et al., 2014). Mediterranean ecosystem services are particularly sensitive to extreme events or seasons, such as very hot and dry summers

(Ciais et al., 2005; Reichstein et al., 2007; Vennetier et al., 2007; Navarra and Tubiana, 2013a, Chapter 3) and mild winters or windstorms and heavy rains (IPCC, 2014). Ecosystem services are also threatened by long-term climate-driven changes such as aridification and degradation, eventually leading to irreversible desertification (Rubio et al., 2009; Santini et al., 2010). Future climate change is also projected to affect typical Mediterranean crops, e.g. grapevine, durum wheat and olive (Ponti et al., 2014; Tanasijevic et al., 2014; Saadi et al., 2015). In particular, the area suitable for olive trees is projected to undergo a northwards and eastwards shift owing to the projected warming and drying (Mereu et al., 2008; Navarra and Tubiana, 2013a, Chapter 4). Agriculture also includes the farming of animals, which will be exposed to increased heat stress during summer (Navarra and Tubiana, 2013a, Chapter 7).

Impacts of climate change on the Mediterranean forests (see Section 4.4) are already evident in ecophysiology, productivity, dieback and some shifts in species distributions (Bréda et al., 2006; Vennetier et al., 2007; Allen et al., 2010), and these impacts are projected to further increase as a result of the projected climate change. In particular, the distribution range of typical Mediterranean tree species is likely to decrease in the region, but it could expand to new areas with new Mediterranean-like climatic conditions (Jump et al., 2006; Ruiz-Labourdette et al., 2012). Projected climate change for the Mediterranean region is likely to increase fuel dryness and reduce relative humidity, which will thus lead to a higher forest fire risk, longer fire seasons and more frequent large, severe fires, along with more difficult conditions for ecosystem restoration after fire (Navarra and Tubiana, 2013a, Chapter 6).

The Mediterranean marine ecosystems, which are already experiencing pressures ranging from eutrophication to dumping of waste and fish farming, are expected to suffer additional pressures owing to increased marine temperatures (see Section 4.1).

The Mediterranean is the largest tourism region in the world owing to its unique natural and cultural heritage. Higher air temperatures in northern European countries are expected to reduce the north-south tourism flow (see Section 5.6). Furthermore, the attractiveness and competitiveness of Mediterranean coastal areas could be reduced for tourists because of increasing air temperatures during summer peak seasons and increasing coastal erosion. Further studies on understanding the regional differences within the Mediterranean touristic areas and the role of the non-climatic factors are needed in this sector (Navarra and Tubiana, 2013a).

Higher air temperatures, more frequent and longer heat waves, reduced air quality (mainly PM and ozone), and changes in the distribution patterns of climate-sensitive infectious diseases are expected to lead to an increased risk to human health in Mediterranean countries if adaptation measures are not planned and taken in due time (see Section 5.2).

Table 6.6 provides a summary of the stresses, impacts, sensitivities and critical thresholds for the different ecosystem services and the sectors they support (Navarra and Tubiana, 2013a, Chapter 2).

6.5.8 EU overseas entities

This section covers the EU overseas entities, which comprise nine EU outermost regions (ORs) and 25 overseas countries and territories (OTCs). Both types of region are characterised by their remoteness, specific climatic conditions, very rich biodiversity, high concentration of population and economic activities along the coastline, and economic dependence on a small number of products and services.

The ORs comprise remote regions that belong to an EU Member State and that are an integral part of the EU. There are nine ORs: five French overseas departments (Guadeloupe, French Guiana, Martinique, Réunion and Mayotte), one French overseas collectivity (Saint Martin), two Portuguese autonomous regions (Madeira and the Azores) and one Spanish autonomous community (the Canary Islands). The OTCs comprise 25 regions that are not part of the EU but are constitutionally linked to an EU Member State (in particular to Denmark, France, the Netherlands and the United Kingdom). The type of association with the EU varies across OTCs. The OTCs are a particularly diverse group, as they range from small islands in the tropics to huge territories in the Arctic (Greenland) and the Antarctic (the British Antarctic Territory).

Several research activities and policy initiatives have covered ORs and OTCs jointly, despite their different legal statuses. A first comprehensive overview of the potential impacts of climate change on biodiversity in ORs and OTCs was provided in a report by the International Union for Conservation of Nature (IUCN) in collaboration with the Observatoire National sur les Effets du Réchauffement Climatique (ONERC; the French national observatory about climate change impacts) (Petit and Prudent, 2010), based on the 2008 IUCN conference 'The European Union and its Overseas Entities: Strategies to Counter Climate Change and Biodiversity Loss'. Further relevant information was provided in an IUCN-led review of the implementation of the convention on biological

Table 6.6 Vulnerability of ecosystem services in the Mediterranean

Sector	Ecosystem services	Stress (climate, others)	Impacts/ sensitivities	Critical thresholds for ecosystem services
Agriculture, grazing, agroforestry	Food (crop and livestock) production	• Higher temperatures • Changing precipitation patterns • Water stress • Disease • Erosion • Urban encroachment	• Higher irrigation demand • Reduced productivity • Crop failure • Livestock mortality	• Precipitation threshold beyond which rain-fed systems fail • Fallow groundwater level threshold below which pumping fails
Agriculture	Carbon sequestration	• Higher temperatures • Changing precipitation patterns • Water stress • Disease • Erosion • Urban encroachment	• Higher irrigation demand • Reduced productivity • Soil organic matter decomposition	• Precipitation threshold beyond which rain-fed systems fail • Irrigation water allocations below which permanent cultures die • Fallow groundwater level threshold below which irrigation water pumping fails • Grazing pressure beyond stocking capacity above which productivity sharply declines • Climatic or land-use change threshold beyond which systems turn into carbon sources
Agriculture, forestry	Biofuels, carbon offset	• Higher temperatures • Changing precipitation patterns • Water stress • Disease • Fire • Erosion/overexploitation • Urban encroachment	• Reduced productivity • Crop or tree mortality	• Precipitation threshold below which biofuels can no longer be produced • Water or land scarcity threshold below which food security is threatened
Forestry	Timber production	• Higher temperatures • Changing precipitation patterns • Water stress • Disease • Fire • Erosion/overexploitation	• Reduced productivity • Tree mortality	• Temperature or management threshold beyond which many more fires occur
Forestry, terrestrial ecosystems	Carbon sequestration	• Higher temperatures • Changing precipitation patterns • Water stress • Disease • Fire • Erosion	• Reduced productivity • Tree mortality • Soil organic matter decomposition	• Climatic or land-use change threshold beyond which systems turn into C-sources
Terrestrial and aquatic ecosystems	Water provision/ regulation	• Higher temperatures • Changing precipitation patterns • Water stress • Land cover changes • Landscape degradation • Erosion	• Reduced water availability • Higher water demand • Water quality degradation • Sediment yield	• Precipitation threshold below which groundwater recharge fails • Minimum vegetation cover threshold below which moisture recycling from land surface to atmosphere fails • Minimum vegetation cover threshold below which rapid erosion/siltation starts

Source: Adapted from Hoff, 2013.

diversity (Benzaken and Renard, 2011), even though this review did not focus on climate change. The current NetBiome-CSA project (126) is an EU-funded coordination and support project aiming to strengthen European research cooperation for smart and sustainable management of tropical and subtropical biodiversity in ORs and OCTs.

EU outermost regions

The information presented here builds mainly on the final report of a study commissioned by DG-CLIMA on the impact of climate change and adaptation measures in the ORs (EC, 2014a, 2014b). Further information is available in sectoral assessments, e.g. for coastal areas (EC, 2009a, 2009b).

The ORs, which have been recognised as particularly vulnerable to climate change impacts in the recent EU Strategy on climate change adaptation, have the following features in common that contribute to their general high degree of vulnerability:

- high sensitivity to extreme weather and climate events, e.g. hurricanes, cyclones, storm surges, flooding and droughts;
- high sensitivity of water resources to sea level changes, with a related risk of saltwater intrusions, and also to droughts;
- very rich biodiversity and a high concentration of endemic species that are sensitive to changes in temperature and precipitation and to the introduction or increase in numbers of pests and invasive species;
- high exposure of coastal zones, owing to dense urban areas, socio-economic activities and infrastructures, making them highly sensitive to sea level rise and coastal flooding;
- an economy dependent on a small number of sectors (e.g. fishing and tourism), which makes them highly vulnerable to any potential changes.

Owing to the limited number of specific modelling and impact assessment studies, information about climate change impacts relevant to ORs is mainly based on the IPCC reports. The following are the key impacts of climate change in the ORs (IPCC, 2014):

- a change in annual precipitation patterns (e.g. wetter winters but drier summers);
- increasing sea temperatures and ocean acidification leading to coral bleaching;
- an increasing frequency of inland and coastal floods owing to extreme precipitation events and storms as well as sea level rise;
- increasing saltwater intrusions into freshwater aquifers, with related negative effects on water quality;
- impacts on the health sector as a result of rising temperatures and heat waves causing increasing mortality and related human diseases;
- increasing soil degradation, droughts and wildfires, with increasing related impacts on agriculture and food production due to rising temperatures and heat extremes;
- increasing impacts on the few relevant economic sectors of these regions.

In a study on the impact of climate change and adaptation measures in the ORs, the impacts and vulnerabilities of most of the ORs (127) were scored and combined to give an assessment of the level of risk or opportunity arising from climate change for each OR (EC, 2014a, 2014b). Table 6.7 summarises risks and opportunities across seven selected economic sectors and six human and environmental systems relevant for all the ORs.

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(126) http://www.netbiomecsa.netbiome.eu.

(127) This assessment was performed for only seven ORs, because Mayotte and Saint Martin lack detailed specific information on impacts and vulnerabilities.

Table 6.7 **Risks and opportunities arising from climate change to the EU outermost regions by sector**

	Agriculture	Forestry	Fisheries and aquaculture	Energy	Tourism	Construction and buildings	Transport	Waste	Health	Biodiversity	Coastal zone management	Soil	Water	Disaster and risk
Guadeloupe	🟫	🟫	🟧	🟧	🟧	🟥	🟥	⬜	🟧	🟧	🟥	⬜	🟫	🟧
Martinique	🟫	🟫	🟧	🟧	🟥	🟧	🟥	⬜	🟧	🟧	🟥	🟫	🟧	🟧
French Guiana	🟫	🟧	🟥	🟧	🟫	🟧	🟫	⬜	🟥	🟧	🟧	🟫	🟧	🟥
Réunion	🟫	🟫	🟫	🟥	🟧	🟧	🟧	⬜	🟫	🟥	🟧	🟧	🟫	🟧
Canary Islands	🟧	🟫	🟧 🟩	🟧 🟩	🟥 🟩	🟧 🟩	🟥	🟧	🟧	🟥	🟧	🟧	🟧	🟧
Azores	🟧	🟧	🟧 🟩	🟧 🟩	🟧 🟩	🟧	🟥	🟧	🟧	🟥	🟥	⬜	🟥	🟧
Madeira	🟧 🟩	🟫 🟩	🟧 🟩	🟥 🟩	🟧 🟩	🟧	🟥	🟧	🟥	🟥	🟥	⬜	🟧	🟧

Note: The colour coding of the cells in the risk matrix represents the following: red, high risk; orange, moderate risk; brown, low risk; green, opportunity; grey, the risk is relevant to the sector but could not be assessed. Some sectors in some regions experience both risks and opportunities.

Source: EC, 2014a (Table 1).

Overseas countries and territories

The most recent overview of the potential climate change impacts in OCTs is available from the OCTs Environmental Profiles 2015, which comprise a main report and five regional reports (EC, 2015a). These reports highlight the wide range of observed and projected climate change impacts across OCTs, which reflect their climatic and environmental diversity. A concise summary is available in the main report:

> *'Greenland, the British Antarctic Territory and TAAF* [French Southern and Antarctic Territories] *are well placed to study and understand the effects of global climate change. Ongoing processes in these territories have worldwide impacts: changes in melting of glaciers, sea ice extent, water mass formation. Several OCTs are particularly vulnerable to sea-level rise, and some effects are already visible. Many OCTs lie on the path of hurricanes and increased violence storms are expected more frequently, but also changes in precipitation patterns. Besides, changes in ocean temperatures, salinity and currents will bring changes in marine ecosystems, endanger coral reefs which play a key role in the physical defence and economies of many territories, and have unpredicted effects on fish stocks. Jointly, the OCTs have a comparative advantage in studying first hand these phenomena, and in testing adaptation and mitigation measures that can then be transferred to other neighbouring countries'.*

(EC, 2015b, page 10)