5.7 Terrestrial ecosystems and biodiversity

5.7.1 Introduction

Climate (change) is an important driving force in the distribution and functioning of natural systems (Parmesan and Yohe, 2003). Europe's biodiversity (its species, habitats and ecosystems) has been modified repeatedly during past glacial and inter-glacial periods, with some species recolonising the continent from ancient *refugia*. Today, ecosystems have an essential role in providing services to humankind such as nutrient cycling, pest control, pollination, quality of life, and hydrological, atmospheric and climatic regulation (Díaz *et al.*, 2006; IPCC, 2007). Impoverishment of Europe's biodiversity may affect the delivery of ecosystem services with potentially serious consequences (Lovejoy and Hannah, 2005). Maintaining and enhancing healthy ecosystems are an important element in climate change mitigation and adaptation actions.

About 60 % of the world's known ecosystems are currently used unsustainably (Reid *et al.*, 2005). In Europe, the richness and abundance of biodiversity is undergoing significant decline. This is in large part due to changes in land use and management, which are resulting in degradation of (semi-)natural habitats, declines in traditional agricultural and forest management on which many habitats depend, and now large-scale land abandonment. Urbanisation, industrialisation, modification of rivers and watercourses, fragmentation of habitats by infrastructure and growing pressure from public access to the countryside for tourism and recreation are also causing widespread biodiversity losses (Millennium Ecosystem Assessment, 2005).

It is likely that these losses of biodiversity will be exacerbated by climate change. Projections suggest that between one fifth and one third of European species could be at increased risk of extinction if global mean temperatures rise more than 2 to 3 °C above pre-industrial levels (Lovejoy and Hannah, 2005; IPCC, 2007). A combination of climate change and the drivers of change outlined above will reduce the adaptive capacity (and resilience) of many species, possibly resulting in different ecosystems and landscapes across Europe. Local and regional extinctions are likely (McKinney and Lockwood, 1999). Species at greatest threat include specialists, those at the top of the food chain, those with latitudinal and altitudinal restrictions, and those with poor dispersal abilities.

The European Commission, through its target to 'halt the loss of biodiversity by 2010 — and beyond', is addressing observed and projected declines in biodiversity and their consequences for human well-being. As part of this process, reducing the impacts of other drivers of change will enhance the ability of species to adapt to climate change (IPCC, 2007). But new areas for conservation are also needed, together with measures to improve connectivity, thus facilitating species movement in fragmented landscapes. As such, the robustness of the European ecological network of Natura 2000 sites should be strengthened, including through more widespread implementation of Article 10 of the Habitats Directive (which relates to the network's coherence).

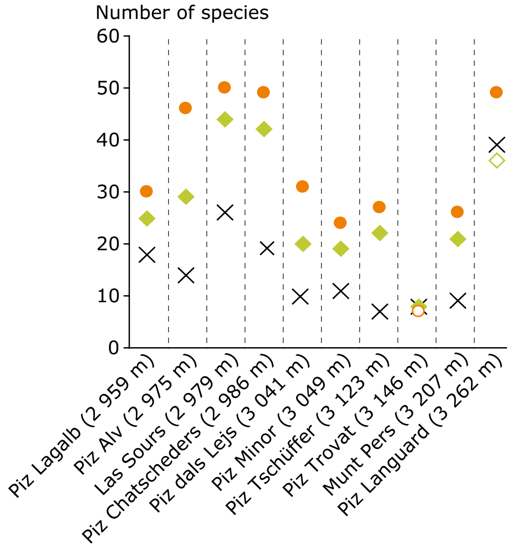
This section outlines the impacts of climate change on biodiversity by showing both observed and projected changes in the distribution and phenology (changes in the timing of seasonal events) of plants and animals, and the implications for communities.

5.7.2 *Distribution of plant species*

Key messages

- Climate change, in particular milder winters, is responsible for the observed northward and uphill distribution shifts of many European plant species. Mountain ecosystems in many parts of Europe are changing as pioneer species expand uphill and cold-adapted species are driven out of their ranges.
- By the late 21st century, distributions of European plant species are projected to have shifted several hundred kilometres to the north, forests are likely to have contracted in the south and expanded in the north, and 60 % of mountain plant species may face extinction.
- The rate of change will exceed the ability of many species to adapt, especially as landscape fragmentation may restrict movement.

Figure 5.31 Increase in species richness on Swiss Alpine mountain summits in 20th century



Note: Endemic, cold-adapted species are declining as pioneer species drive them out of their characteristic niches due warming conditions. ×: 1900s; ◇: 1980s; •: 2003; open symbols indicate a (temporary) decrease in species number (Piz Trovat, Piz Languard).

Source: Walther *et al.*, 2005.

Relevance

The rate of climate change is likely to exceed the adaptive capacity of some wild plant species (IPCC, 2007), whilst others are expected to benefit from changing environmental conditions (Sobrino Vesperinas *et al.*, 2001). Consequently, the composition of many plant communities is changing to the extent that completely new assemblages are appearing. In addition, there is a parallel change in plant distribution and the increased threat of extinction of species at the edge of their geographical and altitudinal ranges — particularly poorly-dispersing endemics. The ecological implications of these changes and the effects on the services that these ecosystems provide are not always clear. Together with the emergence of invasive non-native species, these factors will have challenging consequences for long-term biodiversity conservation (Gitay *et al.*, 2002) and the ability of Europe to meet its target to halt biodiversity loss, not least in relation to the favourable status of Natura 2000 sites.

The adaptive capacity of species is linked to genetic diversity and this too might change under climate change; sensitive and valuable relic populations will be particularly affected.

Past trends

Warmer temperatures in the past 30 years have significantly influenced seasonal patterns across Europe. As evidenced during glacial and inter-glacial periods, the predominant adaptive response of temperature-sensitive plant species has been to shift distributions, resulting in northward and altitudinal movements. One such climate-limited species is holly (*Ilex aquifolium*), which has expanded in southern Scandinavia in a manner consistent and synchronous with recorded regional climate changes, linked in particular with increasing winter temperatures (Walther *et al.*, 2005).

Mountain ecosystems are particularly vulnerable to climate change (IPCC, 2007). There has been a general increase in mountain summit species in Europe since the Little Ice Age in the 18th century. In Switzerland, for example, the uphill shift of Alpine plants showed an accelerating trend towards the end of the 20th century that is likely to be linked with the extraordinarily warm conditions of the 1990s (Walther *et al*., 2005) (Figure 5.31). Evidence also emerged of declines in cold-adapted species as warming conditions and pioneer species drove these from their characteristic niches. Similar observations are expected from current European monitoring programs (e.g. GLORIA) for which results will be available by the end of 2008. In the Swedish Scandes, the tree line of the Scots pine (*Pinus sylvestris*) rose by 150–200 metres as warmer winters significantly lowered mortality and increased rates of establishment. Observations from other continents show that uphill tree line migration is a global phenomenon that could become a major threat to biodiversity in high mountains (Kullman, 2006; 2007; Pauli *et al*., 2007).

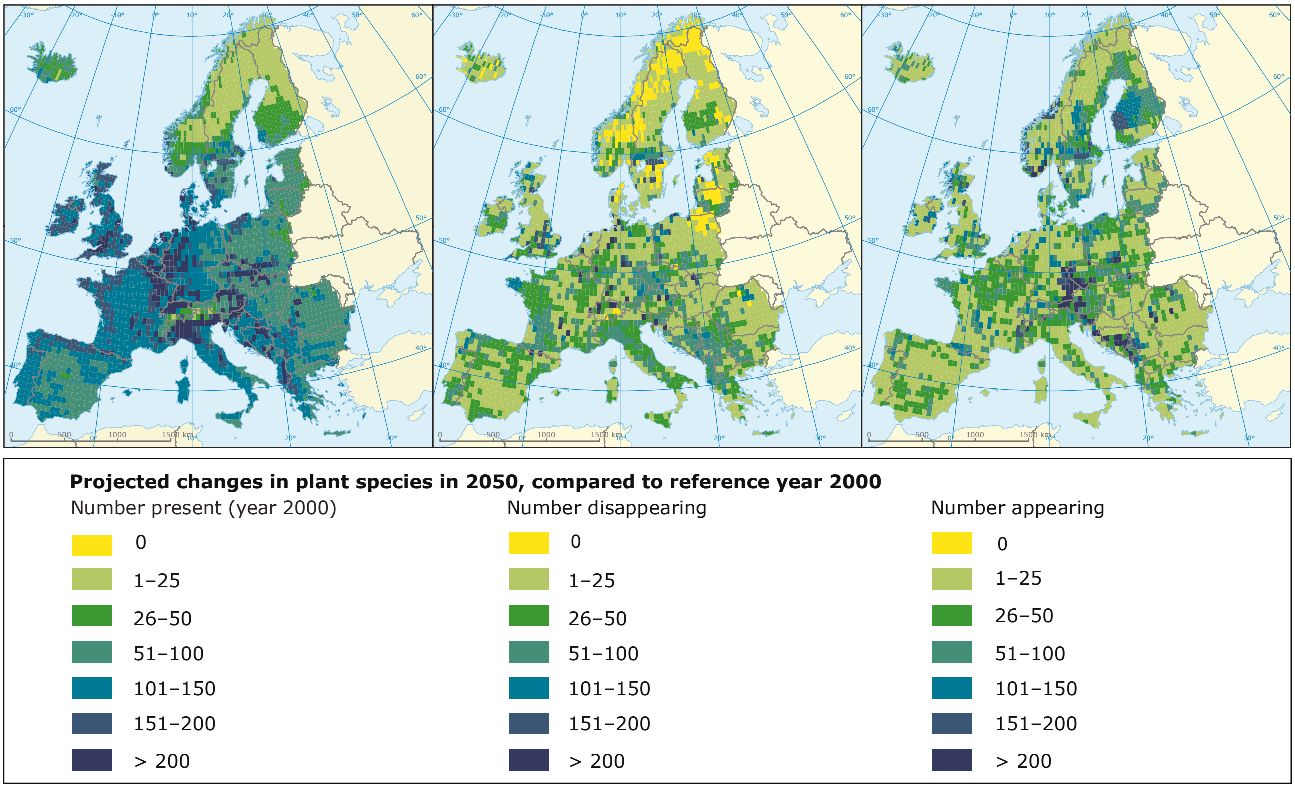
Projections

Projections indicate that, by the late 21st century, the potential range of many European plant species may shift several hundred kilometres in a northerly direction. This is several times faster than past rates as estimated from the Quaternary record or from historic data (Huntley, 2007). The distribution of tree species is also likely change significantly, with forests expanding in the north and contracting in the south, and broadleaved species replacing native coniferous species in western and central Europe (IPCC, 2007).

Modelling of late 21st century distributions of 1 350 European plant species under a range of scenarios led to the conclusion that more than half will be at the edge of their geographic and altitudinal ranges and could become threatened by 2080, with high risks of extinction (Thuiller *et al*., 2005). The greatest changes are projected for endemic plant species in Mediterranean, Euro-Siberian and many mountain regions. Mountain communities may face up to a 60 % loss of plant species under high emission scenarios, reversing the 20th century trend outlined above (Thuiller *et al*., 2005; IPCC, 2007).

Bakkenes *et al.* (2006) obtained similar results from modelling stable areas of plant species distribution for this century under different climate change scenarios (Map 5.30). This study suggests that 10–50 % of plant species in European countries are likely to disappear by 2100 from their current location in the absence of climate change mitigation. Again, species in southeast and southwest Europe are likely to be worst affected. This number will be higher if migration is restricted due to continuing fragmentation or if there is competition with invasive species.

Map 5.30 Projected changes in number of plant species in 2050



Note: Results for stable area per grid cell, using the EuroMove model with HadCM2 A2 climate scenario.

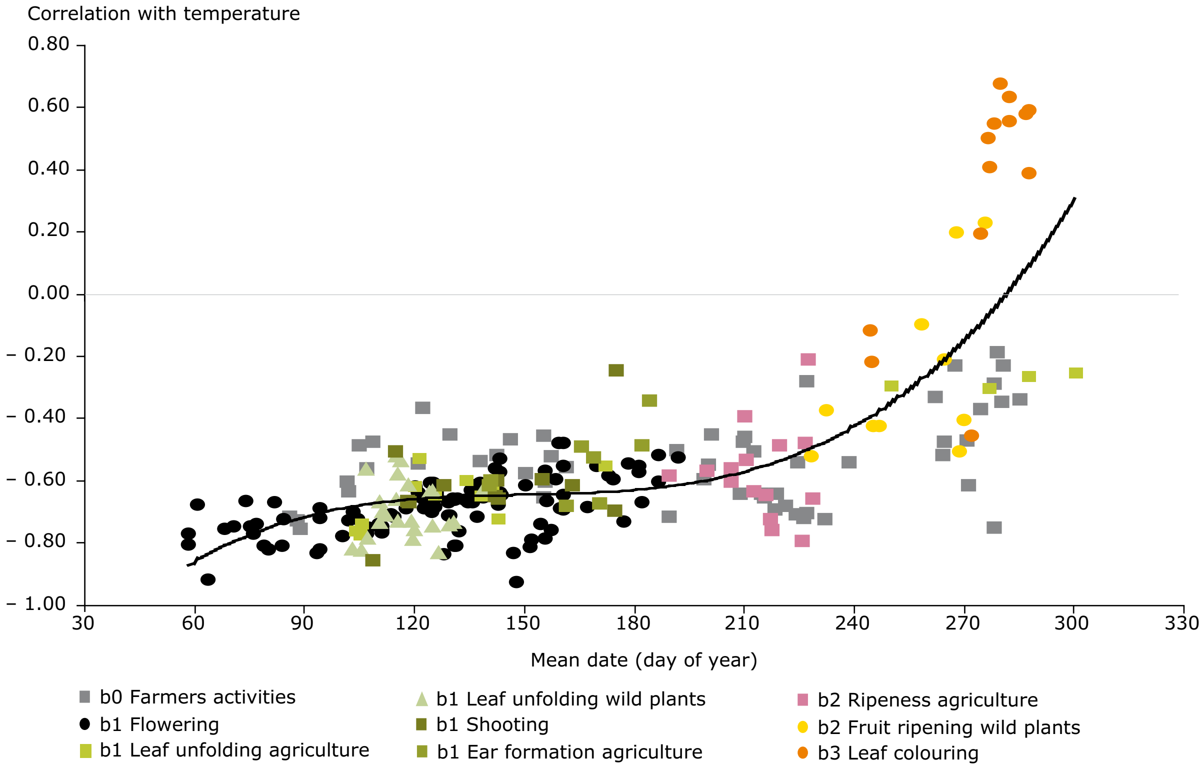
Source: Based on Bakkenes *et al*., 2006.

5.7.3 *Plant phenology*

Key messages

- The timing of seasonal events in plants is changing across Europe, due mainly to changes in climate conditions; 78 % of leaf unfolding and flowering records show advancing trends and only 3 % a significant delay. Between 1971 and 2000, the average advance of spring and summer was 2.5 days per decade.
- As a consequence of climate-induced changes in plant phenology, the pollen season starts on average 10 days earlier and is longer than 50 years ago.
- Trends in seasonal events will continue to advance as climate warming increases in the years and decades to come.

Figure 5.32 Phenological sensitivity to temperature changes



Note: In a study of 254 national records across nine countries, most phenological changes correlated significantly with mean monthly temperatures of the previous two months. The earlier a spring event occurred, the stronger the effect of temperature.

Countries included: Austria, Belarus/northern Russia, Estonia, Czech Republic, Germany, Poland, Slovenia, Switzerland, Ukraine/southern Russia. Phenophase groups included: (b0) Farmers activities, (b1) Spring and summer with different leafing, shooting and flowering phases, (b2) Autumn fruit ripening and (b3) Leaf colouring of deciduous trees in fall.

Source: Menzel *et al.*, 2006.

Relevance

Phenology is the study of changes in the timing of seasonal events such as budburst, flowering, dormancy, migration and hibernation. Some phenological responses are triggered principally by temperature, while others are more responsive to day length (Menzel *et al.*, 2006). Changes in phenology are linked with the growing season and affect ecosystem functioning and productivity.

Farming, forestry and gardening, as well as wildlife, are affected. The timing of tilling, sowing and harvesting is changing, fruit is ripening earlier due to warmer summers (Menzel *et al.*, 2006), and grass in municipal parks and on road verges requires cutting more frequently and for longer.

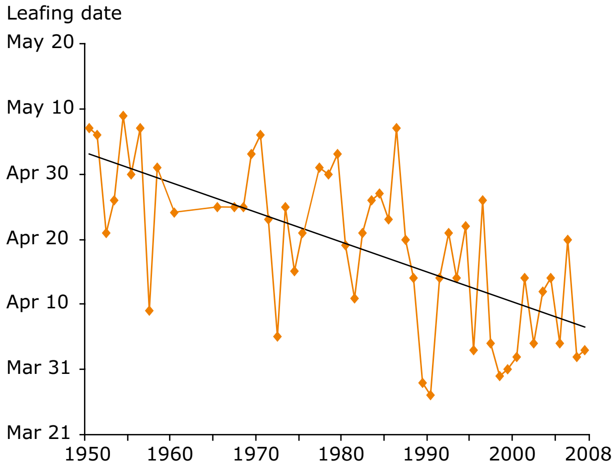
Changes in flowering have implications for the timing and intensity of the pollen season; this is showing an advancing trend as many species start to flower earlier. Allied to this, the concentration of pollen in the air is increasing (Nordic Council, 2005).

Past trends

There is clear evidence of changing phenology across Europe in recent decades (Parmesan and Yohe, 2003; Root *et al.*, 2003; Menzel *et al.*, 2006) (Figure 5.32). Overall, 62 % of the observed variability in the timing of life cycle events can be explained by climate (van Vliet, 2008). However, variability differs between events, with those occurring earlier (i.e. spring) being more variable than later events (Menzel *et al.*, 2006). For example:

- 78 % of all leaf unfolding, flowering and fruiting records across Europe show an advancing trend and only 3 % a significant delay. The average advance of spring/summer phenological events is occurring at a rate of 2.5 days per decade (Menzel *et al.*, 2006).

Figure 5.33 Oak (*Quercus sp*) leafing date in Surrey (United Kingdom) 1950–2008



Note: Annual observations (connected by straight lines); black line: average change in leafing date (showing advancement).

Source: Nature's Calendar, the United Kingdom.

Photo: © European Environment Agency

- The pollen season currently starts on average 10 days earlier and is of longer duration than 50 years ago.
- In Britain, the first flowering date for 385 plant species has advanced by 4.5 days on average during the past decade in comparison with the previous four decades (Fitter and Fitter, 2002); oak leafing has advanced three weeks in the last 50 years (DEFRA, 2007) (Figure 5.33).
- In the Arctic, rapid climate-induced advancement of spring phenomena (e.g. flowering, egg laying) has been observed during the last 10 years. The strong responses of Arctic ecosystems and large variability within species illustrate how easily biological interactions can be disrupted by climate change (Høye *et al.*, 2007).

Projections

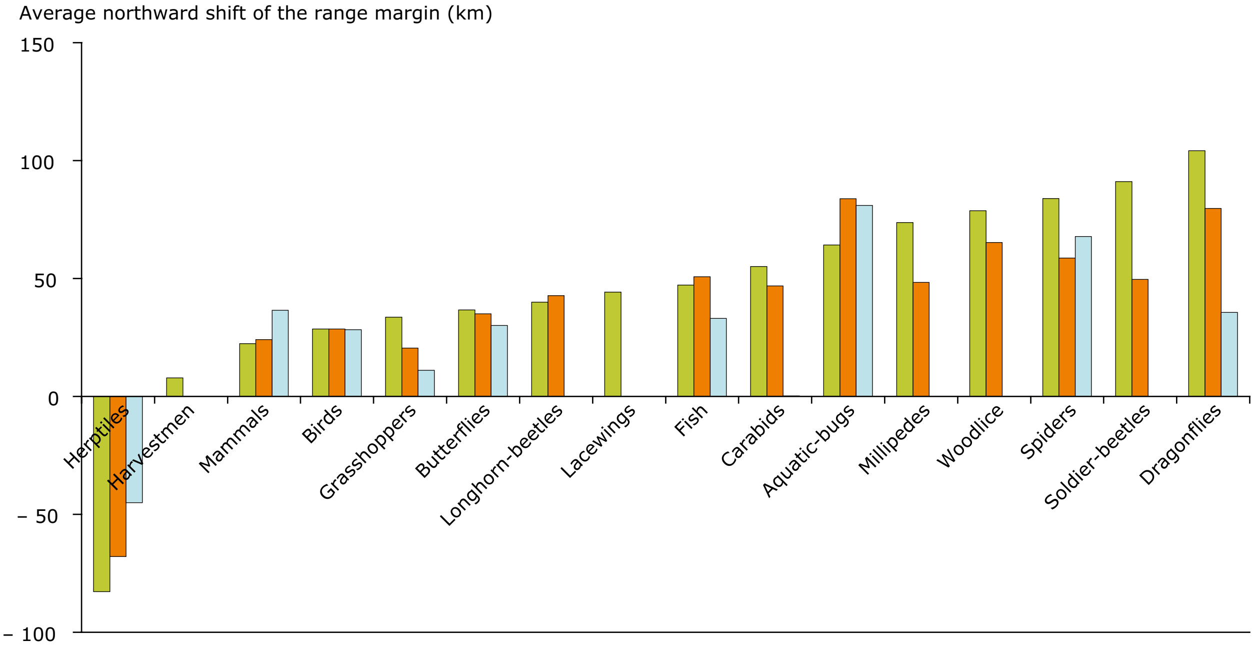
Phenological changes will alter growing seasons, ecosystem production, population-level interactions and community dynamics (Fitter and Fitter, 2002). Different species show different phenological responses; for example, annuals and insect-pollinated species are more likely to flower early than perennials and wind-pollinated species (Fitter and Fitter, 2002). Ecological research is evaluating these response thresholds to better understand what the wider effects might be. While advancing trends in seasonal events will continue as climate warming increases in the years and decades to come, it is uncertain how different species will respond when temperature thresholds are reached and whether linear relationships between temperature and growing season will be realised in the future.

5.7.4 *Distribution of animal species*

Key messages

- Europe's birds, insects, mammals and other groups are moving northwards and uphill, largely in response to observed climate change. But rates of distribution change are not necessarily keeping pace with changing climate.
- A combination of the rate of climate change, habitat fragmentation and other obstacles will impede the movement of many animal species, possibly leading to a progressive decline in European biodiversity.
- Distribution changes are projected to continue. Suitable climatic conditions for Europe's breeding birds are projected to shift nearly 550 km northeast by the end of the century, with the average range size shrinking by 20 %. Projections for 120 native European mammals suggest that up to 9 % (assuming no migration) risk extinction during the 21st century.

Figure 5.34 Latitudinal shifts in northern range margins in the United Kingdom for selected groups of animal species over the past 40 years



Note: Results for 16 taxonomic groups of animal species are given for three levels of data sub-sampling (recorded, green; well-recorded, orange; heavily recorded, blue). Only species occupying more than twenty 10 km grid squares were included in the analysis.

Source: Hickling *et al.*, 2006.

Relevance

The northward shift in distribution of animal species has a range of potential consequences for agriculture (livestock and crops), human health, as well as for biodiversity and its conservation (Sparks *et al.*, 2007). The distribution of many animal species will be particularly affected by climate change if landscape fragmentation impedes their movement to more suitable climatic conditions. This will also affect the ability of Europe to meet its biodiversity target (above). In addition, warmer conditions, particularly warmers winters, are allowing the establishment of new pest species such as the European corn borer (*Ostrinia nubilalis*), American bollworm (*Heliothis armigera*), gypsy moth (*Lymantria dispar*) and some

Sooty copper (*Heodes tityrus*)

Photo: © Guy Padfield, http://www.guypadfield.com

migratory moths and butterflies (see Section 5.7.5). Health risks associated with vector-borne diseases are linked to invasions of species such as ticks and mosquitoes (see Section 5.10).

Past trends

The northward and uphill movement of a wide variety of animal species has been observed over recent decades across Europe. These observations are partly attributable to observed changes in climatic conditions, whilst others are triggered more by land-use and other environmental changes.

In Britain, 275 of 329 animal species analysed over the last 25 years shifted their ranges northwards by 31–60 km, 52 shifted southwards, and two did not move (UKCIP, 2005; Hickling *et al.*, 2006) (Figure 5.34). However, many species, including butterflies, are failing to move as quickly as might be expected under the current rate of climate change (Warren *et al.*, 2001).

Climate change has also already influenced the species richness and composition of European bird communities (Lemoine *et al.*, 2007; Gregory *et al.*, 2008). A recent study of 122 terrestrial bird species indicated that, from around 1985, climate change has influenced population trends across Europe, with impacts becoming stronger over time (Figure 5.35). The study shows that 92 species have declined their populations because of climate change, whereas 30 species have generally increased (Gregory *et al.*, 2008).

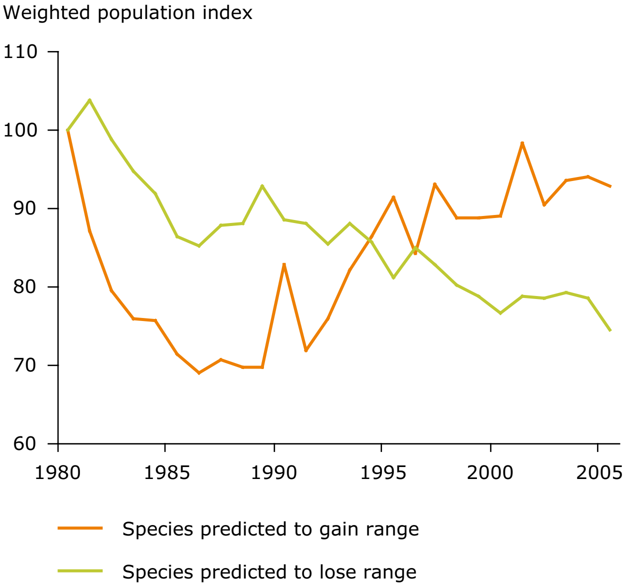
In a study of 57 non-migratory European butterflies, 36 had shifted their ranges to the north by 35–240 km and only two had shifted to the south (Parmesan *et al.*, 1999). The sooty copper (*Heodes tityrus*), for example, spread north from Catalonia and by 2006 had established breeding populations on the Baltic coast (Parmesan *et al.*, 1999). In Spain, the habitat of 16 mountain-restricted butterflies reduced by about one third over the last 30 years; lower altitudinal limits rose on average by 212 m — in line with a 1.3 °C rise in mean annual temperature (Wilson *et al.*, 2005).

In Germany, the once rare scarlet darter dragonfly (*Crocothemis erythraea*) has spread from the south, paralleling observed changes in climate, and is now found in every federal state (Ott, 2007). Similarly, the spread of the comma butterfly in the Netherlands has been linked to recent climate change patterns.

Projections

Projections suggest that the northward and uphill movement of many animal species will continue this century. Widespread species may be less vulnerable, while threatened endemics — already

Figure 5.35 Impact of climate change on populations of European birds, 1980–2005



Note: Weighted composite population trends under climate change were modelled as an index for two groups of widespread European land birds for 1980 to 2005, using climate envelope models. The index is set to 100 in 1980. The orange line shows the modelled weighted composite trend of 30 bird species. It shows an increase of their geographical range in the study region. The green line shows the modelled trend of 92 species that have lost range. Range changes were modelled by averaging using three global climate models and two emissions scenarios.

Source: Gregory *et al.*, 2008.

under pressure — will be at greatest risk, although there will be spatial variation (Levinsky *et al.*, 2007; Lemoine *et al.*, 2007). An important constraint will be the ability of species to move. This ability represents a significant research challenge, especially in the context of the effectiveness of ecological networks under a fast-changing climate.

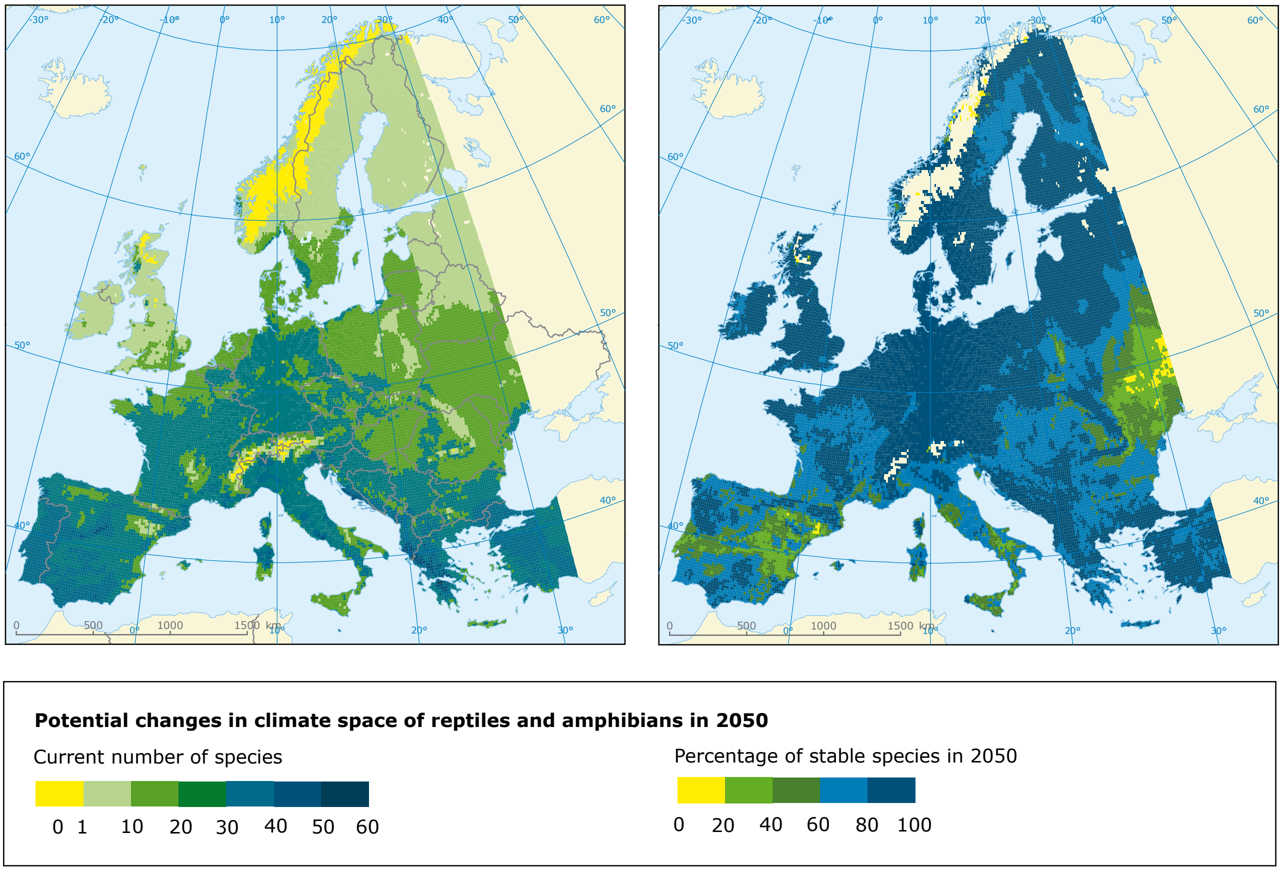
The limited dispersal ability of many reptile and amphibians, coupled with the fragmentation of ecological networks, is very likely to reduce the ranges of many species (Hickling *et al.*, 2006; Araújo *et al.*, 2006), particularly those in the Iberian Peninsula and parts of Italy (Map 5.31).

A study of 120 native terrestrial mammals projected that species richness is likely to reduce dramatically this century in the Mediterranean region, but increase towards the northeast and in mountainous areas such as the Alps and Pyrenees, assuming that movement through fragmented landscapes is possible.

Under a 3 °C climate warming scenario (above pre-industrial levels), the ranges of European breeding birds are projected to shift by the end of the 21st century by about 550 km to the northeast, with average range size being 20 % smaller. Arctic, sub-Arctic, and some Iberian species are projected to suffer the greatest range losses (Huntley *et al.*, 2008).

In polar regions, projected reductions in sea ice will drastically reduce habitat for polar bears, seals and other ice-dependent species (IPCC, 2007). In addition to climate change, these top predators will also be affected by declining fish stocks.

Map 5.31 **Projected impact of climate change on the potential distribution of reptiles and amphibians in 2050**



Note: Projected data based on the Generalised Linear Model map using the HadCM3 A2 scenario for the 2050s are compared with the current situation.

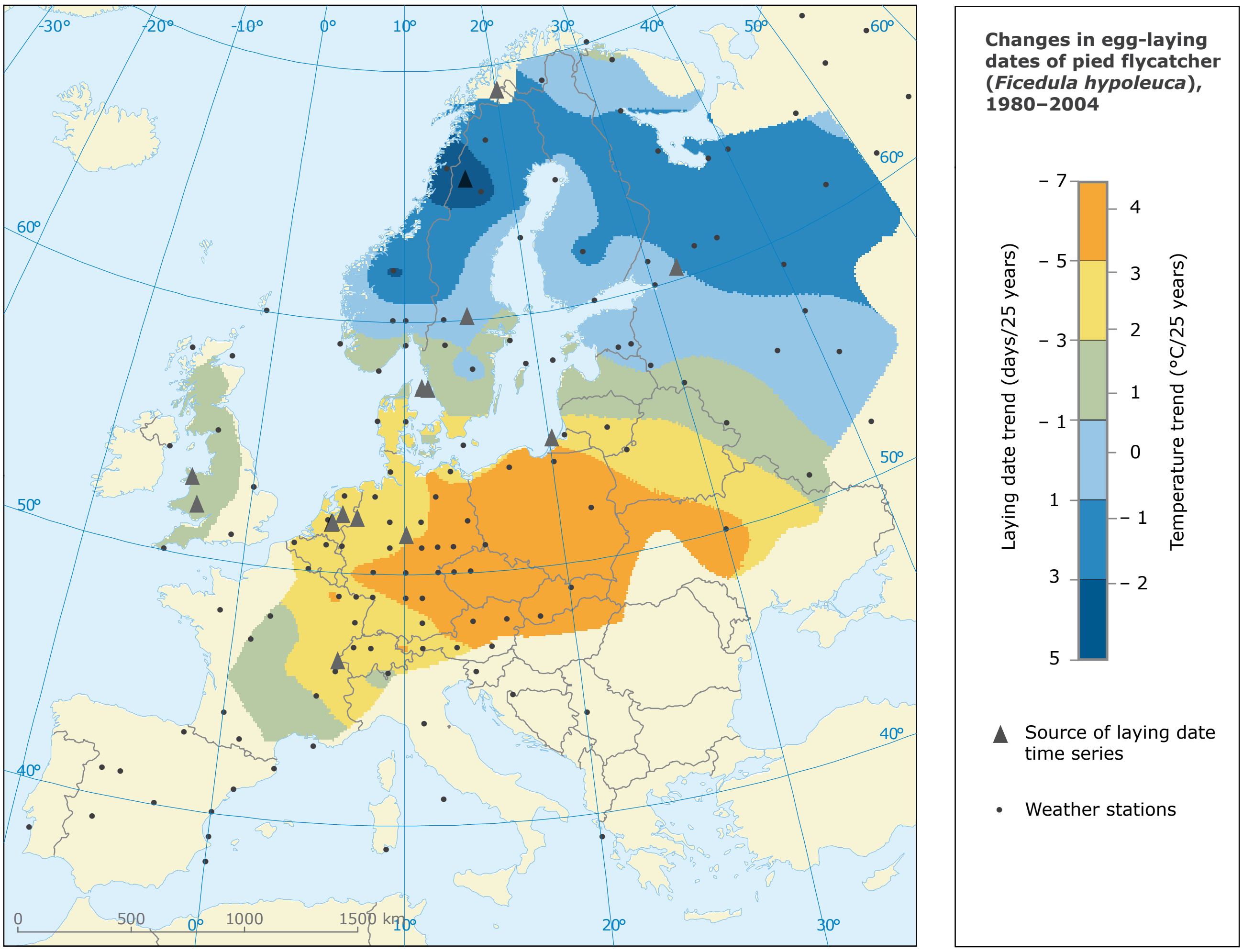
Source: Bakkenes, 2007, based on Araújo *et al.*, 2006.

5.7.5 *Animal phenology*

Key messages

- 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.
- These trends are projected to continue as climate warming increases in the decades to come. Populations may explode if the young are not exposed to normal predation pressures. Conversely, populations may crash if the emergence of vulnerable young is not in synchrony with their main food source or if shorter hibernation times lead to declines in body condition.

Map 5.32 **Changes in egg-laying dates (1980–2004) of the pied flycatcher (*Ficedula hypoleuca*)**



Note: Dots: weather stations used to calculate changes in local egg-laying dates (derived from temperature data); triangles: location of pied flycatcher laying date time series.

Source: Both and Marvelde, 2007.

Relevance

Climate warming affects the life cycles of many animal species, particularly those such as butterflies, dragonflies and damselflies that are sensitive to temperature. Milder springs are allowing earlier onset of breeding and extra generations to emerge during the year. Furthermore, populations may explode if the young are not exposed to normal predation pressures. Conversely, populations may crash if the emergence of vulnerable young is not in synchrony with their food source or if shorter hibernation times lead to declines in body condition — as evidenced in the lower survival rates of some amphibians (Reading, 2007).

Insect pests are likely to become more abundant as temperatures increase (Cannon, 1998). As the impacts of climate change on ecosystems favour generalists, and as warmer temperatures increase insect survival and reproduction rates, more frequent, severe and unpredictable pest outbreaks may occur (McKinney and Lockwood, 1999). In temperate regions, milder winters are allowing increased rates of winter survival (Bale *et al.*, 2002) and it has been estimated that, with a 2 °C temperature increase, some insects could undergo up to five additional life cycles per season (Yamamura and Kiritani, 1998).

Past trends

As spring temperatures increased in Europe over the past 30 years, many organisms responded by advancing the timing of their growth and reproduction.

A study in Britain (Crick and Sparks, 1999) analysed 74 258 records for 65 bird species from 1971 to 1995. The study showed significant trends towards earlier (8.8 days on average) laying dates for 20 species (31 %), with only one species laying significantly later. The effects, however, are not necessarily uniform. The predicted egg-laying date for the pied flycatcher (*Ficedula hypoleuca*), for example, shows significant advancement during the period 1980 to 2004 in western and central Europe, but delays in northern Europe (Map 5.32); both are strongly driven by temperature trends (Both and Marvelde, 2007).

Strong and rapid phenological changes have been observed in the high latitudes in response to warming of the region occurring at twice the global average rate (Høye *et al.*, 2007). The date of snowmelt in northeast Greenland has advanced by an average of 14.6 days since the mid 1990s, resulting in earlier egg-laying dates for birds in the region.

Projections

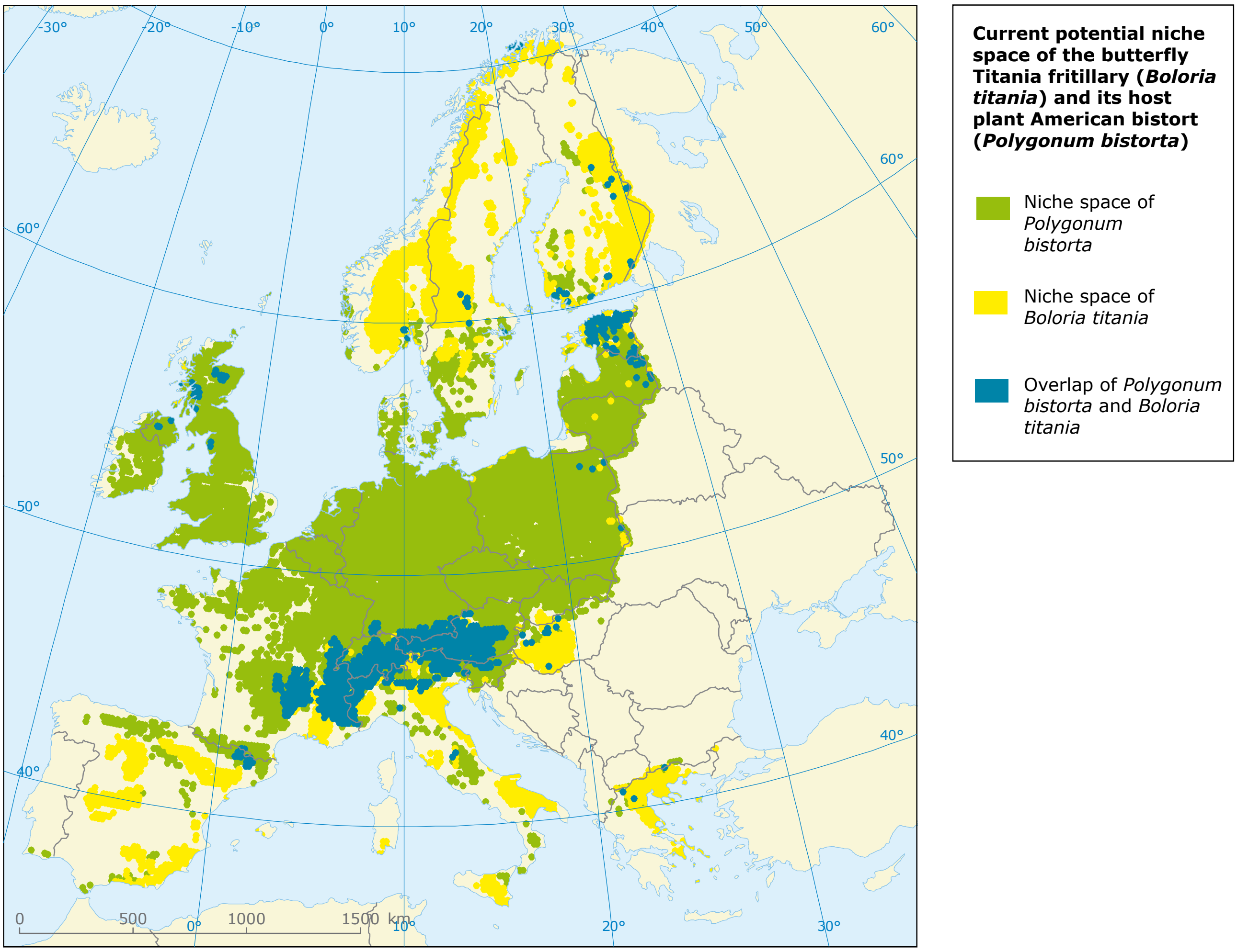
The future impacts of climate change on animal phenology are poorly understood, but could include increasing trophic mismatch and disturbance to ecosystem functioning. The trend towards warmer springs may continue to induce earlier breeding and migration activity. Unpredictable cold snaps are likely to cause high mortality amongst early movers. Meanwhile, species whose life cycles are calibrated according to day length, and which do not respond so readily to changing temperatures, will not be able to exploit earlier spring resources unless they can adapt.

5.7.6 Species-ecosystem relationships

Key messages

- The stability of ecosystems and, therefore, the services that they provide, will become increasingly affected by climate change due to species-specific responses and, thus, the disruption of established biotic interactions.
- The changing range of host species has major implications for range expansions of species and places additional pressures on those of conservation importance.

Map 5.33 **Current potential niche space of the butterfly Titania fritillary (*Boloria titania*) and its host plant American bistort (*Polygonum bistorta*)**



Source: Schweiger *et al.*, in press.

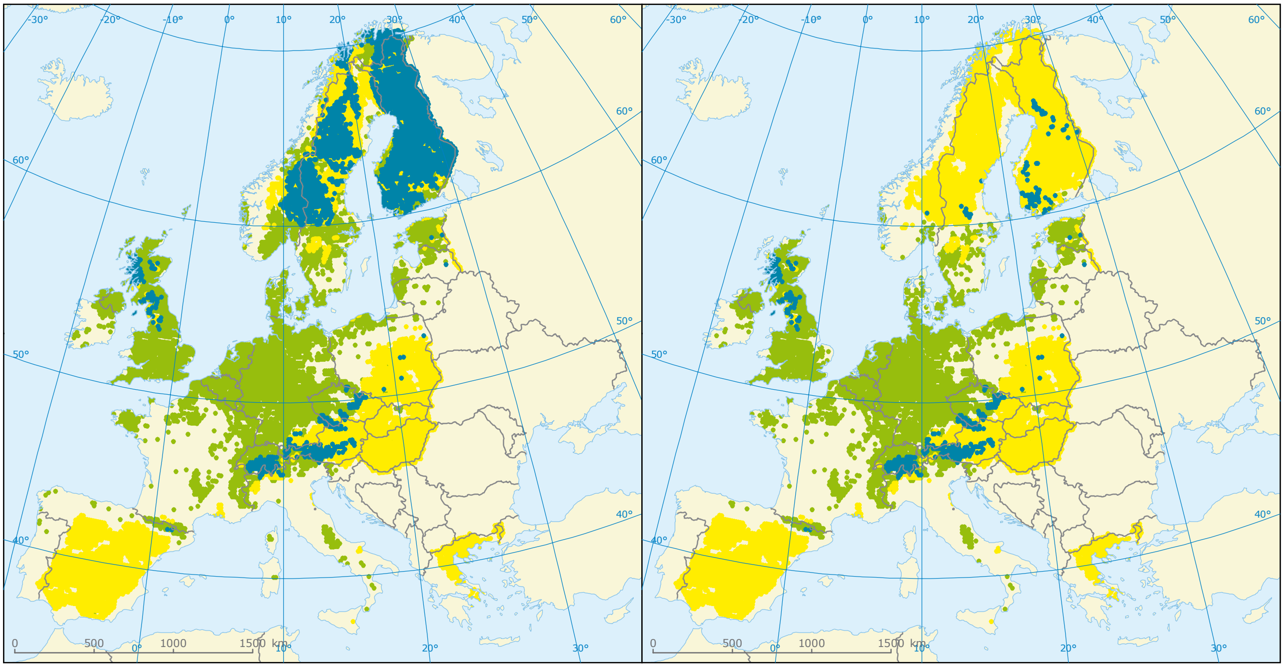
Relevance

Suitable climate is an important factor in determining the distribution of species and the composition and stability of ecosystems. For many animal species, a major constraint on successful colonization of new areas is the absence of ecologically-linked host plants (Schweiger *et al.*, in press). Advancements in spring activity may result in asynchrony between food sources and breeding, causing starvation of young that emerge too early, and the disruption of predator-prey relationships.

Map 5.34 Relationship between projected distribution space of the butterfly Titania fritillary (*Boloria titania*) and its host plant American bistort (*Polygonum bistorta*) for 2080

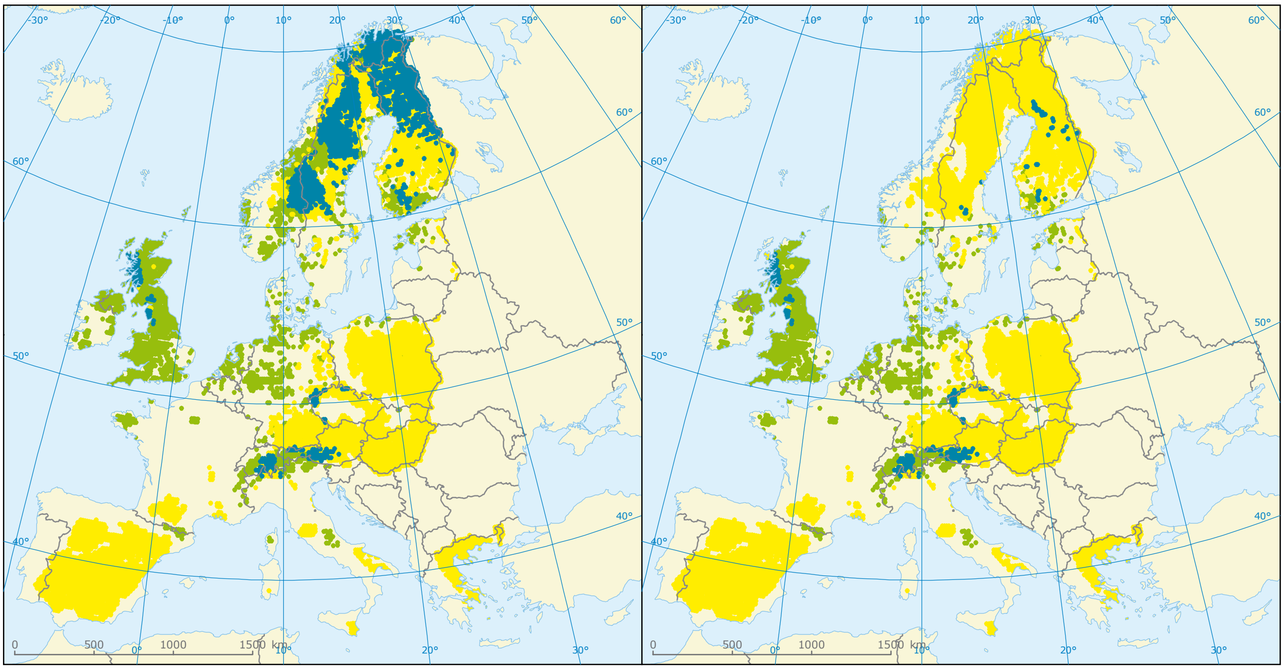
a) Moderate change

b) Moderate change



c) High change

d) High change



Relationship between projected distribution space of the butterfly Titania fritillary (*Boloria titania*) and its host plant American bistort (*Polygonum bistorta*) for moderate (a, b) and high (c, d) climate change scenarios for 2080 under the assumption of unlimited (a, c) and no (b, d) dispersal of its host plant

- 🟩 Niche space of *Polygonum bistorta*
- 🟨 Niche space of *Boloria titania*
- 🟦 Overlap of *Polygonum bistorta* and *Boloria titania*, which is the butterfly's potential future niche space

Note: Global change scenarios based on storylines developed within the EU-funded project ALARM (Settele *et al.*, 2005, Spangenberg 2007, www.alarmproject.net).

Source: Schweiger *et al.*, in press.

This so-called trophic mismatch has been demonstrated for various animal groups, including birds (Both *et al.*, 2006), and in some cases is causing crashes or explosions in populations. Additionally, extreme events such as floods, drought and fire can disrupt ecosystems, preventing growth of key plant species and limiting nesting, breeding and feeding opportunities for animals.

Past trends

Many butterfly species are moving northward (see Section 5.7.4), but often with overall declines in abundance and range size (Warren *et al.*, 2001). Biotic interactions are important factors in explaining the distributions of butterflies, because they are often host-specific. For example, many parts of Europe are climatically suitable for the butterfly Titania fritillary (*Boloria titania*) (Map 5.33) and the species may even be able to migrate quickly in response to climate change. However, an important constraint to range expansion is the presence of its host plant American bistort (*Polygonum bistorta*) (Schweiger *et al.*, in press). Likewise, the current distribution of the clouded Apollo (*Parnassius mnemosyne*) is explained not only by climate suitability, but also by the presence of its Corydalis host plant (Araújo and Luoto, 2007).

Climate change has also had a disruptive effect on Scottish seabird communities and their food webs. During 2004 and 2005, major population crashes have been observed. In Shetland, over 1 000 guillemot nests and 24 000 nests of the Arctic tern were almost entirely deserted, and on the nearby island of Foula, the world's largest colony of great skuas saw only a few living chicks. The cause was a drastic reduction in the populations of sandeel, their principal food source. The disappearance of the sandeel was due, in turn, to the northward movement of cold-water plankton on which these fish feed (see Section 5.4). The plankton's range had shifted because the waters between Britain and Scandinavia had become too warm for it to survive there. Since 1984, some seabird species around Scotland have decreased by 60–70 % (CEH, 2005).

Projections

The response to climate change of the butterfly Titania fritillary (*Boloria titania*) and its host plant American bistort (*Polygonum bistorta*) is likely to lead to a reduction in range overlap and, thus, an uncertain future for this specialist butterfly. Played out on a larger scale, these trophic mismatches benefit generalists at the expense of specialists, putting additional pressures on the capacity of ecosystems to provide certain services and on species of conservation importance (McKinney and Lockwood, 1999; Reid *et al.*, 2005; Biesmeijer *et al.*, 2006).

5.8 Soil

5.8.1 *Introduction*

Climate is an important factor in soil development and a major driver of the processes of soil formation. At the same time, changes in the bio-physical nature of soil, due to rising temperatures, changing precipitation intensity and frequency and more severe droughts, are likely to release substantial amounts of greenhouse gases. However quantitative information, from observations and modelling of the impacts of climate change on soil and the various related feedbacks, is very limited. To date, assessments have relied mainly on local case studies that have analysed how soil reacts under changing climate in combination with evolving agricultural and forest practices. Indicators with full European coverage, to help policymakers identify appropriate adaptation measures, are absent, as can be seen from the limited number of indicators in this chapter. There is an urgent need to address this unsatisfactory situation through the establishment of appropriate monitoring schemes.

Soil has many biological, chemical and physical characteristics with a marked spatial and temporal variability. Changing climate will affect these characteristics and may also have serious consequences for the well-being of people, who are dependent on the broad range of environmental goods and services regulated by soil. Soil is one of the key life-support systems on the planet, responsible for major ecological and other functions such as:

- supply of water and nutrients for plant growth and food production (ecosystems, agriculture and forestry);
- regulation of the water cycle;
- nutrient cycles, storage of carbon and regulation of greenhouses gases;
- trapping of contaminants (buffering capacity);
- source of raw material (e.g. clay minerals);
- preservation of cultural heritage;
- habitats for animal and plant species, maintaining their biological and genetic diversity;
- support to human settlements, providing a basis for buildings and infrastructures, disposal of waste material, slope stability.

The EU's Thematic Strategy for Soil Protection (EC, 2006) has stated that several soil functions are under serious pressure in many parts of Europe. The understanding of soil as an important contributor to water systems, the global carbon cycle and other systems is still evolving and needs to be developed further; so far soil has been perceived mainly in the context of arable land and fertility for crop production. The perception of soil as an environmental medium providing substantial goods and services for all land and aquatic ecosystems has developed over recent decades but still with a focus on economic aspects and valuing different types of land use.

Significant projected changes in precipitation patterns will affect soil formation and functions. Soil as part of the soil-water-plant system contributes and influences changes in groundwater recharge, water quality through buffering capacity, plant growth and evapotranspiration through water available to roots, and run-off through retention capacity. This is vital for land and water management. Better and more quantitative understanding of this system is needed to improve forecasts and possible response actions. Indicators with sufficient resolution in time and space are needed to link observations and new models which include climate change.

Based on the current limited amount of observations and some modelling, the following issues are highlighted in this chapter. Soil organic matter drives the majority of soil functions; any reduction can lead to a decrease in fertility and biodiversity (see Box 5.10), a loss of soil structure, reduced water retention capacity and increased risk of erosion and compaction. Changes in rainfall and wind patterns will lead to an increase in erosion in vulnerable soils which often suffer from low organic matter content. Climate change will further increase the risk of desertification, which is already affecting southern Europe and is expected to move gradually northward (see Box 5.11). Desertification (4) is an advanced stage of land degradation where the soil has lost part of its capability to support human communities and ecosystems. By absorbing water, soil organic matter can contribute to the mitigation of flooding following extreme rainfall events, while storing water in the event of more frequent and severe droughts (see

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(4) Desertification is defined by the United Nation Convention to Combat Desertification (UNCCD) as 'land degradation in arid, semiarid and sub-humid areas resulting from various factors, including climatic variations and human activities' (UNCCD, 1997).

Section 5.5). However evaluation of the impact of climate change remains difficult. Changes to features such as texture and mineralogical composition will only occur over long 'geological' time spans, while properties such as pH, organic matter content or microbial activity will show a more rapid response. In addition, the response of a particular soil type may be both positive and negative, depending on its function. Rising temperatures and precipitation may support increased agricultural productivity (see Section 5.9) but may also increase the risk of erosion.

Soil can also act as a carbon sink, absorbing carbon dioxide from the atmosphere and thus mitigating global warming. In areas with low temperatures and sufficient moisture, the decomposition of dead biomass (leaves, stems, roots of plants) is reduced, leading to accumulations of soil organic matter. Increasing temperatures will accelerate decay rates, leading to increased carbon dioxide and methane emissions from soil. Appropriate wetland management and land-use practices should thus be enhanced to maintain or enhance soil carbon stocks.

Box 5.10 The impacts of climate change on soil biodiversity

Key messages

- Soil organisms control numerous ecosystem processes, supplying the environment and society with a number of important economic and ecosystem goods and services.
- Climate change alters the habitat of soil biota, which affects the diversity and structure of species and their abundance. Ecosystem functioning, including nutrient supply, carbon and nitrogen cycles, is modified consequently. However, quantified knowledge of these impacts is limited.

Soil biodiversity controls several processes such as organic matter and nutrient cycling, degradation of organic pollutants, nitrogen biotic fixation, plant-microbe symbiotic nutrient uptake, plant growth promotion and plant protection, maintenance of soil physical structure and pollination. Perhaps the most important potential impacts of climate change on soil relate to below-surface biodiversity, which ranges from bacteria, fungi, microbes, microscopic invertebrates to larger invertebrates such as ants, earthworms and termites. Because the majority of soil and sediment biodiversity is hidden beneath the surface, this species richness remains mostly unknown, poorly mapped, and rarely considered in models of climate change or adaptation plans (Behan-Pelletier and Newton, 1999; Paustian *et al.*, 2000; Wolters *et al.*, 2000). Yet, the biological diversity of soils is estimated to be greater than that in above-ground systems (Wall and Virginia, 2000). This vast biodiversity is critical to the well-being of all life, both below and above the surface: it provides ecosystem services such as filtering of air and water, control of erosion, regulation of the global cycles of nutrients, carbon, nitrogen, and phosphorus (Brussard *et al.*, 1997), waste recycling through decomposition, bio-control of plant and human pests, and soil fertility.

The SCOPE Committee on Soil and Sediment Biodiversity and Ecosystem Functioning recently synthesized knowledge on below-ground species diversity and ecosystem functioning in a series of international workshops (Behan-Pelletier and Newton, 1999; Brussaard *et al.*, 1997, 2007; Hooper *et al.*, 2000; Wolters *et al.*, 2000). Most of the stages involved in soil ecosystem processes are performed by groups of species from many phyla, resulting in high species redundancy (different species performing same ecosystem process). Some critical processes are performed by a few 'keystone' taxa (e.g. mostly larger invertebrates such as termites, earthworms, enchytraeids).

Soils contain a large amount of carbon, and CO_2 release to the atmosphere depends to a large degree on the activities of soil biota. Soil biota regulate the decay process or decomposition, which directly affects carbon level in soils. Climate-induced loss of key invertebrates in a variety of low-diversity ecosystems that are widespread throughout the world can contribute to significant changes in carbon cycle and hence carbon pools and fluxes through the modification of ecosystem functioning (Ayres *et al.*, 2008; Barrett *et al.*, 2008; Poage *et al.*, 2008).

Our understanding of the soil species involved in decomposition and whether individual soil species have an effect on ecosystem processes is limited. For example, the relationship between the number of species of any soil group and an ecosystem process, such as the rate of decomposition, has not been established in field studies. Thus when soils are degraded, knowledge of the effects on their biological diversity and ecosystem services is largely missing.

Climate change can affect soil biodiversity directly, by altering the soil temperature and moisture, and indirectly, altering vegetation communities and productivity, and the rate of organic matter decomposition. Not all soil biota, however, will be affected by climate change to the same extent; according to Wall and collaborators (2001), termites and enchytraeids will be the most affected. Effects of warming may be larger in ecosystems that are currently limited by temperature, such as the arctic tundra and semi-polar deserts (Swift *et al.*, 1998; Convey *et al.*, 2002), and mountain areas. In research carried out in the Swedish Lapland using the environmental manipulation approach, it has been demonstrated that a temperature rise results in an increase in bacteria, fungi and nematode density, but a reduction of biodiversity (Ruess *et al.*, 1999).

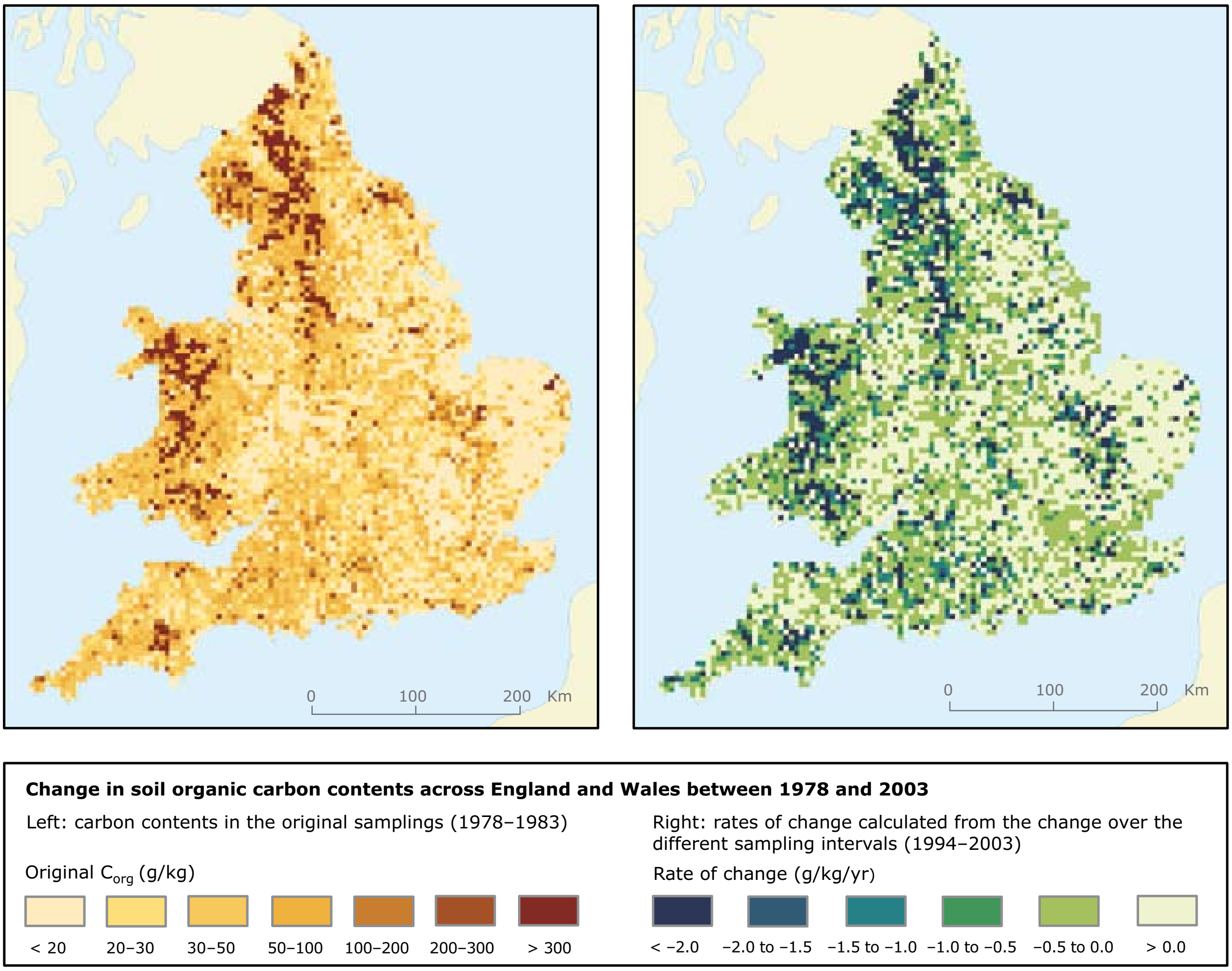
The interrelation between soil fauna and vegetation, for example forests, is critical (Binkley and Cristian, 1998; Gonzalez and Seastedt, 2001; Hooper *et al.*, 2000). The Global Litter Invertebrate Decomposition Experiment (http://www.nrel.colostate.edu/projects/glide/) shows that the soil litter and organisms found under different tree species are highly specific. The loss of tree species due to climate change might cause the loss of the associated soil biodiversity. These ecosystem transformations can affect the capacity of the soil to store carbon. Once soil biodiversity and the species and services it provides are lost or damaged, remediation and restoration takes an extremely long time and in some instances the loss of some species is irreversible.

5.8.2 *Soil organic carbon*

Key messages

- Soil in the EU contains around 71 gigatonnes of organic carbon, nearly 10 % of the carbon accumulated in the atmosphere. An increase in temperature and a reduction in moisture tend to accelerate the decomposition of organic material, leading to a decline in soil organic carbon stocks in Europe and an increase in CO_2 emissions to the atmosphere. This could wipe out all the savings that other sectors of the economy are achieving to reduce anthropogenic greenhouse gas emissions.
- Losses of soil organic carbon have already been observed in measurements in various European regions over the past 25 years.
- The projected changes in the climate during the 21st century will change the contribution of soil to the CO_2 cycle in most areas of the EU. Adapted land-use and management practices could be implemented to counterbalance the climate-induced decline of carbon levels in soil.

Map 5.35 Changes in soil organic carbon content across England and Wales between 1978 and 2003



Source: Bellamy *et al.*, 2005.

Relevance

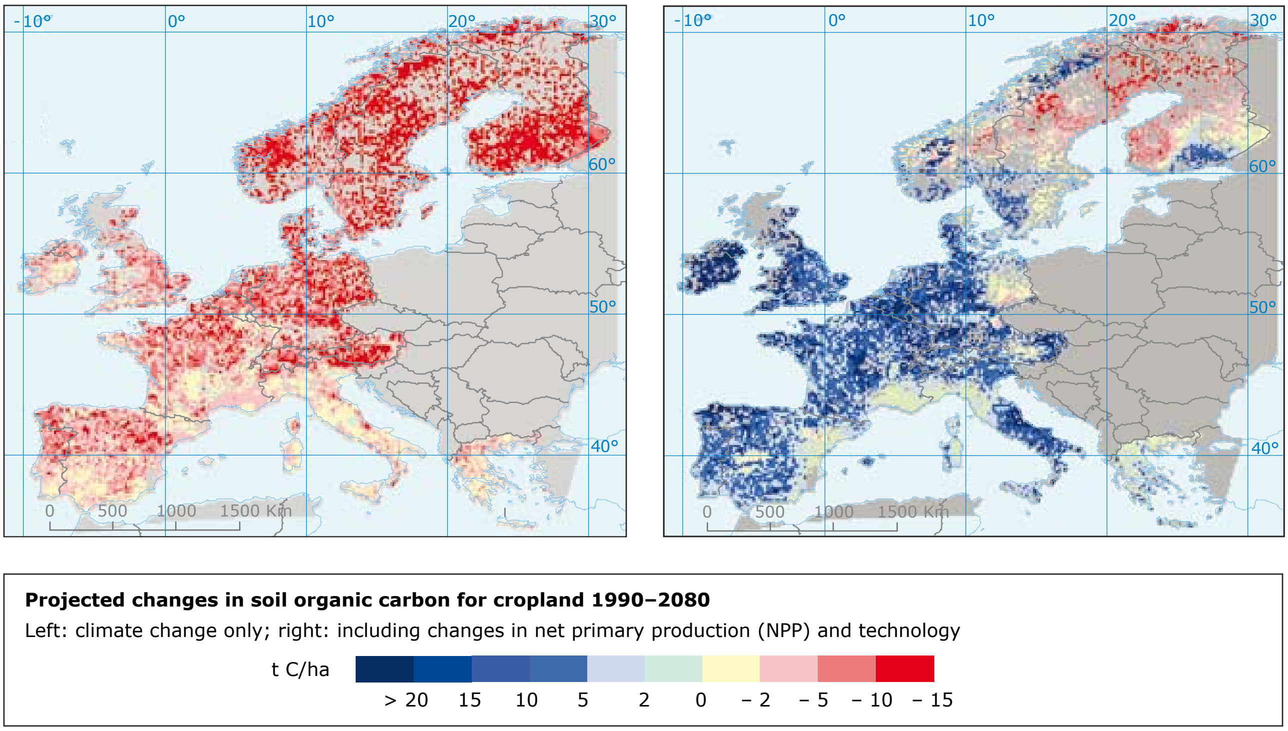
Organic carbon in the soil is a dynamic part of the carbon cycle, which includes the atmosphere, water and constituents of the above- and below-ground biosphere. The main source of organic carbon is organisms that synthesise their food from inorganic substances (autotrophic), such as photosynthesising plants. In this process atmospheric carbon is used to build organic materials and enters the soil layers through decomposition and the formation of humus.

Climatic conditions strongly influence both the trends and rates of accumulation and transformation of organic substances in the soil. Increases in temperature and aridity (see Box 5.11) lead to a decrease in the amount of organic carbon in soils in affected areas. Lower levels of organic carbon in the soil are generally detrimental to soil fertility and water retention capacity and tend to increase soil compaction, which leads to increases in surface water run-off and erosion. Other effects of lower organic carbon levels are a depletion of biodiversity and an increased susceptibility to acid or alkaline conditions. The projected changes will accelerate the release of CO_2 from the soil, contributing to higher concentrations in the atmosphere (Janssens, 2004; Bellamy, 2005). The main measures to reduce the detrimental effect of higher temperatures combined with lower soil moisture on the amount of soil organic carbon are changes in land cover and adaptation of land-management practices (Liski *et al.*, 2002; Janssens *et al.*, 2004; Smith *et al.*, 2005, 2006). Under given climatic conditions, grassland and forests tend to have higher stocks of organic carbon than arable land and are seen as net sinks for carbon (Vleeshouwers and Verhagen, 2002). Land-management practices aim at increasing net primary production and reducing losses of above-ground biomass from decomposition. Adaptive measures on agricultural land are changes in farming practices, such as a reduction in tilling or retaining crop residues after harvesting.

Past trends

In the past, losses in organic carbon in the soil were driven mainly by conversion of land for the production of agricultural crops. A survey

Map 5.36 Projected changes in soil organic carbon for cropland 1990–2080



Projected changes in soil organic carbon for cropland 1990–2080

Left: climate change only; right: including changes in net primary production (NPP) and technology

Source: Smith *et al.*, 2005.

of Belgian croplands (210 000 soil samples taken between 1989 and 1999) indicates a mean annual loss in organic carbon of 76 gCm^{-2} (Sleutel *et al.*, 2003). A large-scale inventory in Austria estimated that croplands were losing 24 gCm^{-2} annually (Dersch and Boehm, 1997). The general intensification of farming in the past is likely to have exceeded the effect of changes in the climate on soil organic carbon on agricultural land. Peat lands in Europe have been a significant sink for atmospheric CO_2 since the last glacial maximum. Currently they are estimated to hold about 42 Gt carbon, about 60 % of all carbon stocked in European soils, and are therefore a considerable component of the European carbon budget (Byrne *et al.*, 2004). The annual loss of carbon due to drainage of peat lands is in the range of 0 to 47 gCm^{-2} (Lappalainen, 1996).

Projections

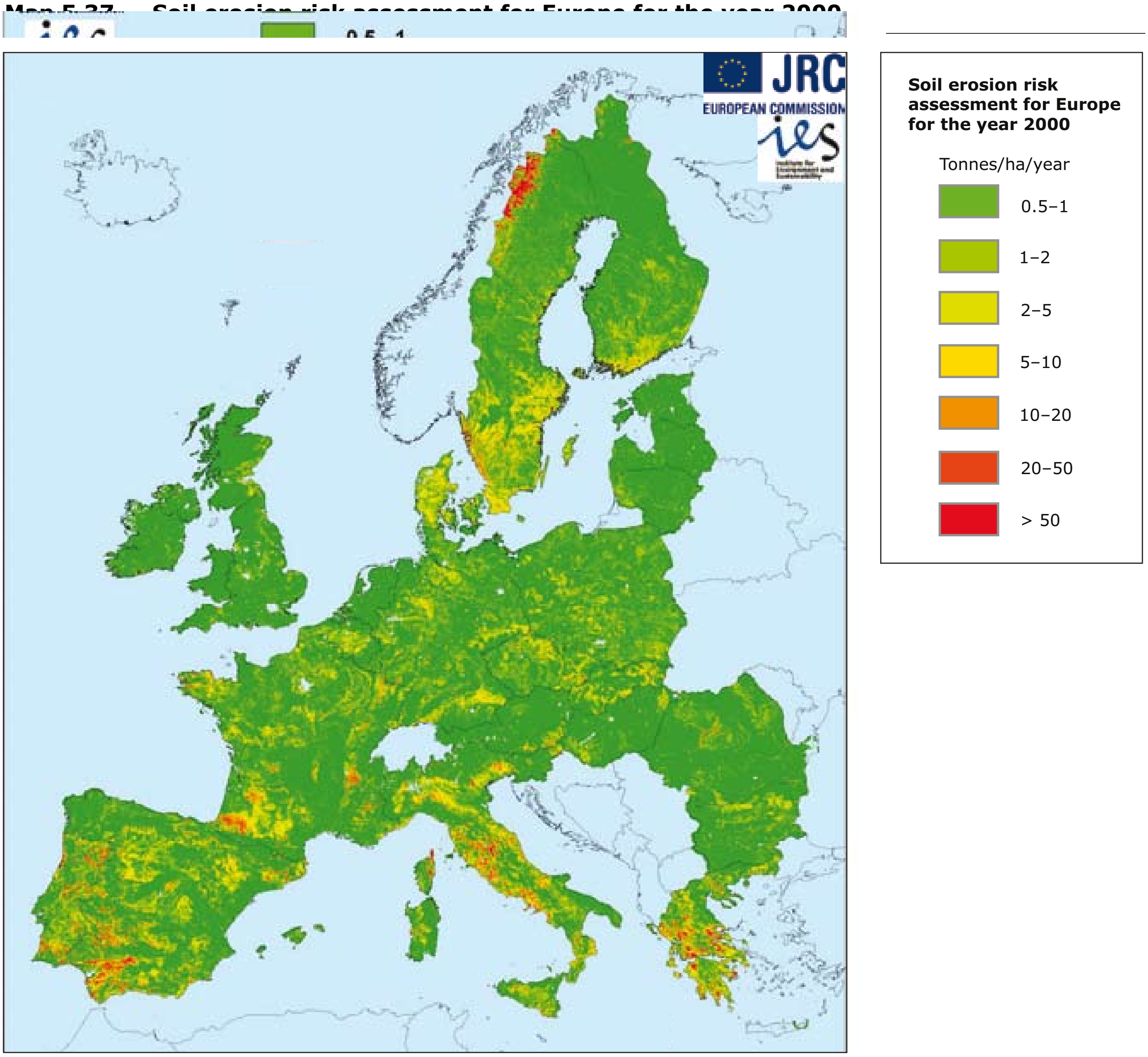
The amount of organic carbon in the soil is determined mainly by the balance between net primary production (NPP) from vegetation and the rate of decomposition of the organic material. Without an increase in NPP, soil carbon for cropland may decrease by 9 to 12 t C ha^{-1}. When taking account of changes in NPP and technological advances, the amount of organic carbon on cropland could increase by 1–7 t C ha^{-1} (Smith, *et al.*, 2005). Map 5.36 shows that climate change may cause loss (red) of soil organic carbon for most areas in Europe. This decline could be reversed (blue) if adaptation measures in the agricultural sector to enhance soil carbon were implemented. It should be noted that these modelled projected changes are very uncertain.

5.8.3 *Soil erosion by water*

Key messages

- An estimated 115 million hectares, 12 % of the total EU land area, are subject to water erosion.
- The projected changes in the climate during the 21st century, with increased variations in rainfall pattern and intensity, will make soils more susceptible to erosion.
- The off-site effects of soil erosion will increase with climate change and related changes in rainfall pattern and intensity.

Map 5.37 Soil erosion risk assessment for Europe for the year 2000



Note: Results obtained with application of two models (PESERA and RUSLE, JRC). Areas with yellow and red shades are highly vulnerable to soil erosion by water.

Source: Joint Research Centre (JRC), INRA (France), (http://eusoils.jrc.it/ESDB_Archive/serae/Serae_data.html).

Relevance

Climate change will influence soil erosion processes. Excess water due to intense or prolonged precipitation can cause tremendous damage to soil. Sheet-wash, rill and gully development can strip the topsoil from the land, thus effectively destroying the capability of the soil to provide economic or environmental services. Favis-Mortlock and Boardman (1995), using the Erosion Productivity Impact Calculator (EPIC) model (Williams and Sharpley, 1989), found that a 7 % increase in precipitation could lead to a 26 % increase in erosion in the United Kingdom. In high mountain regions like the Alps, decreasing permafrost (observed and projected) can lead, for example, to more landslides with substantial impact on infrastructure (roads, railways, cable cars) and economic sectors like tourism (see Section 5.3).

Many of the soil erosion risk models contain a rainfall erosivity factor and a soil erodibility factor that reflect average-year precipitation conditions. However, currently available values for the rainfall erosivity and soil erodibility factors may inadequately represent low-probability return-period storms and the more frequent and intense storms under projected climate change.

The relationship between climate change and soil erosion is complex and needs to be better defined, investigated and monitored in order to have a clear picture of future trends. Measurements and models with more detailed temporal and spatial distribution of precipitation and impacts on soil erosion or risk of erosion should be developed, as should indicators for assessing appropriate measures.

Past trends

Past trends for erosion are not available on the European scale. Based on EU-wide modelling, an estimated 115 million hectares or 12 % of the total EU land area is (in 2000) subject to water erosion (see Map 5.37). In this assessment the risk of erosion by water was calculated by using yearly average values for precipitation. However such risks are in fact to a large extent determined by extreme precipitation events (e.g. daily, hourly). The uncertainty of this modelled erosion risk is therefore high, especially at the local level.

Projections

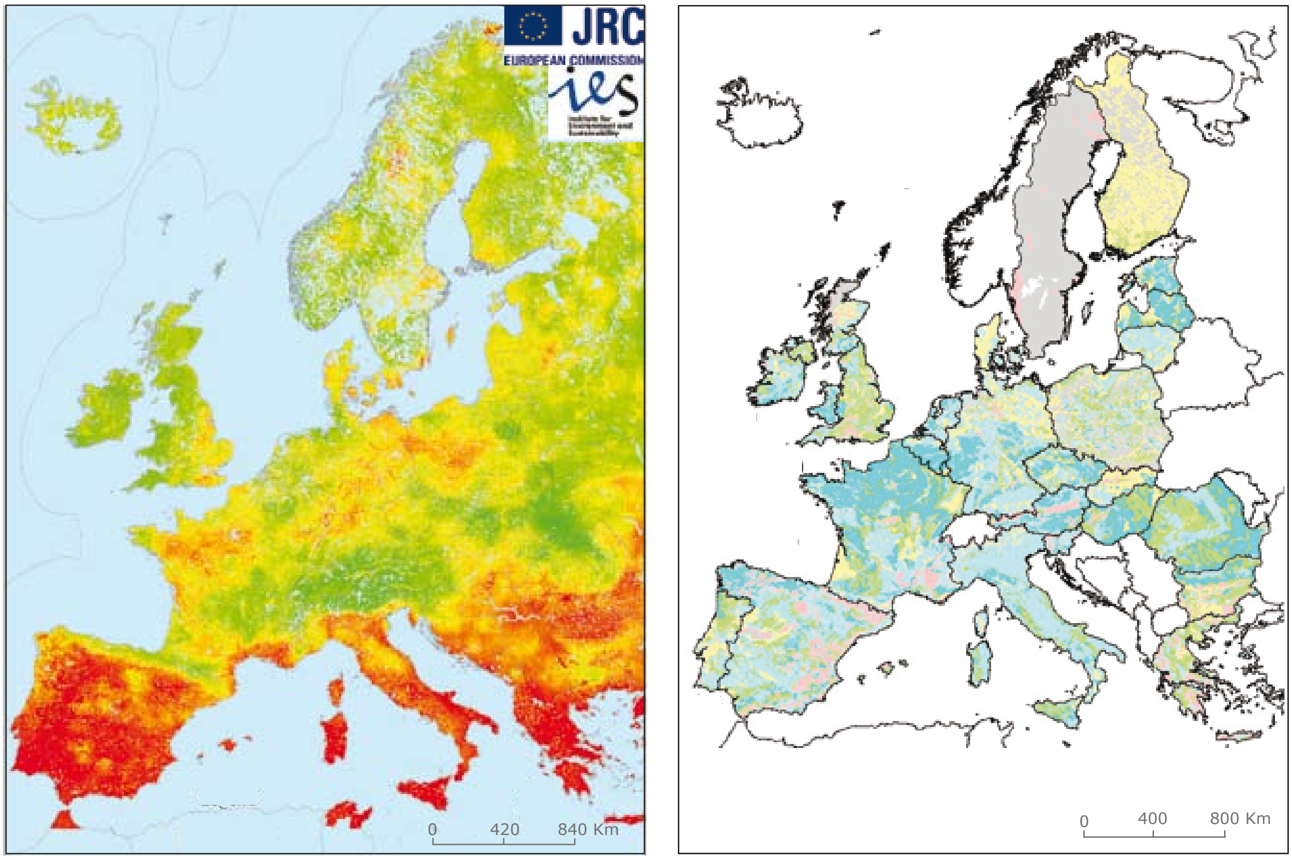
Several studies have been conducted to model the effects of future climate change on soil erosion (e.g. Kirkby *et al.*, 2004). These show a non-linear spatial and temporal response of soil erosion to climate change, with relatively large increases in erosion during wet years compared with dry years, and sporadic increases spatially. Erosion is projected to increase with increases in precipitation amount and intensity, and to decrease with increases in ground cover and canopy cover (IPCC, 2007a).

5.8.4 *Water retention*

Key messages

- Water retention capacity and soil moisture content will be affected by rising temperatures and by a decline in soil organic matter due to both climate change and land-management changes.
- Projections (for 2071–2100) show a general reduction in summer soil moisture over most of Europe, significant reductions in the Mediterranean region, and increases in the north-eastern part of Europe.
- Maintaining water retention capacity is important to reducing the impacts of intense rainfall and droughts, which are projected to become more frequent and severe.

Map 5.38 Modelled soil moisture in Europe



Modelled soil moisture in Europe

Left: modelled daily soil moisture 15 July 2008

Very dry 🟥🟧🟧🟨🟨🟩🟩 Very wet

Right: modelled subsoil available water capacity (AWC)

🟥 Very low (~ 0 mm/m)
🟨 Low (< 100 mm/m)
🟩 Medium (100–140 mm/m)
🟦 Very high (> 190 mm/m)
🟦 No data or not applicable

Note: Left: example of a forecast of topsoil moisture (15 July, 2008), right: subsoil available water capacity derived from modelling data.

Sources: European Soil Data Centre (ESDAC), http://eusoils.jrc.ec.europa.eu/library/esdac/index.html (left); and European Flood Alert System (EFAS) http://efas.jrc.ec.europa.eu/ (right).

Relevance

Soil water retention is a major soil hydraulic property that governs soil functioning in ecosystems and greatly affects soil management. Soil moisture forms a major buffer against flooding, and water capacity in subsoil is a major steering factor for plant growth. The effects of changes in soil water retention depend on the proportions of the textural components and the amount of organic carbon present in the soil. At low carbon contents, an increase in carbon content leads to an increase in water retention in coarse soils and a decrease in fine-textured soils. At high carbon contents, an increase in carbon content results in an increase in water retention for all soil textures (Rawls *et al.*, 2003). Soil organic matter can absorb up to twenty times its weight in water. Changes in temperature result in changes in evapotranspiration, soil moisture, and infiltration. These will also influence groundwater recharge by changing the ratio of surface run-off to infiltration. Projections for climate change indicate greater droughts in some areas, which might lead to substantial reductions in summertime soil moisture, and more rainfall — even too much — in others, and also increases in the off-site impacts of soil erosion. Maintaining or even enhancing the water retention capacity of soils can therefore play a positive role in mitigating the impacts of more extreme rainfall intensity and more frequent and severe droughts. Harmonised time-series on relevant soil properties are not available but should be developed. The development of projections for the soil characteristics presented here (subsoil available water capacity and topsoil moisture), which depend entirely on soil properties, is difficult due to lack of data to validate the models. Further research is needed using satellite information and linking this to representative observed data.

Past trends

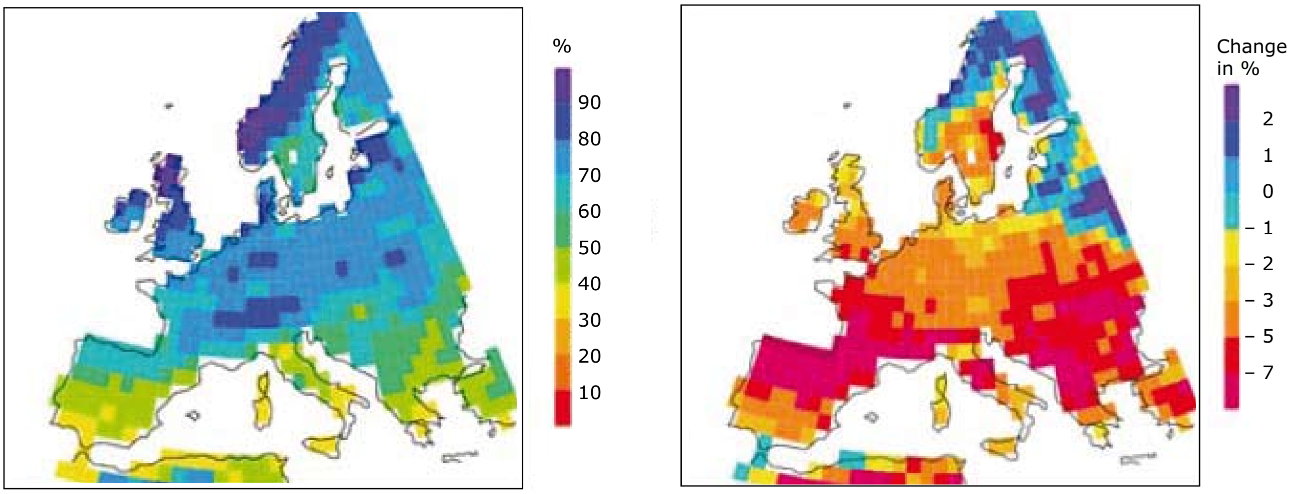
There is no clear indication on past trends for water retention across the EU except for local field data. However several models can be used to assess soil moisture, for both subsoil and topsoil. Map 5.38, right shows the subsoil available water capacity derived from modelling data. Capacity is high in north-western and central Europe and low in parts of the Mediterranean. Forecasts of soil moisture trends (an example for 15 July 2008 is shown in Map 5.38, left) show very wet topsoils in north-western and central Europe and dry topsoils in the Mediterranean.

Long-term past trend analysis of these modelled characteristics is not possible due to lack of information over a sufficient time-period for the main soil properties that are the input parameters for the models used.

Projections

Map 5.39 presents summer soil moisture over continental Europe for the IPCC A2 scenario (2071–2100), compared with 1961–1990. The projections show a general reduction in summer soil moisture over most of Europe and significant reductions in the Mediterranean region, while the north-eastern part of Europe will experience an increase in summer soil moisture.

Map 5.39 Modelled summer soil moisture (1961–1990) and projected changes (2071–2100) over Europe



Note: Simulated soil moisture by ECHAM5/T106L31 for the baseline period (1961–1990) (left) and relative changes in % under the IPCC A2 scenario (2071–2100) (right).

Source: Calanca *et al.*, 2006.

Box 5.11 Soil degradation and loss under desertification

Key messages

- Soil degradation is already intense in parts of the Mediterranean and central-eastern Europe. Soil degradation, together with prolonged drought periods and increased numbers of fires, leading to marginalisation and even land abandonment, is already contributing to an increased risk of desertification.
- The risk of desertification is expected to be the highest in areas with projected decreases in precipitation, increases in the frequency of summer droughts and the incidence of forest fires, and intensive land-use.
- In many cases, desertification is irreversible, leading to adverse social, economic and environmental effects.

Soil, under desertification processes (an advanced stage of land degradation), loses part of its capability to support human communities and ecosystems. Quantitative information on the causal factors is scarce and the most common approach to assessing the sensitivity of soil to desertification and drought is to use models (EC, 2004).

Climatic conditions make the Mediterranean region one of the areas most severely affected by land degradation. Much of the region is semi-arid and subject to seasonal droughts, high rainfall variability and sudden intense precipitation. Some areas, especially along the northwest coasts of the Black Sea, are classified as semi-arid. The level of soil degradation is severe in most of the region, and very severe in some parts, for example along the Adriatic, where soil cover has almost disappeared in some areas (UNCCD, 2008; EEA, 2007). 12 of the 27 European Union Member States declared themselves as affected countries under the 1992 United Nation Convention on Combating Desertification (UNCCD): in the Mediterranean: Cyprus, Greece, Italy, Malta, Portugal, Slovenia and Spain and in central and eastern Europe: Hungary, Latvia, Slovak Republic, Bulgaria and Romania.

In addition, other physical factors, such as steep slopes and the frequency of soil types susceptible to degradation, increase the vulnerability. These factors, coupled with changes in land use, the cessation of soil erosion protection measures due to the abandonment of marginal land, and increases in the frequency and extension of forest fires, have had a strong impact on soil vulnerability. Individual storms in the region have been known to remove 100 tonnes of soil from a hectare of land, and frequently remove 20 to 40 tonnes. In the most extreme cases, soil degradation has led to desertification (EEA, 2005).

Soil loss, in turn, reduces the regeneration potential of the ecosystems. The areas most sensitive to this are those with shallow soils, steep slopes and slow rates of recovery of the vegetative cover. For example, burned forests in dry areas with shallow soils often do not regenerate (WWF, 2007).

Changes in data quality and the methodology of the indicator make the analysis of desertification difficult. Nevertheless, an increase in vulnerability in affected regions has been observed in recent decades (IPCC, 2007b; EEA, 2004ab; EEA, 2005b; national reports of affected country parties to the UNCCD (*), ECCE, 2005).

The Mediterranean lies in a transition zone between the arid climate of northern Africa and the temperate and wet climate of central Europe. Even minor shifts in large-scale climatic factors could result in relatively large impacts on the climatic regime of Mediterranean areas. Summer warming and drying are expected to result in an increase in arid and semi-arid climates throughout the region. Furthermore, due to the complex topography and coastlines of the region, shifts in climates could lead to quite different effects at local scales (Gao *et al.*, 2006).

In these sensitive areas, therefore, vulnerabilities are likely to increase due to projected climate change. The projected decrease in summer precipitation in southern Europe, the increase in the frequency of summer droughts and the increased incidence of forest fires will probably induce greater risks of soil erosion (IPCC, 2007a). In sensitive areas, climate change is likely to increase the regional differences in terms of quality and availability of natural resources and ecosystems, and to pose challenges to the main economic sectors (such as agriculture and tourism) (IPCC, 2007b; ECCE, 2005). In currently affected areas, desertification is likely to become irreversible if the environment becomes drier; the pressure from human activities will increase and the soil will be further degraded.

(*) National reports are available through the UNCCD website at: http://www.unccd.int.

5.9 Agriculture and forestry

5.9.1 *Introduction*

The impacts of medium and long-term climate change on agriculture and forestry are often difficult to analyse separately from non-climate influences related to the management of the resources (Hafner, 2003). However, there is growing evidence that processes such as changes in phenology, length of growing season and northwards shift of crops and forest species can be related to climate change (IPCC, 2007a). There are also increasing impacts due to an increased frequency of some extreme events which can be attributed to climate change.

Potential positive impacts of climate change on agriculture in general are related to longer growing seasons and new cropping opportunities in northern Europe, and increased photosynthesis and CO_2 fertilisation throughout Europe. These possible benefits are counterbalanced by potentially negative impacts that include increased water demand and periods of water deficit, increased pesticide requirements and crop damage, and fewer cropping opportunities in some regions in southern Europe (Olesen and Bindi, 2004; Maracchi *et al.*, 2005; Chmielewski *et al.*, 2004; Menzel *et al.*, 2003). In general, changes in atmospheric CO_2 levels and increases in temperature are changing the quality and composition of crops and grasslands and also the range of native/alien pests and diseases. These may affect livestock and ultimately humans as well as crops. In addition, the increase in ozone concentrations related to climate change (Meleux *et al.*, 2007) is projected to have significant negative impacts on agriculture, mainly in northern mid-latitudes (Reilly *et al.*, 2007).

The link of forestry with climate change is twofold. Forests play a fundamental role in mitigating climate change because they act as sinks for carbon dioxide. However, they are also very vulnerable to changes in temperature, precipitation and extreme weather events which can have destructive impacts and reduce the carbon sequestration potential of the forest. Events such as forest fires have an even more negative effect since destroying the forest increases the amount of carbon dioxide in the atmosphere. The majority of forests in central Europe are growing faster than in the past, partly because of regional warming. In contrast, the extended heat-wave of 2003 caused a significant reduction in biomass production of forests (Gabron, 2005).

Although the economic impacts of climate change on agriculture and forestry in Europe are very difficult to determine because of the effects of policies and market influences and continuous technological development in farming and silviculture techniques, there is evidence of wider vulnerability for both sectors (see also Chapter 6). Management actions can counteract but may also exacerbate the effects of climate change and will play an important role in measures for adaptation to climate change (AEA, 2007).

The indicators included in this section are related to agricultural production, phenology, forestry growth and distribution, and the observed and projected impacts of forest fires.

Good data availability and quality are essential for monitoring trends and threats relating to European forests and agricultural products. The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forest), originally set up to monitor the effects of air pollution, now includes surveys that could also be used to monitor the effects of climate change (e.g. phenology). Another clear step forward in the collection of relevant information is being achieved by the establishment of the European Data Centres on Soil and Forestry.

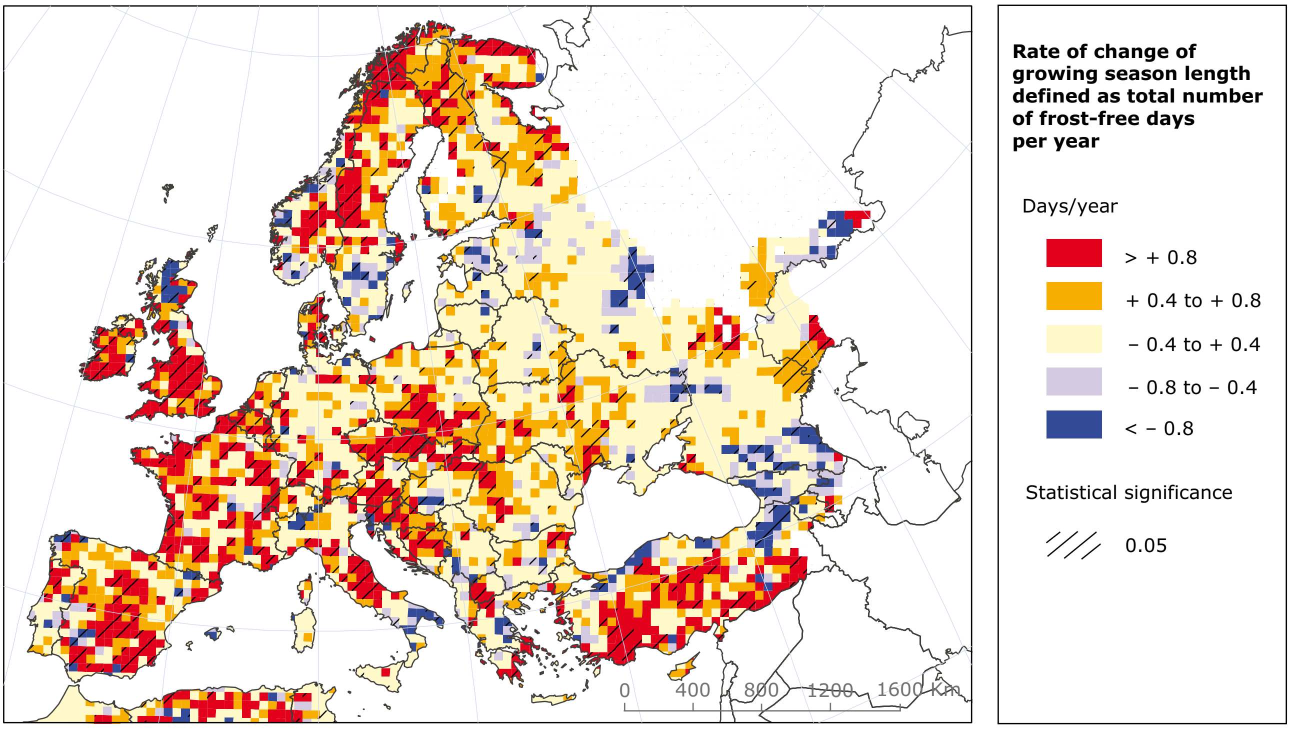
5.9.2 Growing season for agricultural crops

Key messages

- There is evidence that the length of the growing season of several agricultural crops in Europe has changed.
- A longer growing season increases crop yields and insect populations and favours the introduction of new species in areas that were not previously suitable for these species.

  These observed facts are particularly important for the northern latitudes.
- Locally at southern latitudes, the trend is towards a shortening of the growing season, with consequent higher risk of frost damage from delayed spring frosts.

Map 5.40 Rate of change of crop growing season length 1975–2007



Note: The rate of change (number of days per year) of the duration of the growing season (defined as total number of frost-free days per year) as actually recorded during the period 1975–2007.

Source: MARS/STAT database (Genovese, 2004a, 2004b).

Relevance

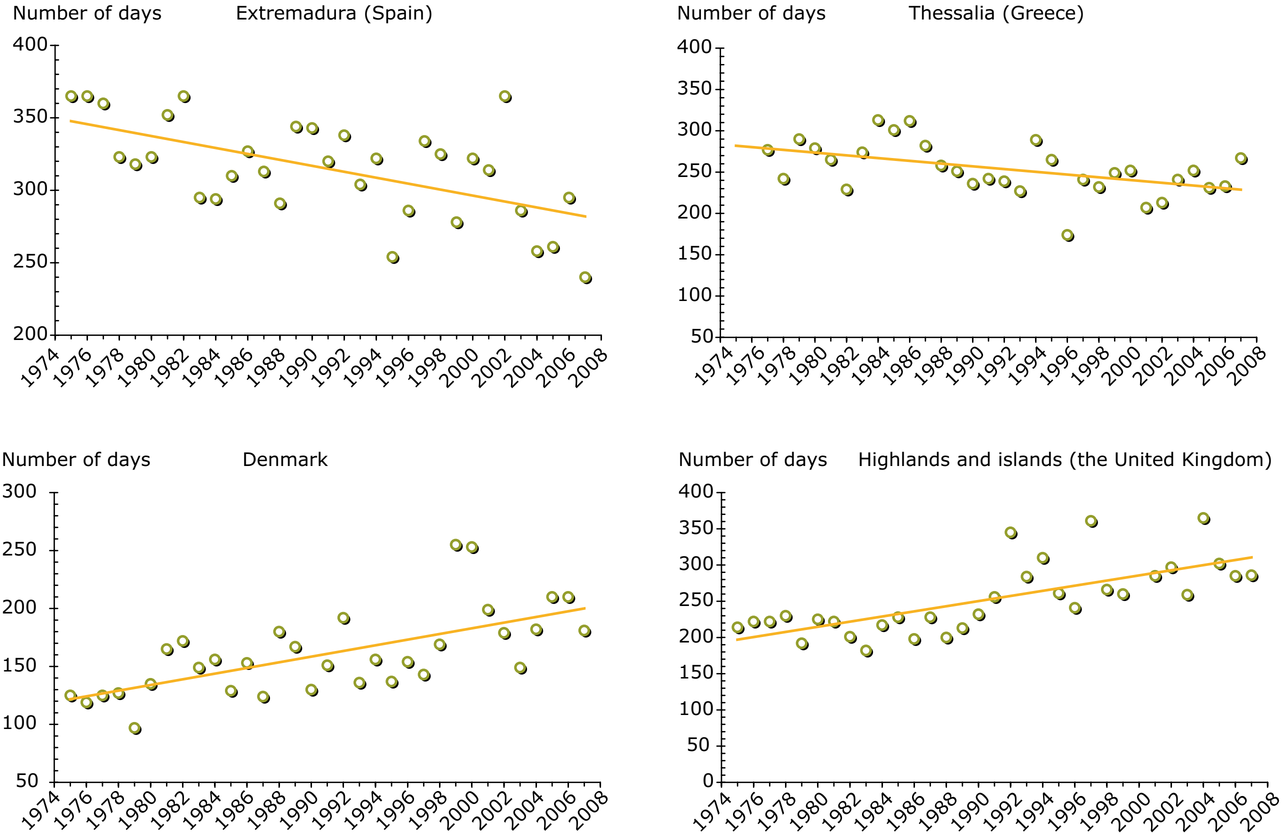
Increasing air temperatures are significantly affecting the duration of the growing season over large areas of Europe (Scheifinger *et al.*, 2003). The number of consecutive days with temperatures above 0 °C can be assumed to be the period favourable for growth. The timing and length of this frost-free period is of interest to naturalists, farmers and gardeners among others. The impact on plants and animals is reported mainly as a clear trend towards an earlier start of growth in spring and its prolongation into autumn (Menzel and Fabian, 1999). A longer growing season allows the proliferation of species that have optimal conditions for development and an increase in their productivity (e.g. crop yields, insect population), and the introduction of new species (very sensitive to frost) in areas previously limited by unfavourable thermal conditions. Changes in management practices, e.g. changes in the species grown, different varieties, or adaptations of the crop calendar, can counteract the negative effects of a changing growing season (pests) and capture the benefits (agricultural crops).

Photo: © European Environment Agency

Past trends

Many studies report a lengthening of the period between the occurrence of the last spring frost and the first autumn frost. This has occurred in recent decades in several areas in Europe and more generally in the northern hemisphere (Keeling *et al.*, 1996; Myneni *et al.*, 1997; Magnuson *et al.*, 2000; McCarthy *et al.*, 2001; Menzel and Estrella, 2001; Tucker *et al.*, 2001; Zhou *et al.*, 2001; Walther *et al.*, 2002; Root *et al.*, 2003; Tait and Zheng, 2003; Yan *et al.*, 2002; Robeson, 2002; Way *et al.*, 1997). An analysis of the growing period in Europe between 1975 and 2007 (Figure 5.36) shows a general and clear increasing trend. The trend is not uniformly spread over Europe. The highest rates of change (about 0.5–0.7 days per year) were recorded in central and southern Spain, central Italy, along the Atlantic shores, and in the British Isles, Denmark and the central part of Europe. The extension of the growing season is either due to a reduction in spring frost events or to a progressive delay in the start of autumn frosts. However, a decline has been observed in the Mediterranean countries, in the Black Sea area and in parts of Russia. In areas where

Figure 5.36 Length of frost-free period in selected European areas 1975–2007



Source: MARS/STAT database (Genovese, 2004a, 2004b).

a decrease in the length of frost-free period occurred, in particular in southern Europe, the plants are more at risk from frost damage due to a delay in the last winter-spring frost.

Projections

Following the observed trends (which have accelerated even more in the past decade) and in line with projections for temperature increase, a further lengthening of the growing season (both an earlier onset of spring and a delay of autumn) as well as a northward shift of species is projected. The latter is already widely reported (Aerts *et al.*, 2006). The length of the growing season will be influenced mainly by the increase in temperatures in autumn and spring (Ainsworth and Long, 2005; Norby *et al.*, 2003; Kimball *et al.*, 2002; Jablonski *et al.*, 2002).

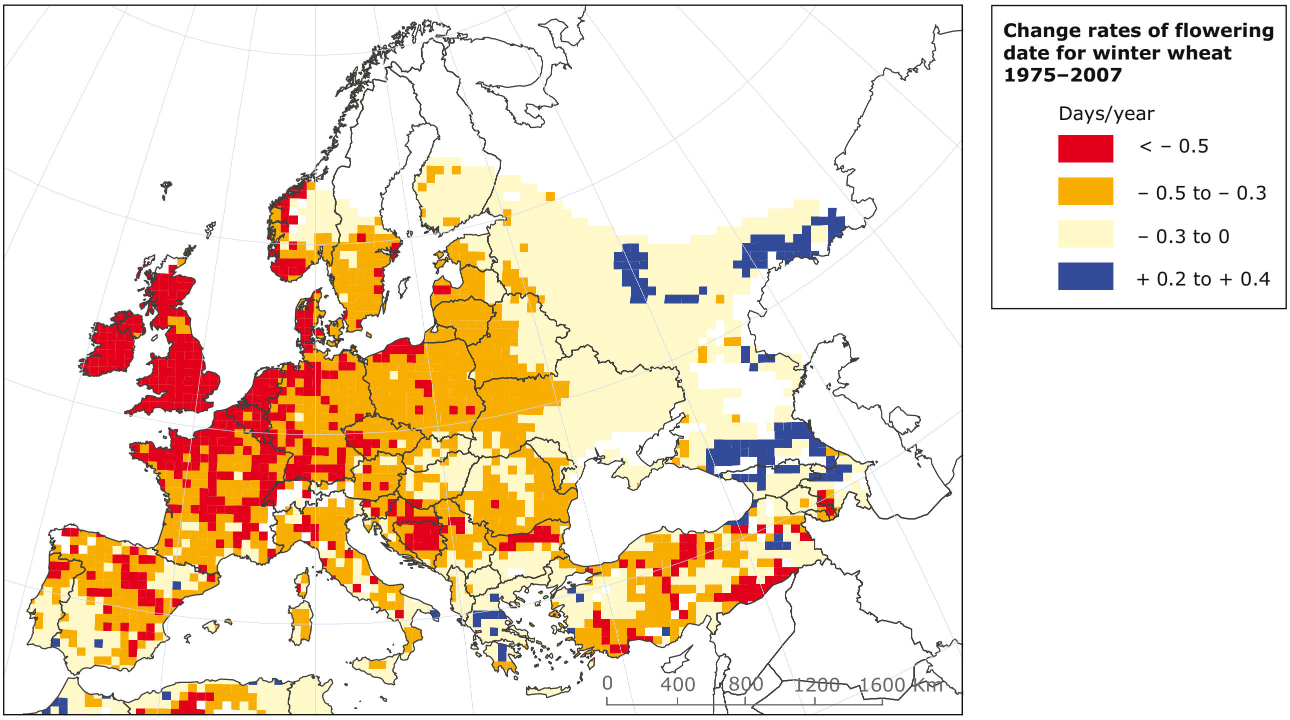
According to the IPCC analysis, Europe will warm in all seasons for all scenarios, but warming will be greater in western and southern Europe in summer and northern and eastern Europe in winter. More lengthening of the growing season is therefore expected in these northern and eastern areas, while in western and southern Europe the limited water availability and high temperatures stress during summer will hinder plant growth.

5.9.3 *Timing of the cycle of agricultural crops (agrophenology)*

Key messages

- There is evidence that the flowering and maturity of several species in Europe now occurs two or three weeks earlier than in the past.
- The shortening of the phenological phases is expected to continue if temperatures continue to increase.
- Adaptations of farm practices will be crucial to reduce or avoid negative impacts of crop-cycle shortening.

Map 5.41 Modelled change of flowering date for winter wheat 1975–2007



Note: The day of the year of flowering has been simulated by using a crop growth model (CGMS — Crop Growth Monitoring System).

Source: MARS/STAT database (Genovese, 2004a, 2004b).

Relevance

Changes in crop phenology provide important evidence of responses to recent regional climate change (IPCC, 2007). Although phenological changes are often influenced by management practices and new farming technologies, recent warming in Europe has clearly advanced a significant part of the agricultural calendar. Specific stages of growth (e.g. flowering, grain filling) are particularly sensitive to weather conditions and critical for final yield. The timing of the crop cycle (agrophenology) determines the productive success of the crop. In general, a longer crop cycle is strongly correlated with higher yields, since a longer cycle permits maximum use of the available thermal energy, solar radiation and water resources. The impacts of unfavourable meteorological conditions and extreme events vary considerably, depending on the timing of occurrence and the development stage of the crops. However, shortening of the growth period can also help avoid summer stress conditions in areas prone to drought. European farmers have already adapted their practices to the changing climate by selecting suitable varieties or adapting the crop calendar, and can be expected to do so increasingly in the future.

Past trends

Several studies have collected data and observed changes in the phenological phases of several perennial crops in Europe, such as the advance in the start of the growing season of fruit trees (2.3 days/10 years), cherry tree blossom (2.0 days/10 years), and apple tree blossom (2.2 days/10 years), in line with increases of up to 1.4 °C in mean annual air temperature in Germany (Chmielewski *et al.*, 2004), and the advance of apricot and peach tree flowering by 1–3 weeks over the past 30 years for in France (Chuine *et al.*, 2004). Sowing or planting dates of several agricultural crops have been advanced, by 5 days for potatoes in Finland, 10 days for maize and sugar beet in Germany and 20 days for maize in France (IPCC, 2007).

Projections

Assuming that the warming trend will continue, further reductions in the number of days required for flower opening (anthesis) and maturity may be expected for areas in western Europe, where phenological changes are strongly accelerating (ECCE, 2005). However, the rate of the reduction of these phases may gradually decrease with a further increase in temperature due to a reduced efficiency of photosynthesis at high temperatures.

Box 5.12 Grapevine phenology

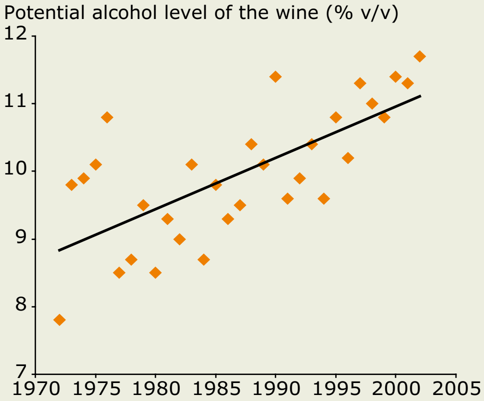
Wine quality is determined by various parameters: grape variety, rootstock, soil type, cultivation techniques, and climatic characteristics. The first three are generally constant over time, while cultivation techniques are most often responsible for long-term variability. Climate influences year-to-year variability and is responsible for variations in the amount and quality of wines.

Wine production areas, and particularly those for premium wines, are limited to regions climatically conducive to growing grapes with balanced composition and degree to which they reflect their origin ('varietal typicity'). Three conditions are required: (i) adequate heat accumulation; (ii) low risk of severe frost damage; and (iii) the absence of extreme heat. Moreover, vines are resistant to limited water availability in summer and it is essential to have no rainfall during harvest time, in order to increase sugar concentration and reduce disease development.

Observed climate change during recent years has resulted in a general increase in wine quality, due mainly to the increase in temperature and reduction of rainfall, particularly during the last part of the ripening period, with a gradual increase in potential alcohol levels (Duchêne and Schneider, 2005). Future possible impacts are:

- seasonal shift: a move forward in time of all the phenological phases with an increase of frost risk and a shortening of the ripening period. As a possible effect, the harvest time may occur during periods of high temperatures, with negative effect on wine quality;
- expansion of wine production areas, to north and more elevated regions;
- water stress due to a reduction of available water;
- modification of pest and disease development;
- increase of sugar concentration resulting in wine with high alcohol and low acidity. The consequence is a reduced possibility of wine ageing and poorer phenolic ripening;
- modification of natural yeast composition.

Figure 5.37 Potential alcohol level at harvest for Riesling in Alsace (France) 1972–2003



Note: Reprinted with permission from Duchêne and Schneider, Grapevine and climatic changes: a glance at the situation in Alsace. Agron. Sustain. Dev. 25 (2005) 93–99. Copyright: 2005 INRA, EDP Sciences. Permission has been kindly given by Dr. Eric Lichtfouse, Editor-in-Chief of Agronomy for Sustainable Development. http://www.agronomy-journal.org.

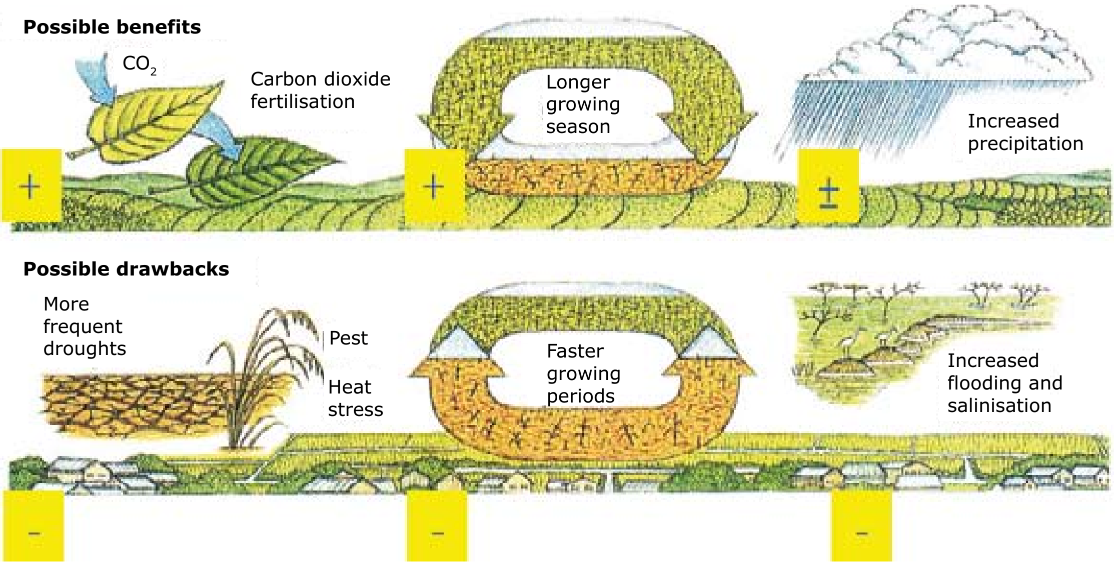
Source: Duchêne and Schneider, 2005.

5.9.4 *Crop-yield variability*

Key messages

- Climate and its variability are largely responsible for variations in crop suitability and productivity in Europe.
- Since the beginning of the 21st century, the variability of crop yields has increased as a consequence of extreme climatic events, e.g. the summer heat of 2003 and the spring drought of 2007.
- As a consequence of climatic change, such events are projected to increase in frequency and magnitude, and crop yields to become more variable. Changes in farming practices and land management can act as risk-mitigating measures.

Figure 5.38 Agro-ecosystem processes and a changing climate



Note: A changing climate will affect agro-ecosystems in various ways, with either benefits or negative consequences dominating in different agricultural regions. Rising atmospheric CO_2 concentration, higher temperatures, changing patterns of precipitation, and changing frequencies of extreme events will have significant effects on crop production, with associated consequences for water resources and pest/disease distributions.

Source: Bongaarts, 1994.

Relevance

Climate change introduces new uncertainties for the future of the agricultural sector. Climatic conditions are projected to become more erratic with an increase in the frequency of extreme events (floods, hurricanes, heat waves, severe droughts) (Parry, 2000). Biomass production of plants, and thus crop yields, are fundamentally determined by climatic conditions, i.e. the stable availability of energy (radiation, temperature) and water (rain) to support growth. Other environmental and anthropogenic factors, such as soil fertility, crop varieties and farming practices, also influence crop yields. These factors imply that, in principle, many adaptation options are available to adjust agricultural practices to the changing climate, but that opportunities differ between regions.

Past trends

While the area under arable cultivation in most of western Europe has decreased over the past 40 years, crop yields have increased almost continuously (Eurostat). This trend has persisted into the 21st century, although crop-yield variability

Photo: © Pawel Kazmierczyk

increased as a consequence of several extreme meteorological events in short succession: a late frost in 2003 followed by a severe drought reduced cereal yields over most of Europe, a drought in 2005 severely affected western Europe (Iberian Peninsula), and an early drought in 2006 was followed by extreme rains during the summer, resulting in lower cereal production, especially in eastern Europe (EC, MARS Bulletins, 2008). Alexander *et al.* (2006) found a general increase in the intensity of precipitation events observed at the global level. For the Mediterranean area, where climate vulnerability is high, several studies found an increasing trend towards more intense precipitation and a decrease in total precipitation (Alpert *et al.*, 2002; Maheras *et al.*, 2004; Brunetti *et al.*, 2004). In general, it is difficult to separate the climate effects from those of improved agricultural techniques in the development of historic crop yields. Adaptive management is expected to continue to help reduce the risks to agricultural yields from climate change, and to make better use of opportunities.

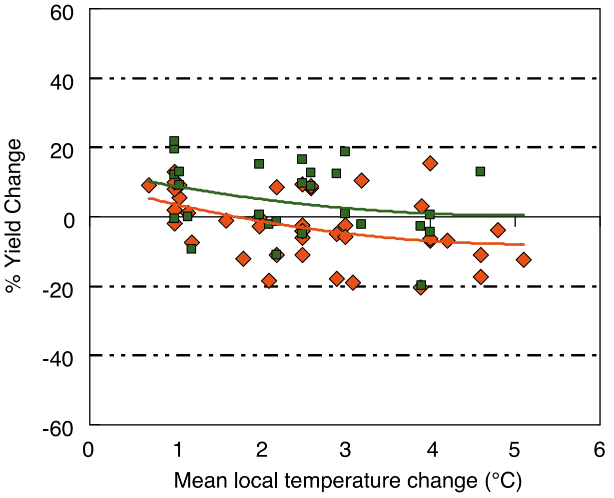
Projections

The effects on agricultural yields of increasing mean daily temperatures depend on their magnitude and geographic extent. The production areas of some crops could expand northwards in Europe, e.g. for maize. With an increase in mean annual temperature of 2 °C, cereal yields are expected to increase, partly because of the fertilisation effect of the increase in CO_2 (Parry *et al.*, 2004). However, an increase of 4 °C or more will shorten the crop cycle and the CO_2 effect will not compensate for the resulting loss of yield. Crop yields are also at risk from more intensive precipitation and prolonged periods of drought, particularly in areas bordering the Mediterranean basin.

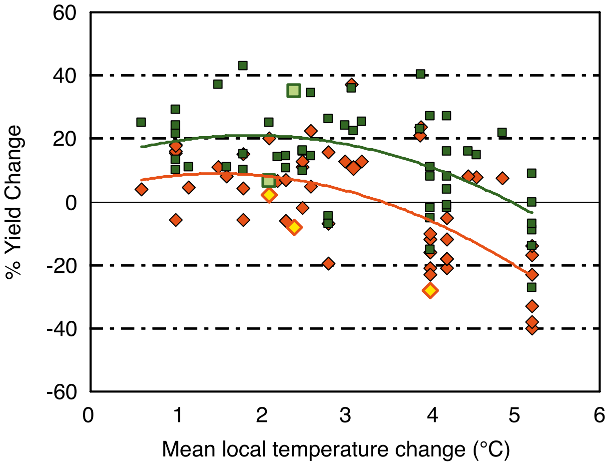
Figure 5.39 shows the sensitivity of maize and wheat yields to climate change, as derived from the results of 69 published studies. These span a range of precipitation changes and CO_2 concentrations, and vary in how they represent future changes in climate variability. Responses include cases without adaptation (red dots) and with adaptation (dark green dots). Adaptation represented in these studies includes changes in planting dates and crop varieties, and shifts from rain-fed to irrigated conditions.

Figure 5.39 Sensitivity of cereal yields to climate change for maize and wheat

(a) Maize, mid- to high-latitude



(c) Wheat, mid- to high-latitude



Note: A small increase in temperature has a positive impact on cereals yield, while a high increase (3–5 °C) has a negative impact. Lines are best-fit polynomials and are used here to summarise results across studies rather than as a predictive tool.

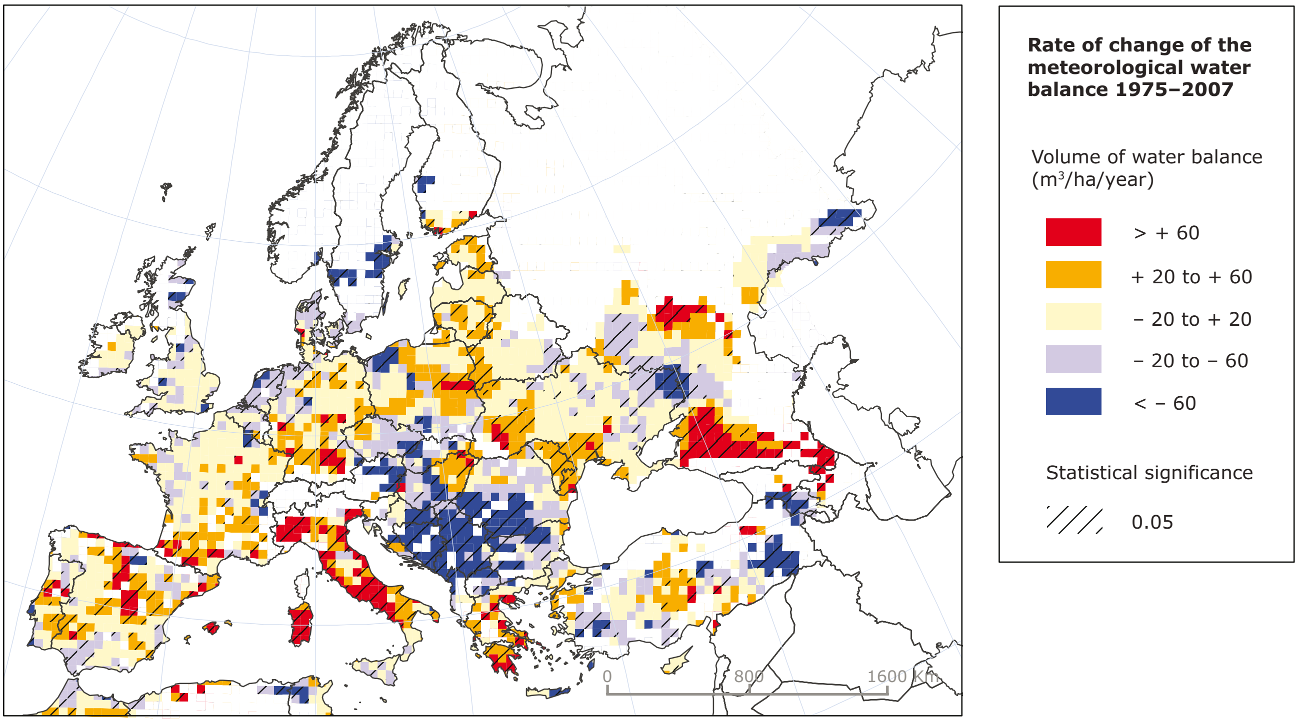
Source: Eastering *et al.*, 2007. Published with permission of the Intergovernmental Panel on Climate Change.

5.9.5 *Water requirement*

Key messages

- Between 1975 and 2006 clear trends, both positive and negative, were evident in water requirement across Europe, with marked spatial variability. A significant increase in water demand (50–70 %) occurred mainly in Mediterranean areas; large decreases were recorded mainly in northern and central European regions.
- Current trends and future scenarios depict an increase in the demand for water in agriculture, potentially increasing competition for water between sectors and uses.

Map 5.42 Rate of change of the meteorological water balance 1975–2007



Note: The rate of change of the 'meteorological water balance', expressed in m^3 ha^{-1} y^{-1} The map provides an estimate of the increase (red in the map) or decrease (blue in the map) of the volume of water required from irrigation in order to ensure that crop growth is not limited by water stress.

Source: MARS/STAT database (Genovese, 2004a, 2004b).

Relevance

Climate change may affect agriculture primarily through increasing atmospheric CO_2, rising temperatures and changing rainfall. Where rainfall does not limit crop growth, these conditions allow for earlier sowing dates and enhanced crop growth and yield (see previous indicators). Where reduced rainfall is predicted, however, the increased requirement for irrigation water can have an overall negative impact in economic and environmental terms. In these areas, increased water shortages are expected to increase competition for water between sectors (tourism, agriculture, energy, etc.), particularly in southern Europe where the agricultural demand for water is greatest. Several adaptation options are available to mitigate the risks of water shortage. Increased irrigation can further burden surface and groundwater resources and increase greenhouse gas emissions, adding to the mitigation challenge.

Past trends

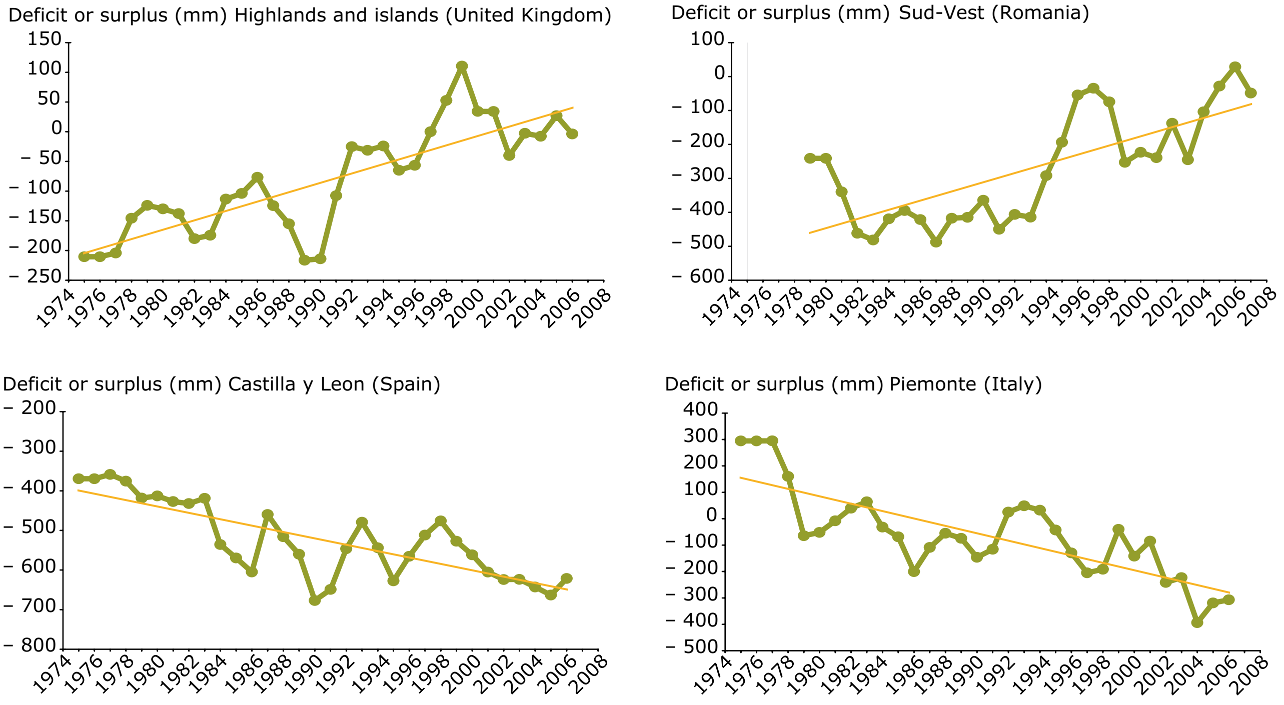
Systematic observations of water demand for agriculture do not exist at the European scale, however local trends can be reconstructed by using meteorological data. On average, the rate of increase in water demand is around 50 m^3/ha/year, but in some cases (Italy, Greece, Maghreb, central Spain, southern France and Germany) it is more than 150–200 m^3/ha/year. Areas with upward trends in the water balance (due mainly to an increase in rainfall), have been observed in the Balkan Peninsula, the Alpine region, Scandinavia, Scotland, Benelux, the Czech Republic, Slovakia, Poland and Hungary, as well as in many Turkish areas. In the Mediterranean area, a worsening meteorological water deficit (declining water balance) has been observed over the past 32 years.

Projections

No quantitative projections of irrigation demand are available. Many climatic projections for Europe (IPCC, 2007) foresee a very likely precipitation increase in the north and a decrease in the south, especially during the summer. Also the extremes of daily precipitation are projected to increase in the north and the annual number of rainy days to decrease in the Mediterranean (see Section 5.5.4). The risk of summer drought is therefore likely to increase in central Europe and in the Mediterranean area. Agricultural crops will be affected, among other factors, in positive and negative ways by changes in the length and timing of the vegetative cycle. Crop management will have to be adapted in order to try to avoid crucial development stages sensitive to water-stress (flowering, grain filling, etc.) occurring during generally dry periods.

Photo: © Jörg Rechenberg

Figure 5.40 Meteorological water balance in selected parts of Europe 1975–2007



Deficit or surplus (mm) Highlands and islands (United Kingdom)

Deficit or surplus (mm) Sud-Vest (Romania)

Deficit or surplus (mm) Castilla y Leon (Spain)

Deficit or surplus (mm) Piemonte (Italy)

Note: Surplus means positive values of meteorological water balance.

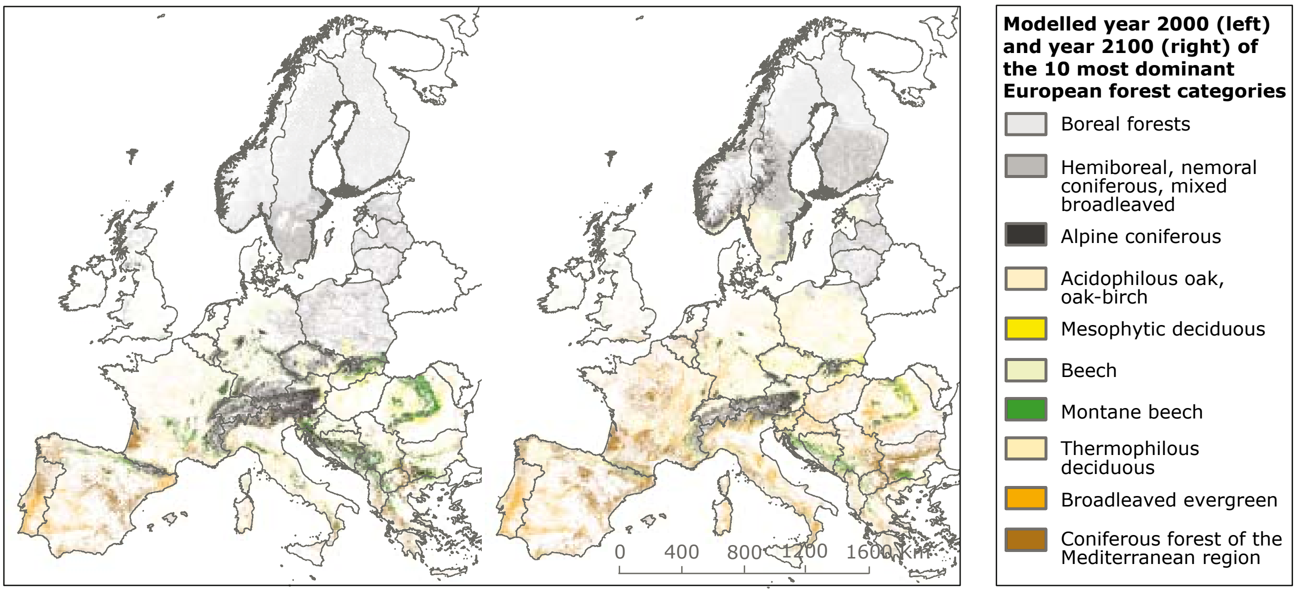
Source: MARS/STAT database (Genovese, 2004a, 2004b).

5.9.6 *Forest growth*

Key messages

- In much of continental Europe, the majority of forests are now growing faster than in the early 20th century.
- A changing climate will favour certain species in some forest locations, while making conditions worse for others, leading to substantial shifts in vegetation distribution.
- The distribution and phenology of other plant and animal species (both pests and pollinators) are likely to change, leading to further alterations in competitive dynamics in forests that will be difficult to predict.
- Periods of drought and warm winters are increasing pest populations and further weakening forests.

Map 5.43 Current (2000) and projected (2100) forest coverage in Europe



Note: Modelled to evaluate the change of habitat suitability coverage of the ten most dominant European Forest Categories (EEA, 2006), used IPCC SRES A1B scenario and NCAR CCM3 model.

Source: Casalegno *et al.*, 2007.

Relevance

Forests contain 77 % of the global carbon pool in vegetation biomass and hence play an important role in the global carbon cycle (Dixon *et al.*, 1994; IPCC, 2007). Forests and woodlands provide many things that society values, including food, marketable products, medicines, biodiversity, carbon reservoirs and opportunities for recreation. In addition, they regulate biogeochemical cycles and contribute to soil and water conservation. Changes in global climate and atmospheric composition are likely to have an impact on most of these goods and services, with significant impacts on socioeconomic systems (Winnett, 1998).

Management has a significant influence on the development of the growing stock and forest productivity. Adaptation measures include changes to plantation practices and forest management, the planting of different species mixtures, better matching of the species to the specific site, planting of similar species from their places of origin and non-native species in anticipation of climate change

(Broadmeadow *et al.*, 2003), and the restoration of forest typologies that could offer greater flexibility to climate change (Kölling, 2008).

Past trends

For many centuries, most European forests were overexploited. Growth rates were reduced and biomass stocks were depleted until the middle of the 20th century, when growth rates started to recover (Spieker *et al.*, 1996). Much of this increase can be attributed 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. Trees have long been known to respond to changes in climate: variations in tree-ring widths from one year to the next are recognised as an important source of climatic information (see Chapter 2).

Several studies have already noted changes in dates of budburst and therefore longer growing seasons in several species (see Section 5.7.3), shifts in tree-line, and changes in species distribution (see Section 5.7.2). A north-east shift of forest categories has already been observed for European forest species (Bakkenes *et al.*, 2002; Harrison *et al.*, 2006).

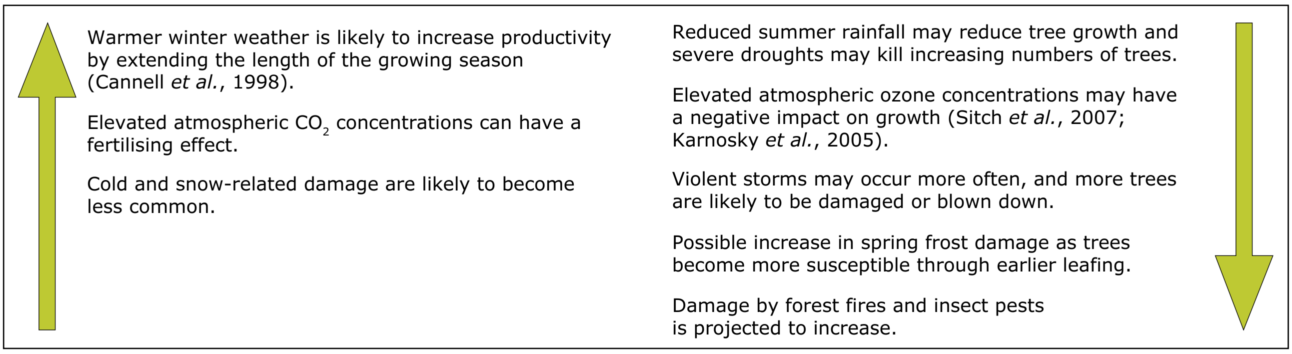
Projections

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 (see Section 5.9.7), more severe droughts in some areas, increased storm damage, and increased insect and pathogen damage (Eastaugh, 2008). 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).

Photo: © Pawel Kazmierczyk

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.

Figure 5.41 Impacts of climate change on forest growth and forest conditions



Warmer winter weather is likely to increase productivity by extending the length of the growing season (Cannell *et al.*, 1998).

Elevated atmospheric CO_2 concentrations can have a fertilising effect.

Cold and snow-related damage are likely to become less common.

Reduced summer rainfall may reduce tree growth and severe droughts may kill increasing numbers of trees.

Elevated atmospheric ozone concentrations may have a negative impact on growth (Sitch *et al.*, 2007; Karnosky *et al.*, 2005).

Violent storms may occur more often, and more trees are likely to be damaged or blown down.

Possible increase in spring frost damage as trees become more susceptible through earlier leafing.

Damage by forest fires and insect pests is projected to increase.

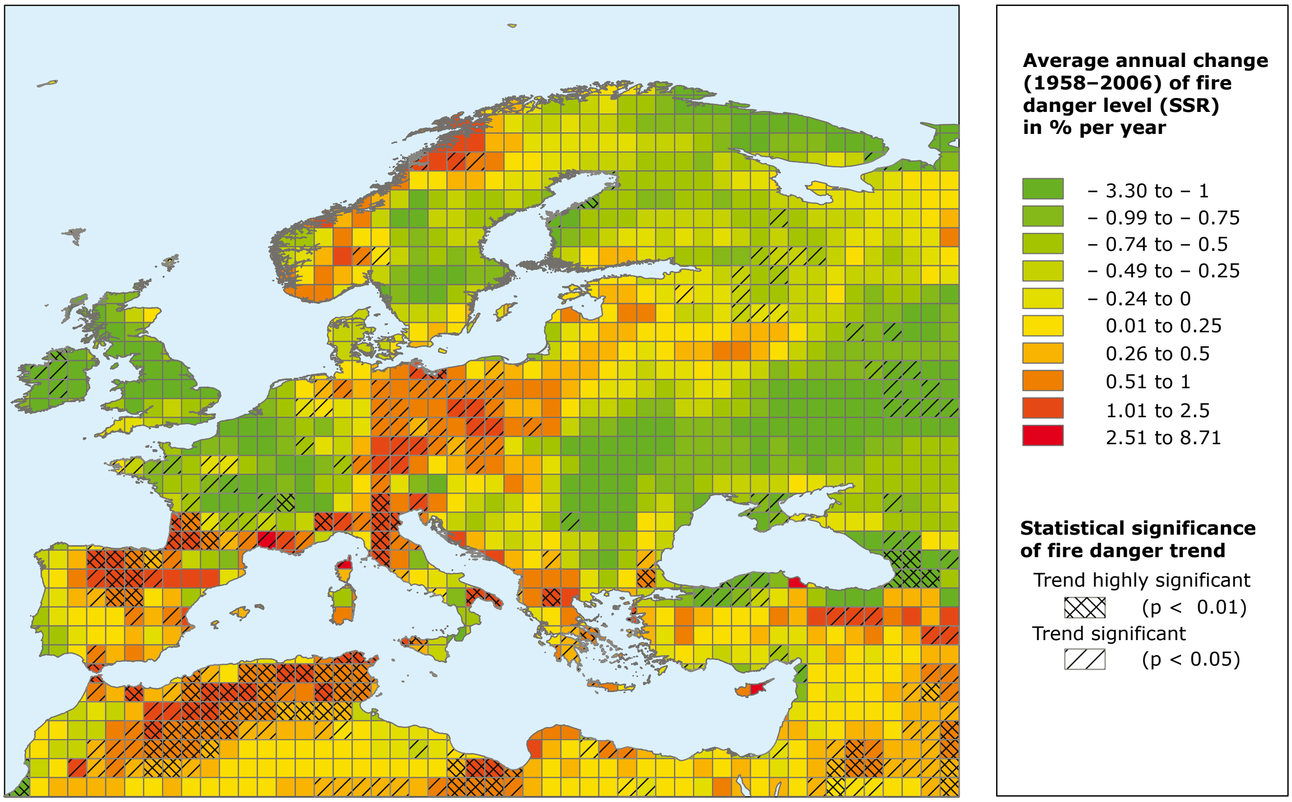
Source: Produced by Tracy Houston Durrant (Joint Research Centre (JRC)) for this report.

5.9.7 *Forest fire danger*

Key messages

- In a warmer climate, more severe fire weather is expected and, as a consequence, more area burned, more ignitions and longer fire seasons.
- Climate change will increase the fire potential during summer months, especially in southern and central Europe.
- The period during which fire danger exists will become longer as a result of climate change, with a probable increase in the frequency of extreme fire danger days in spring and autumn.

Map 5.44 Average annual changes in fire danger level 1958–2006



Note: Based on use of Seasonal Severity Rating (SSR). The map indicates the increase in fire danger in as a percentage of a historic absolute value which is not shown in the figure.

Source: Camia *et al.*, 2008.

Relevance

Wildfires are a serious threat to forests and ecosystems in Europe and climate is the most important driving force affecting fire potential changes over time (Flannigan *et al.*, 2000). Although it is generally recognised that 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. Changes in fire regimes may have strong impacts on natural resources and ecosystem stability, with consequent direct and indirect economic losses. On other hand active forest and fire management practices can counteract the impacts of a changing climate to some extent.

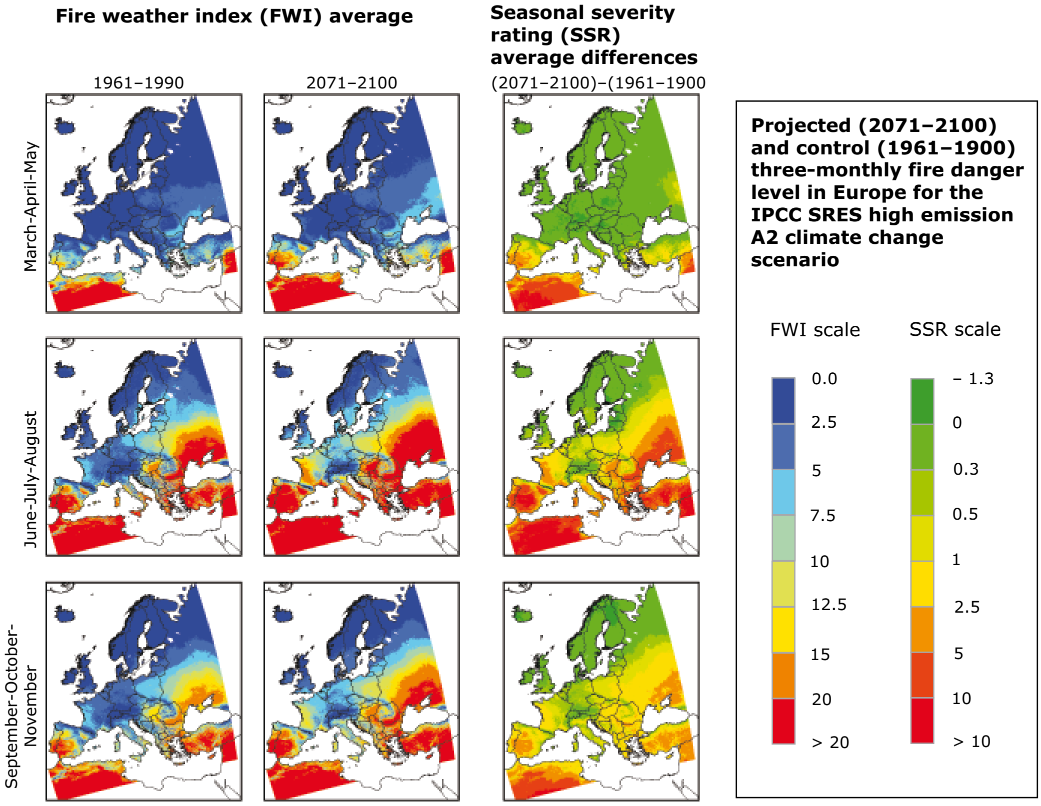
Past trends

Fire risk depends on many factors of a different nature that change over time (e.g. weather, fuel load, fuel type and condition, forest management practices, socio-economic context). Historic fire series can be used to support statements on trends but, unfortunately, long and consistent time series of fire events are rarely available in Europe. In addition, by looking at the historic fire series alone, it is difficult to get a clear picture and recognise the effect of climate on fire potential. In contrast, meteorological fire danger indices, which are designed to rate the component of fire risk that depends on weather conditions, can be usefully employed to analyse fire trends in a consistent way over longer periods. These indices, normally applied on a daily basis, can be summarised on a seasonal basis to rate the overall fire potential of a given year (seasonal fire severity) due to meteorological conditions. The index of Seasonal Severity Rating (SSR) has been derived from daily values of Van Wagner's Fire Weather Index (FWI), Van Wagner (1987), the fire danger assessment method most widely applied throughout the world (San Miguel-Ayanz *et al.*, 2003). Results of a recent study on SSR development are shown in Map 5.44. The average trend for 1958–2006 was computed for all the grid cells, but it was statistically significant for only 21 % of the cases (15 % positive and 6 % negative), which appear to be concentrated in specific geographical areas.

Projections

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) (see Map 5.45). In agreement with a similar assessment performed for North America (Flannigan *et al.*, 2005), 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.

Map 5.45 Modelled three-monthly fire danger levels in Europe for 1961–1990 and 2071–2100 and change between these periods



Note: Based on the IPCC SRES high emissions A2 scenario and the HIRAM model. Fire danger in winter months (DJF) is not shown because it is negligible.

Source: Camia *et al.*, 2008.