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Extreme weather:
does nature keep up?

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Observed responses of species and ecosystems to changes in climate and extreme weather events: many more reasons for concern

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Foreword

There have been numerous scientific reports and studies in the last years regarding the impacts of climate change on “nature”. These studies, such as “Extinction risk from climate change” (Thomas et al., 2004), have been immensely powerful and worrying, noting both that climate change is already impacting ecosystems in a significant manner and that it is likely to lead to many extinctions in the coming years and decades. These are tremendously important findings and should guide policymakers in their decision-making.

What this study now finds, however, is that it is very likely that those studies have underestimated the impacts on nature due to the fact that they have not linked the observed changes in species and ecosystems with the changes in extreme weather events. After Leemans and van Vliet did so they found that there were “many more reasons for concern” and specifically pointed out that “it will be impossible under such conditions of rapid climate change to uphold the UN Convention on Biodiversity’s aim to reduce the rate of biodiversity decline significantly by 2010.”

It seems that extreme weather events contribute disproportionately to recently observed climate change explaining why ecological impacts have become so abundant over the last decade.

In response, the authors clearly state their scientific judgment is that “efforts be made to limit the increase in global mean surface temperature to maximally 1.5 ºC above pre-industrial levels and limit the rate of change to less than 0.05 ºC per decade.”

In other words, there can be no further delay in reducing emissions. In fact, the scale and urgency just got bigger and greater. Global emissions must be on a steep downward trend in the next decade in order to avoid the worst impacts.

To ensure this occurs sooner rather than too late, WWF has launched the PowerSwitch! Campaign, challenging the biggest CO_2 polluting sector, the power sector, to be carbon neutral in OECD countries by 2050 and undergo a major switch from coal to clean in developing countries.

Whether a politician, a utility executive or a banker, each person must play their part in mapping the way to a future where global warming does not wreak havoc on nature, but rather is slowed down and contained. Only when that has been secured can we look our children in the eyes and explain that we did everything we could to stop the disaster of global warming.

Jennifer Morgan

Director WWF Climate Change Campaign
December, 2004

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Main findings

Widespread ecological impacts of climate change are visible in every part of the world and in every ecosystem.

Plants, birds, insects, mammals, amphibians and fishes are rapidly responding to the observed changes in climate everywhere on the planet. Extreme high temperatures immediately result in hefty responses. The responses, however, significantly differ from species to species and from year to year, which complicates a clear attribution of causes. The ecological impacts are nowadays visible everywhere through changes in the timing of life cycle events and the geographic distributions of species. Plants have advanced flowering by up to 30 days and are now doing so at dates never documented in the last two centuries. Some species show a dramatic increase in range area, disrupting ecosystems like, for example, the rapid spread over millions of hectares of the Mountain Pine Beetle in North America and the northward expansion of the Oak Processionary caterpillar in The Netherlands. Also fires have increased catastrophically in tropical wet forests during the severe droughts of the El Niño years in the nineties. Other species show a dramatic decrease in distribution or population sizes, illustrated by bleaching corals and disappearing amphibians worldwide. Warm winters, hot summers, excessive precipitation and extended droughts are weather events that trigger these responses.

Observed ecological changes are larger than expected.

Traditional impact assessments focused on future range shifts of biomes on a large scale and in the longterm. These studies indicated approximate shifts of 300 kilometres polewards for each °C of warming for the edges of biomes. Recently several studies also focused on the responses of individual species. These studies show that each species responds in a unique way and, consequently they depict larger and more numerous impacts than the traditional biome studies (i.e. not along edges but everywhere). Our study supports the higher-impact levels of these species-based studies. However, over the last decade, many more ecological responses have occurred than expected from the average 0.7 °C warming trend alone. Current impact assessments of climate change therefore likely underestimate ecological impacts and vulnerability.

Ecosystems respond faster to changes in extreme weather than to ‘normal’ climate characteristics. This explains the more rapid appearance of ecological responses throughout the world.

Observed climate change now by far exceeds all the natural climate variations of the last 1000 years. Although regional differences exist, temperatures are increasing and precipitation frequency and intensity are changing rapidly. In the last 100 years, northern Europe, for example, has become 10–40% wetter and southern Europe up to 20% drier. The Royal Dutch Meteorological Institute (KNMI) (Klein Tank, 2004) concluded that for Europe changes in average weather are largely attributable to significant changes in extremes: fewer cold extremes, more heatwaves, smaller diurnal and seasonal ranges, heavier precipitation. Similar trends have been reported for other regions in the world. This study evaluates the observed ecological impacts of local, regional and global climate. If climate only changes gradually, ecological impacts should have been smaller and less pronounced. The observed responses of species and ecosystems correlate well with the changes in extreme weather events, and provide a consistent account of adequate forcing and response. With this new understanding it is obvious that traditional impact assessment approaches are inadequate to precisely estimate the extent and magnitude of ecological responses. They only provide the proper direction.

With continued climate change over the coming decades, natural responses of species and ecosystems will not be adequate for survival, and many ecosystems will rapidly become depauperated

Revision of political climate protection targets is urgently needed.

The IPCC indicated that above a 2°C increase in global mean surface temperature the risk of adverse impacts will rapidly increase. This study suggests this level is too high. Even with small global temperature changes, there will be disproportionately large changes in the frequency and magnitude of extreme events, and consequently unpredictable and undesirable impacts on species and ecosystems.

Anthropogenic climate change will continue for many decades, likely even for centuries. We are venturing into the unknown and the associated impacts could be very disruptive. Defining strict targets for climate protection and emissions reduction is becoming vital. Given the wide recognition that human-induced climate change is a serious environmental and development problem, adequate measures are needed to reduce emissions of greenhouse gases and the vulnerability of different sectors and ecosystems to climate change. Based on current scientific understanding of the response of species and ecosystems, we suggest that efforts be made to limit the increase in global mean surface temperature to 1.5°C above pre-industrial levels and limit the rate of change to less than 0.05°C per decade.

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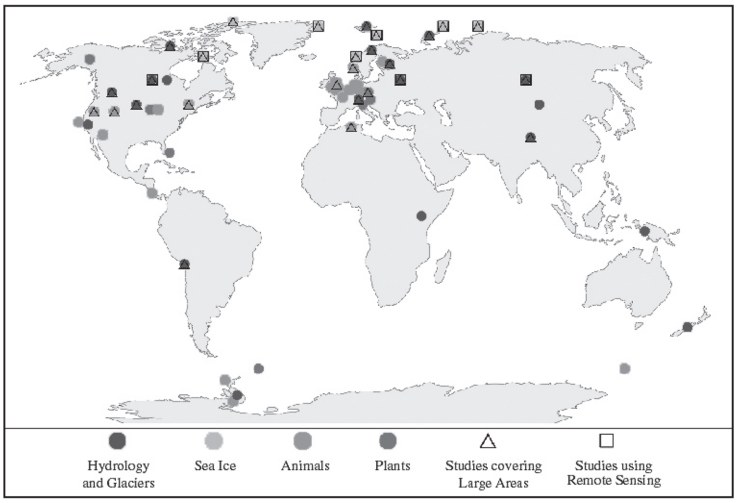
1. Introduction

The history of the Earth's climate has been characterized by many changes (see for example: Huntley and Webb, 1988, Bradley et al., 1991, Petit et al., 1999, EPICA community members, 2004). But the extent and the rate of current climate change exceeds all natural variation in the last thousand years and possibly further back in history (Houghton et al., 2001). Most of the observed recent warming is attributable to human activities, in particular to the increase in the atmospheric concentrations of greenhouse gases (GHGs) from burning fossil fuels, cement production, deforestation and industrial activities (Houghton et al., 2001). GHGs have the ability to intercept and re-emit heat which is radiated from the Earth's surface, and thus warm the lower atmosphere.
The last assessment of the Intergovernmental Panel on Climate Change (2001) (www.ipcc.ch) has provided evidence that 'an increasing body of observations gives a collective picture of a warming world and other changes in the climate system.' Such evidence led to the panel's conclusion that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". This is a much clearer statement than the 1996 conclusion of the second assessment report (Houghton et al., 1996): "The balance of evidence suggests a discernible human influence on global climate".
Climate change has already had a considerable impact on species and ecosystems, and on human health and society (Parmesan and Yohe, 2003, Root et al., 2003). These impacts are now being documented more carefully. The large number of observed responses seems to be linked to the recent changes in extreme weather events. The continuously updated World Impact Map (Box 1) illustrates that climate change is apparent and affects many different aspects of climate, nature and society. Al these impacts are expected to become more severe (Leemans and Eickhout, 2004).

Clearly, many ecological impacts of climate change can and have occurred naturally in the past, some even during times not considered to be globally warm periods. Impacts and the changes they generally depict, represent complex phenomena that generally have many causes. Thus, while many are consistent with warming trends, it is impossible to state for any single weather event that it is due to anthropogenic warming. A statistically rigorous attribution to global warming is often impossible because long-term data on weather and climate are rarely collected simultaneously with impacts. Observations of specific responses seem anecdotal, but all these responses put together start to corroborate clearer proof. Also recently, better documented and carefully analyzed climate changes and their consequent ecological responses have been published. The analysis and mapping of these few studies by the IPCC (Figure 1) led to their far-reaching conclusion that "recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems." In other words: climate change will not only happen in the future but it is already here.

The IPCC (2001) also concluded that there are severe time lags between climate policy development and actual emissions reductions, atmospheric concentrations and climate change. Additionally, emissions are likely to increase worldwide in the near future. Therefore, no matter what action is taken, the rise in global temperatures is expected to continue during the twenty-first century. As a response to these threats, the United Nations Framework Convention on Climate Change (UN-FCCC) was established in 1992. The ultimate objective of the UN-FCCC is to realize stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved with a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in

Figure 1 IPCC's global map of observed responses (Smith et al., 2001).



a sustainable manner (UNEP and WMO, 1992). The question is, however, how long do ecosystems require to adapt naturally?

In the early 1990s , climate protection targets were proposed based on irreversible impacts, but these were never seriously discussed within the UN-FCCC. Only Europe stated that climate change should be limited to 2°C (European Parliament and Council, 2002). In its third assessment report, the IPCC demonstrated that a global mean increase in average surface temperature of more than 2°C leads to a rapidly increasing risk of adverse impacts (Smith et al., 2001). In its own assessment, the UN Convention on Biological Diversity (UN-CBD) reviewed IPCC's evidence (AdHoc Technical Expert Group on Biological Diversity and Climate Change, 2003). They concluded that a climate change beyond 2oC was unacceptable for ecosystems and biodiversity.

Recent research (e.g. UNEP and WMO, 1992, Hare, 2003, Arctic Climate Impact Assessment, 2004, Leemans and Eickhout, 2004, Thomas et al., 2004) has shown that regionally species and ecosystems are much more vulnerable. Even below 2°C, many unique ecosystems will be threatened. Swart et al. (1998) pioneered a different approach. They looked at which ecosystems could adapt to rapid climate change by shifting ranges and concluded that a warming beyond 0.05°C per decade strongly limits the natural adaptive capacity of ecosystems like forests. This more transient approach thus could further constrain the targets that comply with the objective of UN-FCCC. This threshold was, however, exceeded during the 20th century and will probably continue to be exceeded in the 21st century.

In this report we will review the recent literature on observed and expected ecological responses of anthropogenic climate change. Our starting point is the IPCC reports, the CBD (2003) and EEA's climate impact report (EEA ETC/ACC et al., 2004). We will emphasize European responses. Parmesan and Gailbraith (2004) recently published a similar report reviewing the impacts in the US. Plants and animals respond to climate change in many ways. However, special emphasis will be made on changes in the timing of life-cycle events (phenological changes) and on changes in the geographical distribution of species. The ecological observations related to these indicators often systematically cover larger regions and periods. Additionally we provide evidence from the Dutch Nature Calendar project (www.natuurkalender.nl), which collects phenological information from all over The Netherlands from a large number of voluntary observers. The information provides a clearer fingerprint of observed changes since the last IPCC assessment and the World Impact Map. Chapter 2 provides a comprehensive overview of observed responses. It starts with a short overview of the observed changes in climate and other changes in the environment, such as glaciers and permafrost, followed

Box 1

The World Impact Map

(http://www.climatehotmap.org)

The World Impact Map of Early Warning Signs illustrates the global nature of climate changes. The map is designed to stimulate concern for the impacts of global climate change on the environment and society. To ensure its integrity and usefulness every effort was made to conform to sound scientific principles in its research and categorization. The basic criterion for inclusion of an event or trend on the map was its consistency with global climate model projections of a world with increased levels of atmospheric greenhouse gases, as outlined by IPCC (see also Smith et al., 2001). Events indicated on the map are divided into two categories:

Fingerprints. Some of the events are direct manifestations of a widespread and long-term trend toward warmer global temperatures, as already documented and projected to continue by models of a changing climate. The following events are identified as global warming fingerprints:

- Heat waves and periods of unusually warm weather
- Ocean warming, sea-level rise and coastal flooding
- Glaciers melting
- Arctic and Antarctic warming

Harbingers. The map also identifies events that foreshadow the types of impacts likely to become more frequent and widespread with continued warming. For these events, evidence for a direct link to long-term climate change cannot be confirmed or ruled out at this time. The following events are identified as global warming harbingers:

- Spreading disease
- Earlier spring arrival
- Plant and animal range shifts and population changes
- Coral reef bleaching
- Downpours, heavy snowfalls, and flooding
- Droughts and fires

Dr. Sharon Locke of the University of Southern Maine and Dr. Susanne Moser of the Union of Concerned Scientists researched, categorized, and described the events featured on this world map and completed a map update in January 2003 based on the latest scientific findings. This updated map builds on work originally undertaken by the Sierra Club and extended by Dr. Janine Bloomfield and Molly Smith of Environmental Defense and Dr. Sharon Locke for the first edition, published in 1999.

by a much more extensive discussion of observed responses for plants, animals and ecosystems.

Then we present expected changes derived from impact models and scenarios, and discuss the limitations of these approaches and relate their results to all the observed responses. One of the problems here is that most of the future impact assessments apply large climate changes (more than 2°C globally), while the observed responses result from a below-1°C warming. Another problem is that future impact assessment aggregate ecosystems into coarse units, while the observed responses show that each species displays unique responses. This study aims to overcome these shortcomings and analyzes why observed ecological responses are now reported more frequently.

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2. Observed Changes

2.1 Observed changes in climate

Briffa et al. (1995) have reconstructed temperature by comparing northern hemisphere treerings over the last 1,000 years. They found that the magnitude of 20th-century warming is likely the largest and exceeds by far all natural climate variations during this period. Similar but less pronounced trends are observed in the southern hemisphere. These changes are unusual both in terms of magnitude and rate of temperature change (Mann et al., 1999). However, if past climate variations were greater than those being measured now, then future climate also will be more sensitive to human activity (von Storch et al., 2004). In addition, direct measurements show that the 1990s are the warmest decade of the century. This rapid warming has continued in the first years of the 21st century. 1998 was the warmest year on record, immediately followed by 2002 and 2003. The IPCC (2001) supported this view and estimated global surface temperature to have increased 0.7°C increase since the late 19th century (with a 95% confidence interval of 0.4 to 0.8°C), but noted that this warming was also superimposed on strong decadal and regional variability worldwide (Figure 2). The IPCC (2001) attributed much of the warming to increased concentrations of greenhouse gases (Box 2).

Box 2

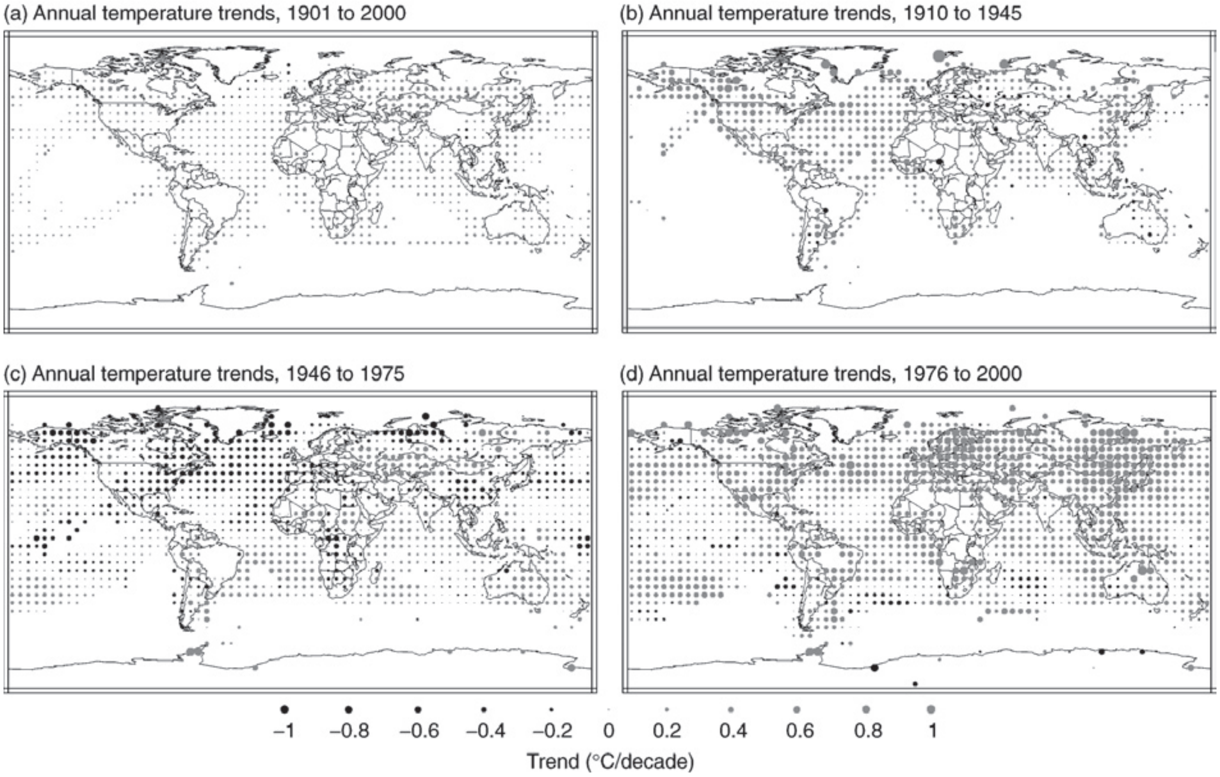
The increase in atmospheric concentrations of green house gases

According to IPCC (2001), the observed warming could not be explained alone by natural variability. The most important cause is the increase of GHGs, initiated in the nineteenth century, and particularly rapid since 1950. The maximum carbon dioxide (CO_2) levels during the last 1,000,000 years of 280 ppmv (EPICA community members, 2004) are already exceeded by 34 %. Also methane (CH_4) and nitrous oxide (N_2O) increased by 153 % and 17 %, respectively. The present concentrations of CO_2 of 375 parts per million (ppm) and CH_4 of 1,772 parts per billion (ppb) are unprecedented high; the present N_2O concentration of 317 ppb has most likely not been exceeded in the past 1000 years.

Concentrations of CO_2 seem to have increased more rapidly over the last few years. The reason for this is unclear. Possible mechanisms include less CO_2 uptake by warmer oceans (unlikely) or by the saturation of managed forests in temperate regions (likely and man-made), increased decomposition in boreal forests (likely but unfortunately natural and thus difficult to offset) or an increase of anthropogenic emissions, especially in rapidly developing countries such as China and India (very likely). The actual cause still has to be documented. CH_4 concentrations have leveled off in the last few years because of effective emission control. Concentrations of N_2O continue to rise at rates similar to those of the past decades. Concentrations of the ozone depleting gases CFCs and HCFCs, which were abandoned under the Montreal Protocol of the Ozone Convention, are now slowly declining. However, concentrations of halofluorocarbons are rapidly increasing, partly because they are substitutes for CFCs and HCFCs.

Most of this increase has occurred in two periods, from about 1910 to 1945 and since 1976 (Figure 2). Winter and nighttime minimum temperatures are continuing to increase faster than summer and daytime maximum temperatures, respectively, reducing seasonal and diurnal temperature ranges. New record high night-time minimum temperatures are shortening the frost season in many mid- and high latitude regions. Furthermore, most of this warming occurred on land, which tracks temperature change faster than large water bodies, although the oceans have also warmed significantly in the last 50 years, especially in the upper 300 metres. Since the late 19th century, the global average sea surface temperature has increased by 0.6°C, consistent with the increase in global air temperature. The Baltic and North Seas and the western Mediterranean show a warming of about 0.5°C over the past 15 years (EEA ETC/ACC et al., 2004). Sea surface temperatures in the North Atlantic has been rising since the mid-1980s, which could have been part of a fluctuation over several decades. This is, however, unlikely because the warming has accelerated over the last five years. This contributed to the rapid parallel increases of surface air temperature in much of Europe (KNMI, 2003).

Figure 2 Regional trends in annual temperature during the 20th century (after Houghton et al., 2001).



Because of the increase in the temperature of the North Atlantic, Europe has warmed more than the global average, with a 0.95°C increase since 1900. The warming has been greatest in north-west Russia and the Iberian Peninsula (EEA ETC/ACC et al., 2004). Additionally, in the past 100 years the number of cold and frost days has decreased in most parts of Europe, whereas the number of days with temperatures above 25°C and of heatwaves has increased considerably (EEA ETC/ACC et al., 2004).

The increase in global temperatures has thus resulted mainly from a significant reduction in the frequency of much below normal seasonal mean temperatures across much of the globe, with a correspondingly smaller increase in the frequency of much above “normal” temperatures. The high temperatures of the European summer in 2003 were partly caused by a simultaneous lack of soil moisture and evaporation, which raised temperatures over land much more rapidly than anticipated. Such systemic interactions could well lead to larger extreme events in the future (Klein Tank, 2004).

Annual precipitation trends in Europe for the period 1900–2000 show a contrasting picture between northern Europe (10–40% wetter) and southern Europe (up to 20% drier). Changes have been greatest in winter in most parts of Europe (EEA ETC/ACC et al., 2004). The IPCC (2001) states that there has likely been a widespread increase in very heavy rain in regions where total precipitation has increased. In some regions, increases in heavy rainfall have been identified where the total precipitation has decreased or remained constant, such as east Asia. This is attributed to a decrease in the frequency of precipitation. Where data are available, changes in annual river run-off relate well to changes in total precipitation and partly explain the increase in the frequency and severity of floods.

Although the temperature changed significantly in the past decades, there seems to be little sign of long-term changes in storm intensity and frequency, but inter-decadal variations are pronounced. Recent analyses of changes in severe local weather (tornadoes, thunder, lightning and hail) in a few selected regions provide evidence for widespread systematic long-term changes. This is because it is extremely difficult to relate individual events to larger scale trends. However, the unusual intensity of hurricanes and typhoons in 2004 cannot be explained by natural variability alone and could well be linked to human-induced climate change, as shown by new model results from Sumi et al. (2004).

The costs of extreme weather events have risen rapidly in recent decades, despite significant and increasing efforts at strengthening infrastructure and enhancing disaster preparedness (McCarthy et al., 2001). Also in Europe, a larger number of all catastrophic events since 1980 are attributable to weather and climate extremes: floods, storms, droughts and heatwaves (EEA ETC/ACC et al., 2004). Part of the observed upward trend in historical disaster losses is linked to socio-economic factors such as population growth, increased wealth, and urbanization in vulnerable areas, and also to climatic factors such as observed changes in precipitation, flooding and drought events. Precise attribution is complex, and there are differences in the balance of these two causes by region and by type of event. Many of the observed trends in weather-related losses, however, are consistent with what would be expected under climate change. Notably, the growth rate in human-induced losses and those unrelated to weather has been far lower than that of weather-related events.

Klein Tank (2004) recently analyzed European patterns of climate change and came to a surprising conclusion: although there have been obvious changes in the mean climate, most of the observed ongoing climate change can be attributed to changes in extremes. He and his colleagues have created a meticulous database of long daily temperature and precipitation series. This series clearly showed statistically significant and non-trivial changes in extremes: fewer cold extremes, more warm extremes (heatwaves), smaller diurnal and seasonal ranges, more precipitation that comes mostly in the form of intense showers. Selten et al. (2004) showed that these changes could not be the result of natural variability but are linked to anthropogenic changes of the climate system. Klein Tank (2004) concludes that larger extreme events can be expected in the future, often also aggravated by systematic interactions. This was well illustrated by the exceptionally hot summer in Europe in 2003. The high temperatures were partly caused by a simultaneous lack of soil moisture and evaporation, which raised temperatures over land much more rapidly than anticipated.

The next sections discuss the consequences of these changes. First, the changes in the physical environment are reviewed (glaciers, ice sheets, snow cover, the hydrology of rivers, sea level rise and fires). Most of these changes are well documented (e.g. Figure 1) and their links with climate change are established. Second, the changes in ecosystems are presented and discussed. These changes occur on a much smaller scale and cannot always be unequivocally connected to ongoing climate change. These reviews indicate that many more impacts have been identified since the last IPCC assessment (2001) and the last update of the World Impact Map (cf. Box 1). Now not a single region is unaffected.

2.2 Observed changes in the physical environment

2.2.1 Changes in the cryosphere

The cryosphere consists of land-based ice, sea ice and permafrost. Ice accumulates during cold periods and melts during warm periods. A glacier, ice cap or ice sheet gains mass by accumulating snow, which is gradually turned into ice, and loses mass (ablation) mainly by melting at the surface or base with subsequent run-off or evaporation of the meltwater. Some meltwater may refreeze within the snow instead of being lost, and some snow may sublimate (i.e. escape as water vapour) or be blown off the surface. The mass balance for an individual body of ice is usually expressed as the rate of change of the equivalent volume of liquid water (in m3/yr). The mass balance is zero for a steady state. The winter mass balance mostly measures accumulation; the summer surface melting. Changes have been observed in the cryosphere over the last century. For many decades, most of the glaciers have been retreating, ice has been getting thinner, permafrost has disappeared and the season of snow and ice cover has shortened (McCarthy et al., 2001). Most of the recent changes are consistent with observed and simulated warming. Over the last few years the rate of change in the cryosphere has accelerated (Diaz et al., 2003).

Lake ice duration

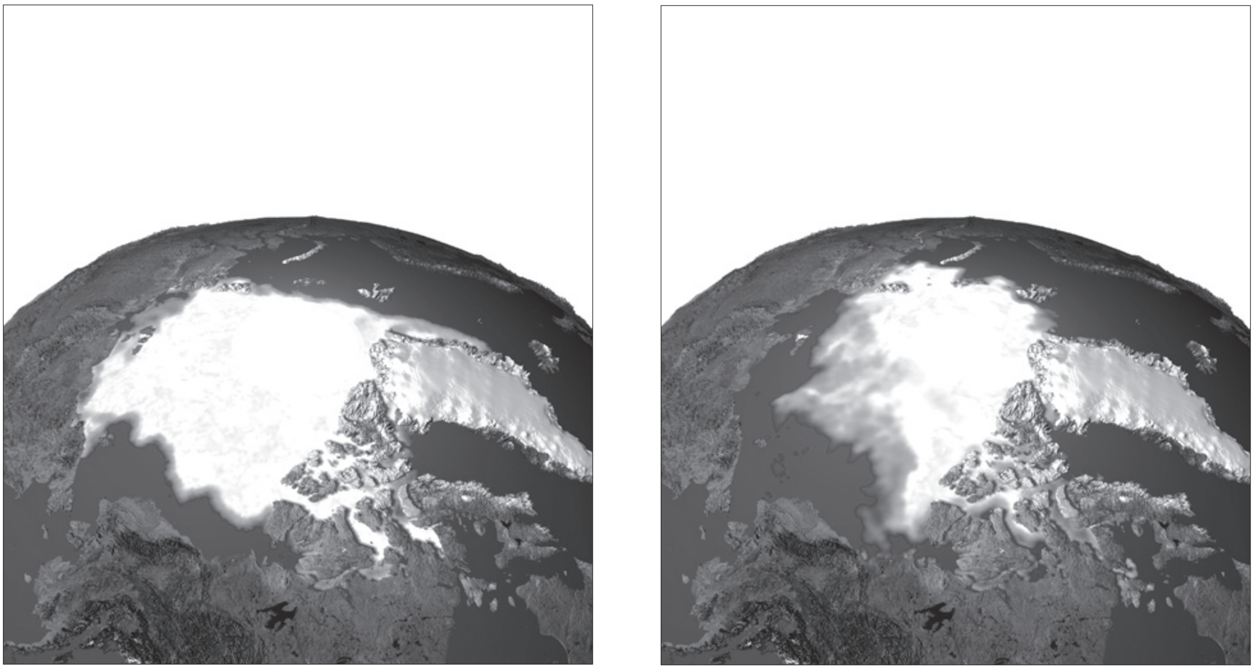
Although in the early 1990s, data for some regions, such as eastern Canada, do not apparently show decreasing trends in lake ice duration (Walsh, 1995), there is nowadays a clear decreasing trend globally (Caine, 2002).

Sea ice cover and thickness

The potential of monitoring by satellite has been realized for several variables (extent of sea ice, snow cover). This has unambiguously shown that the extent of the Arctic ice has decreased considerably in the last decade. These changes are probably also attributable to recent warming.
The total area of Arctic sea ice shrank by more than 7% during the last two decades (Figure 3). Recent data from submarines indicate that the thickness of the ice submerged under the sea at the end of the melting season decreased from three to less than two metres. The volume is down by about 40% on average (i.e. near 4cm per year) between the late 1950s and the present, albeit with large regional variability (Grumet et al., 2001, Arctic Climate Impact Assessment, 2004). The duration of the summer melt season over a large proportion of the perennial Arctic sea ice increased by 11 days since the 1970s. The reduction in seaice in the Arctic spring and summer is consistent with an increase in spring temperatures, and to a lesser extent with summer temperatures in the high latitudes. There is little indication of reduced Arctic seaice extent during winter, when temperatures are still far below freezing, despite apparent warming.

Similar trends are observed in Antarctica. The sea ice around Antarctica declined over the last century. This has been reconstructed by using the well-documented location of whale catches (de la Mare, 1997). The melting of seaice and the consequent decrease in its extent has continued (Curran et al., 2003). These changes in Arctic and Antarctic sea ice cover have significant consequences for vulnerable wildlife, such as polar bears, seals and penguins.

Figure 3 The extent of Arctic seas ice in 1979 (left) and 2003 (right) (Source: NASA, http://earthobservatory.nasa.gov/Newsroom/).



The new satellite instruments show that the Greenland Ice Sheet is losing mass by near-coastal thinning, and that the West Antarctic Ice Sheet, with thickening in the west and thinning in the north, is probably thinning overall (Shepherd et al., 2003). The mass imbalance of the East Antarctic Ice Sheet is small. Large sectors of ice in southeast Greenland, the Amundsen Sea Embayment of West Antarctica, and the Antarctic Peninsula are changing quite rapidly (Rignot and Thomas, 2002). All these changes are a consequence of greater than average warming in Antarctica (Vaughan et al., 2003).

Snow cover

Although many data collections suggest an increase of snowfall over high latitudes, Myneni et al. (1997) show that annual snow cover extent has decreased by about 10% in the northern hemisphere. The snow-cover period in the northern hemisphere land areas between 45°N and 75°N grew shorter by an average of nine days per decade between 1971 and 1994. This results in earlier and more rapid melting, which has consequences for river run-off and water availability (Serreze et al., 2000). There is a highly significant correlation visible between increases in the northern hemisphere spring land temperatures and a reduction in the snow cover since measurement data have been collected.

Size of glaciers

Most mountain glaciers are receding rapidly. For example, the hundreds of glaciers in the US Glacier National Park and adjacent Canadian Waterton Lakes National Park are expected to disappear completely by 2030 (Arendt et al., 2002). However, glaciers in a few maritime regions are advancing, mainly due to increases in precipitation (e.g., Norway, New Zealand). Many glaciers in the Alps receded more than 5% in 2003 alone. During the extremely warm summer of 2003, some of these glaciers did not retreat but actually collapsed. Such rapid melting creates unstable slopes when the sun melts surface ice. Rockfalls can then pose a hazard to climbers and tourists. All these changes have large implications for tourism (mountaineering, hiking and skiing), water resources and

hydroelectric power, and land-use management and planning. For example, the recent outlawing of climbing on the Swiss Eiger's north face due to unstable snow and rock shows that alpine climbing may soon face crisis.
In the tropics, all glaciers (South America, Africa and Asia) are retreating rapidly (e.g. Schotterer et al., 2003). The last ice of the glacier on mount Kilimanjaro in Kenya/Tanzania will likely melt before 2020 (Thompson et al., 2002), threatening several unique alpine ecosystems and local biodiversity and run-off volumes. Similar trends are observed for most of the Himalayan glaciers (Sharma et al., 2000, Singh and Sontakke, 2002). The shrinking of glaciers could threaten water availability downstream in the warmer seasons and adversely impact many ecosystems, biodiversity and the livelihoods of many people.

Permafrost

Permafrost is permanently frozen soil. Changes in permafrost are not as easily detected as those in ice and snow, but have far-reaching consequences. In constructing infrastructure in polar regions, such as roads and pipelines, it is generally assumed that permafrost provides a stable foundation. Anisimov (1989) was among the first to show that nowadays this assumption is flawed. He analyzed long-term data for Russia and Siberia and concluded that permafrost is already thawing, resulting in a polewards shift of seasonally unfrozen ground. The melting of the polar permafrost areas actually began in the middle of the 19th century, due to somewhat warmer temperatures (Overpeck et al., 1997). Their analyses clearly demonstrate the sensitivity of permafrost regions to even slight warming. Warming has accelerated more over the last decades here than in any other region of the world. Yet increased melting trends are now observed in all the world's polar systems (e.g. Kwong and Gan, 1994, Serreze et al., 2000). In Fairbanks, for example, the mean annual temperature of the soil increased with by between 2°C and 3°C in the last 50 years. The temperature at a soil depth of one metre increased to just below freezing point.
The accelerated melting of permafrost will alter the hydrology of many northern rivers (van der Linden et al., 2003). Major implications for vegetation structure and processes are also foreseen. Jorgenson et al. (2001), for example, experimented with the warming of ecosystems and unambiguously showed that warming of a few degrees leads to release of carbon (e.g. Waelbroeck et al., 1997, Welker et al., 2000). This process might explain recent observed accelerated rapid increase in atmospheric CO2 concentrations.

2.2.2 Changes in river discharge

The water that flows in the world's rivers originally comes from precipitation. Run-off results from the balance between precipitation, groundwater recharge, groundwater discharge and evaporation. There are many delays in the system. Precipitation can be stored in winter as snow and ice and is only released during the melting season. Some water slowly infiltrates the soil, flows as groundwater and re-emerges in spring. These storage processes often buffer water sources and determine water availability for human use, even when there is little precipitation.
The declining glaciers and snowfields in the Himalayas, for example, strongly affect run-off and water availability in the Indo-Gangetic plains region of India and Bangladesh, which is very important for the food security of South Asia. The region's population grew at a rate of about 1% per annum during the past four decades, which has led to a strong intensification of crop irrigation and of agricultural land use. Although temperature and precipitation increased somewhat, the river data indicated an overall decrease in discharge (Sharma et al., 2000). The decreasing trends of stream flow were more significant during the low-flow months when most of the water originates from snow melt, which permits a constant water supply throughout the year (Sharma et al., 2000, Singh and Sontakke, 2002). All these factors make the society of the Indo-Gangetic plains region one of the most vulnerable in the world to changes in climate.

Annual river discharge has changed over the past few decades across Europe. In some regions, including eastern Europe, it has increased, while it has fallen in others, including southern Europe. Some of these changes can be attributed to observed changes in precipitation. The combined effect of projected changes in precipitation and temperature will in most cases amplify the changes in annual river discharge. Annual discharge is projected to decline strongly in southern and south-east Europe but to increase in almost all parts of northern and north-east Europe, with consequences for water availability. Between 1975 and 2001, 238 flood events were recorded in Europe. Over this period the annual number of floods clearly increased. The number of people affected rose significantly, with adverse physical and psychological consequences for people. Deaths per flood decreased significantly due likely to improved warning and rescue measures (EEA ETC/ACC et al., 2004).

2.2.3 Sea level rise

Over the last 100 years, the global sea level has risen by about 10cm to 25cm. Sea level change is difficult to measure. Relative sea level changes have been derived mainly from tide data. In the conventional tide-gauge system, the sea level is measured relative to a land-based tide-gauge benchmark. The problem is that land suffers vertical movement (e.g. isostatic effects and sedimentation) and these complicate measurement. However, improved methods to remove the effects of long-term vertical land movements, as well as a greater reliance on the longest tide-gauge records and new satellite measurements for estimating trends, have provided greater confidence that the volume of ocean water has indeed been increasing, causing the sea level to rise within the given range. The major causes of this increase are thermal expansion of the surface waters and melting of glaciers and snow on land and the Greenland ice cap (McCarthy et al., 2001).

2.2.4 Fire in ecosystems

Climatic changes have increased the length and intensity of summer drought in many regions. This has increased the susceptibility of ecosystems to fires. Over the last decade fire frequency increased in many regions:

- Spain lost more than 485,622 hectares of forest to wildfires in 1994 and 149,734 hectares burned away in Italy in 1998 (Pinol et al., 1998).
- Fires due to dry conditions and record-breaking heat consumed one-fifth of vegetation on the island of Samos, Greece in July 2000 (C. Körner, personal communication). Temperatures reached 40oC in some localities. Simultaneously, many of the mountain springs dried up. Together they are clear indicators of unprecedented warming trends.
- Fires burned up to 809,371 hectares of rainforest in Indonesia (Page et al., 2002), including almost 101,172 hectares of primary forest and parts of the already severely reduced habitat of the Kalimantan orang-utang .

2.2.5 Treeline and growing season

Since the nineteen seventies, satellite measurements have been made to monitor changes in the environment. Myneni et al. (1997) have analyzed this data to detect if there were indications of widespread global warming over land in the northern hemisphere. From their NDVI (an index of plant growth) data for 1981 to 1991 they found a surprisingly large increase over large regions. They found an earlier greening of vegetation in spring of up to ten days and a later decline of a few days in autumn over large parts of the northern hemisphere. Although it was confirmed later by Los (1998), many have criticized this kind of analysis and blamed it on drift in the satellite instruments (similar arguments arose when the ozone hole was first measured over Antarctica). Lucht et al. (2002) have used a global vegetation model and an independent high-resolution database of observed climate. They simulated a similar trend over the 1980s and a marked setback in this trend after the 1991 volcanic eruption of Mount Pinatubo, which caused a temporary cooling. The observed trend toward earlier spring budding and increased maximum leaf area in the 1980s is reproduced by the model, but restored the two subsequent years after the eruption. They also simulate a small increase in carbon uptake due to this cooling (decomposition was reduced more than primary productivity), which could well explain the slower increase of atmospheric CO2 in those years.

The satellite-observed changes indicate a longer growing season for vegetation. Such phenomena have also been observed elsewhere. Several studies, for example, report a polewards shift of the treeline border between trees and tundra (e.g. Lavoie and Payette, 1994, Walsh, 1995). Increases in the width of tree rings (e.g. Villalba et al., 1994, Villalba et al., 2003) have also been detected near the treeline. These observations are made in many different parts of the world. The next sections discuss them in detail.

2.3 Observed ecological changes

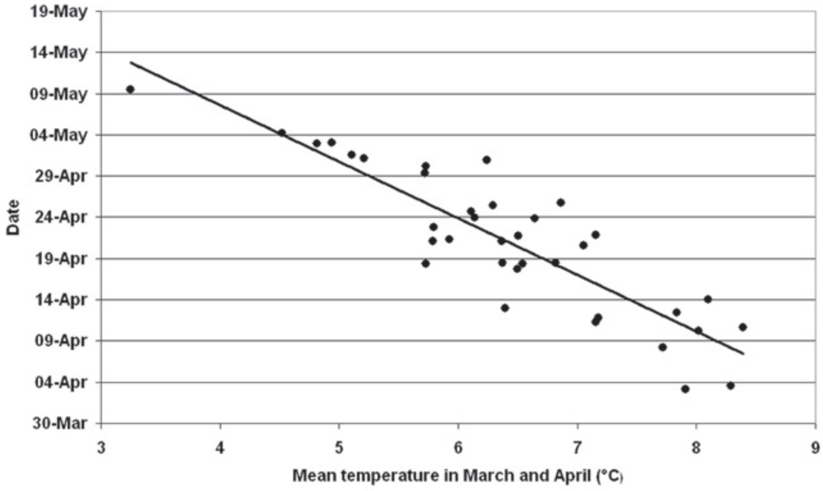
In this chapter we discuss a large number of observed ecological changes. Some were included in the third assessment report of the IPCC (2001) but many are new. We focus on Europe and The Netherlands. Comprehensive global reviews are available elsewhere (e.g. Root et al., 2003). Our aim is not to provide a complete overview of all known impacts but to make clear that ecological changes are already large, and that all species groups show changes which occur in every ecosystem on Earth. We make a distinction between two main biological responses to changes in climate: phenological changes which are changes in the timing of life cycle events, and distributional changes in populations of plants and animals in specific areas.

2.3.1 Phenological changes as a response to climate change

One of the most obvious indicators of ecological impacts of climate change are phenological changes. Phenology deals with the times of annual natural events like flowering, leaf unfolding, ripening of fruits, leaf colouring, leaf fall, bird migration, frog spawning, and bird nesting which can be observed by satellites or in the backyard. The timing of these events is often closely related to temperature and the amount and timing of precipitation. Figure 4 illustrates this relation. It shows that the average temperature in March and April determines the start of flowering of Birch (Betula pubescens) in The Netherlands. In temperate zones an increase in temperature leads to an earlier start of the growing season and a later end. The length of the growing season is expected to increase with warming. Only in those places where environmental conditions like drought, flooding or large amounts of snowfall limit plant growth will an increase in temperature not immediately result in a lengthening of the growing season.

Plants are flexible in adjusting the timing of their phenological events to changes in climate conditions (cf. Figure 4). In warm springs, Birch trees flower at the end of March in The Netherlands while in very cold springs the start of flowering only starts at the end of April. The observed recent increases in temperature should have become visible as changed timings of phenological events. Historical observations are needed to document these changes. One must know dates of the start of past flowering or bird migration events. Fortunately, centuries ago, people recorded the timing of both life-cycle events and weather to help agriculture and hunting. By observing the timing of flowering they knew when to plant and harvest their crops or when to hunt. The documentation of these observations now helps us to assess long-term changes.

Figure 4 **Relation between timing of Birch flowering in The Netherlands and the spring temperature.**



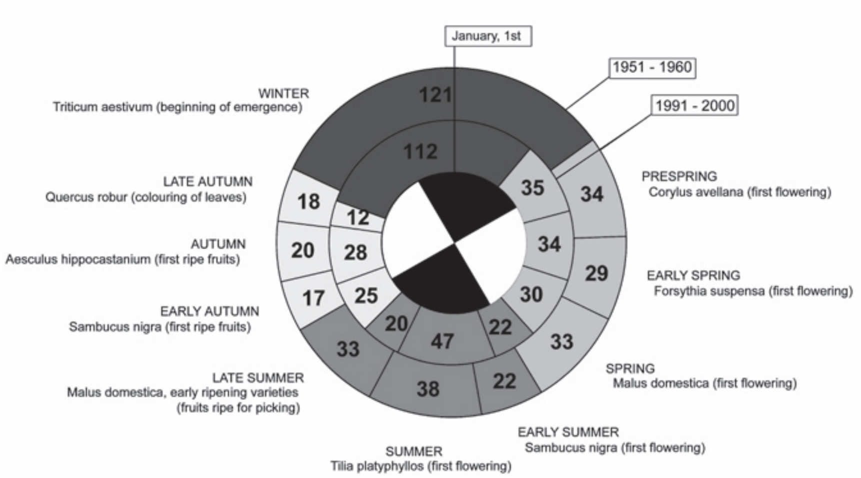
Phenological networks that monitor the timing of life cycle events have been established in many countries. The records go back hundreds of years and many are still being expanded (e.g. in Japan, Finland and the United Kingdom). A detailed overview of the existing networks is provided at the phenological meta-database (http://www.dow.wau.nl/msa/epn). The documentation of these observations now helps us to assess long-term changes. These long-term observations also play a key role in visualizing the ecological impact of climate change on the timing of life cycle events. In the Netherlands, for example, systematic phenological observations have been made from 1869 till 1968. In 2001 this Dutch network was successfully revived under the name Nature's Calendar (Natuurkalender, http://www.natuurkalender.nl). Since then, thousands of volunteer observers have submitted their own phenological observations on plants, butterflies, birds and dragonflies. Because of the availability of historic observations, the visibility of life cycle events and their quick response to climate variations, climate change induced changes in the timing of life cycle events have significantly contributed to the conclusion of IPCC (IPCC, 2001) that the recent changes in climate already have an impact on ecological systems. Many scientific papers on this topic have been published recently (Parmesan and Yohe, 2003, Root et al., 2003). All species groups examined have showed significant changes in the timing of their own life cycle events. Below, an overview of species group responses is given.

Plants

Most of the phenological networks focus on plants. Observers are asked to record the start of flowering, leaf unfolding, fruits ripening, leaf coloring and leaf fall. These events indicate the length of the growing season. In the last few years a large number of studies demonstrated that the length of the growing season is indeed increasing. Menzel (2000) studied phenological changes in international phenological gardens from all over Europe from 1959 till 1996, determining that spring events such as leaf unfolding have advanced on average by 6.3 days whereas autumn events such as leaf coloring have been delayed on average by 4.5 days. The annual growing season thus increased on average with 10.8 days since the early 1960's (Menzel and Fabian, 1999, Menzel, 2000). Even an analysis of the satellite data since 1975 showed a clear signal of lengthening growing seasons over large parts of the Northern hemisphere (Myneni et al., 1997).
Although the first day of meteorological spring, summer, autumn and winter start at the same date every year, the biological start and end of the seasons varies from year to

year. This is illustrated by analyses of the German Meteorological Service. Instead of four seasons they divide the year into 10 different seasons: Pre-spring, early spring, spring, early summer, summer, late summer, early autumn, autumn, late autumn and winter. The start of the next season is determined by the timing of certain life cycle events. Figure 5 presents the changes in seasons that are taking place. It compares the start of various seasonal growth phases in the period 1951 – 1960 with the start in the period 1991-2000.

Figure 5 **Phenological calendar for Rhineland-Palatinate, Germany. Ten phenological seasons (outer sections with the length in days) and the climatological seasons clockwise in the center (source: Y. Henniges, German Metereological Service).**



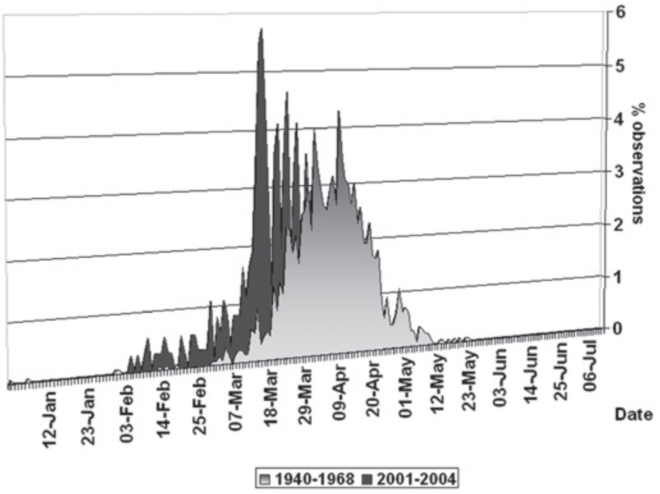
Large changes have been observed in the start of the growing season in the Netherlands. Observations are available from various sources, including the Natuurkalender. The Netherlands experienced several record temperatures. These records show a significant impact on the timing of flowering and leaf unfolding. 2004 was no exception to this trend (Table 1. Figure 6). Already in the beginning of February maximum temperatures rose to 18°C, which was never experienced before. In 2004, the timing of life cycle events in plants was on average 16 days earlier than observations in the past (1868 till 1968). Not all phases advanced in the same way. Yellow Water-Lily, for example, was only 4 days earlier but plants like Snowdrop, Alder, and Cow-parsley were, on average, more than three weeks earlier. In several European countries a significant advance has been observed in the flowering time of Wood Anemone. In Estonia, for example, it advanced its flowering with 17 days in 78 years (Ahas, 1999) and in Norfolk (UK) every 1°C increase in temperature of January to March advances flowering with 7 days (Sparks and Menzel, 2002) while the average advance for the whole of the UK is only 4 days (Sparks et al., 2000).

Table 1 **Difference of the timing of life cycle events in the past compared with 2004. Data are taken from the Dutch Natuurkalender.**

Species	Average date in historic series	Average date in 2004	Number of days difference
Hazel (Corylus avellana), flowering	11-Feb	23-Jan	18
Snowdrop (Galanthus nivalis), flowering	19-Feb	25-Jan	25
Common Alder (Alnus incana) flowering	28-Feb	01-Feb	27
Alder, (Alnus glutinosa) flowering	28-Feb	10-Feb	18
Colt’s foot (Tussilago farfara) flowering	21-Mar	01-Mar	20
Small selandine (Ranunculus ficaria) flowering	23-Mar	03-Mar	20
Blackthorn (Prunus spinosa) flowering	18-Apr	09-Mar	39
Sweet violet (Viola odorata) flowering	28-Mar	10-Mar	18
Wood Anemone (Anemone nemerosa) flowering	05-Apr	21-Mar	15
King-cup (Caltha palustris) flowering	16-Apr	27-Mar	20

Species	Average date in historic series	Average date in 2004	Number of days difference
Ground ivy (Glechoma hederacea) flowering	19-Apr	29-Mar	21
White deadnettle (Lamium album) flowering	23-Apr	04-Apr	19
Horse chestnut (Aesculus hippocastanum) leaf unfolding, flowering	13-Apr	05-Apr	8
Lady's mock (Cardamine pratensis) flowering	21-Apr	05-Apr	15
Birch (Betula pendula) , flowering	20-Apr	07-Apr	13
Cow-parsley (Anthriscus sylvestris) flowering	04-May	09-Apr	24
Bird cherry (Prunus padus), leaf unfolding	15-Apr	11-Apr	3
Beech (Fagus sylvatica), leaf unfolding	29-Apr	13-Apr	15
Mouse-ear chickweed (Cerastium arvense) flowering	02-May	14-Apr	18
Garlic mustard (Alliaria petiolata) flowering	02-May	17-Apr	14
Broom (Cytisus scoparius) flowering	11-May	17-Apr	23
Meadow buttercup (Ranunculus acris) flowering	04-May	19-Apr	15
Bird cherry (Prunus padus), flowering	04-May	20-Apr	14
Pedunculate oak (Quercus robur), leaf unfolding	05-May	20-Apr	15
Common lilac (Syringa vulgaris), flowering	09-May	26-Apr	13
Horse chestnut (Aesculus hippocastanum), flowering	11-May	27-Apr	13
Hawthorn (Crataegus monogyna), flowering	16-May	28-Apr	18
Creeping buttercup (Ranunculus repens), flowering	07-May	28-Apr	8
Rowan (Sorbus aucuparia), flowering	13-May	01-May	12
Laburnum (Laburnum anagyroides), flowering	17-May	02-May	14
Ragged robin (Lychnis flos-cuculi), flowering	14-May	09-May	5
Ox-eye daisy (Leucanthemum vulgaris), flowering	23-May	10-May	13
Yellow flag (Iris pseudacorus), flowering	25-May	17-May	8
Elder (Sambucus nigra), flowering	04-Jun	20-May	15
Yellow water-lily (Nuphar lutea), flowering	28-May	23-May	4
Bog heather (Erica tetralix), flowering	20-Jun	24-May	27
White water-lily (Nymphaea alba), flowering	03-Jun	28-May	5
Meadow sweet (Filipendula ulmaria), flowering	02-Jul	19-Jun	13
Purple loosestrife (Lythrum salicaria), flowering	06-Jul	25-Jun	10
Tansy (Tanacetum vulgare), flowering	17-Jul	01-Jul	16
Heather (Calluna vulgaris), flowering	03-Aug	07-Jul	26
Rowan (Sorbus aucuparia), fruits ripe	24-Aug	27-Jul	27

Figure 6 **Flowering of Wood anemone (Anemone nemerosa) in The Netherlands in two different periods (Source, De Natuurkalender).**

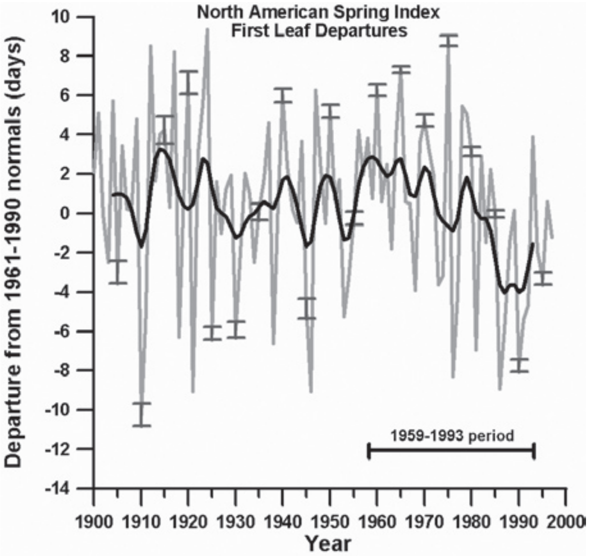


Phenological networks are not the only source of phenological information. Pollen monitoring networks, for example, also are able to provide phenological information. The members of the European Pollen information and the European Aeroallergen Network have set up a database with daily pollen information on 17 pollen types from 450 stations from all over Europe from 1974 onwards. With this pollen database Jäger (2001) calculated trends for start, peak and end of pollen season as well as trends for intensity and duration of pollen seasons during the past three decades. In general, an earlier start and peak of pollen seasons was clearly evident, being more pronounced in species that flower earlier in the year (up to 20 days). The later the flowering time, the less significant trends become towards earlier start of the season. A later end of the season becomes more likely the later the flowering period. Overall, the pollen season expands. Pollen seasons became longer in particular for species flowering after March/April. An increase of the amount of pollen in the air is not common, but is more frequently observed for grass and weed pollen than for trees (Huynen et al., 2003). The trend towards earlier flowering has also been observed in the Netherlands. The start of the pollen season in the Netherlands advanced with up to 22 days between 1969 and 2000. The smallest advance of three days was seen for Ash (Fraxinus excelsior) while the largest advance (22 days) was shown by Elm (Ulmus procera) (van Vliet et al., 2002).

Other examples of observed phenological changes in plants are:

- Flowering dates of the Locust Tree (Robinia pseudoacacia) in Hungary occurred 3-8 days earlier during the period 1983-1994 compared to 1851-1930. The study indicates that a rise in temperature of 1°C causes an advanced flowering by 7 days (Walkovszky, 1998).
- The growing season has lengthened by over 10 days over the last century in Turku, central Finland. Throughout the Nordic region the start of the growing season has become progressively earlier by between 4 and 12 days (Carter, 1998).
- Primack et al (2004) provided a revealing record. They compared the flowering times of 229 living plants in 2003 at the Arnold Arboretum in Boston, Massachusetts, combined with 372 records of flowering times from 1885 to 2002 using herbarium specimens of the same individual plants. During this period, Boston experienced a 1.5 oC increase in mean annual temperature. Flowering times became progressively earlier: plants flowered 8 days earlier from 1980 to 2002 than they did from 1900 to 1920. Most of this shift toward earlier flowering times is explained by the influence of temperature, especially in the months of February, March, April, and May. Plants with a long flowering duration appear to be as useful for detecting responses to changing temperatures as plants with a short flowering duration.
- An increase of average air temperature between February and April of 1.6°C between 1961 and 2000 led to and advance cherry tree blossom in Germany of eight days. The start of flowering of apple trees and the beginning of stem elongation of Winter Rye follow the same pattern (Roetzer and Chmielewski, 2001, Chmielewski, 2003).
- Schwartz and Reiter (2000) examined spring seasons across North America over the 1900-1997 period using modelled and actual Lilac phenological data (Figure 7). Regional differences were detected, as well as an average 5-6 day advance toward earlier springs over a 35-year period from 1959-1993.
- Chen (2003) analyzed phenological research in east Asia. He presented results of an analysis of data from 104 phenological stations in Japan during 1953 to 1990 which concluded that with an increase of 1°C in mean monthly temperatures, the flowering dates of Prunus yedoensis and Prunus mume would advance by 2.7-4.8 days and 4-13 days, respectively. In autumn, the leaf colour changing dates of Ginko biloba and Acer palmatum would be delayed by between 2-7 days. However, as the temperature in Japan decreased with 0.16-0.4°C per ten years, the average start of flowering of Prunus yedoensis was delayed.

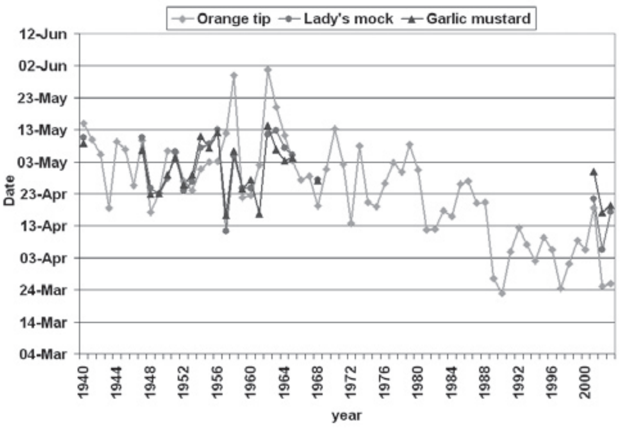
Figure 7 **North American Spring Index, first leaf departures (Source: Schwartz and Reiter, 2000).**



Insects

The Dutch phenological monitoring network also includes butterflies in its monitoring programme. The high temperatures have resulted in remarkable changes. The programme includes two migratory butterflies, the Red Admiral (Vanessa atalanta) and Painted Lady (Vanessa cardui). Every year they migrate to the Netherlands from southern Europe and used to arrive in May. However, the recent warm years have resulted in a large number of first sightings in January. There is evidence that the Red Admiral now manages to winter in the Netherlands. It probably benefitted from now common warm winter winds from the south, explaining many of the early sightings in 2004. At the same time a number of Painted Ladies were observed in the south-west Netherlands and in the south of the United Kingdom. These migratory butterflies are not the only ones that showed a response to warm weather. Most of the butterflies appeared early in the last couple of years. For example, the Orange Tip (Anthocharis cardamines) butterfly appeared early May in the 1940s (Figure 8) while it nowadays appears already early April. The first appearance advanced on average a month in the observation series (source: Dutch Butterfly Conservation). Because of the early start of the flight period, the active season increased substantially and many butterfly species were able to produce more generations each year.

Figure 8 **First appearance of the Orange tip (Anthocharis cardamines) butterfly in The Netherlands in relation to the flowering time of two host plants (Sources: Dutch Butterfly Conservation and De Natuurkalender).**



The advancing first appearance was already studied by Ellis et al. (1997) who found that the flight peak of Microlepidoptera (moths) advanced an average of 11.6 days between 1975 and 1996. A recent analysis of dragonfly data revealed that the first appearance advanced in a spectacular way, sometimes by more than a month (Ketelaar, 2003). Part of the advance is probably caused by an advance in the timing of observers going into the field. However, Ketelaar (2003) also looked at the changes in peak flight of 10 common dragonfly species and found changes ranging from no advance of the Common Blue Damselfly (Enallagina cyathigerum) to an advance of 18.3 days of the Large Red Damselfly (Pyrrhosoma nymphula). It is highly likely that many other insect species respond in the same way as the butterflies and dragonflies. The warm start of 2004 which was followed by a warm summer resulted in a very early appearance of wasps in the Netherlands. Also the number of nests was substantially higher than in other years (source: Dutch Butterfly Conservation).

The first appearances of most British butterflies have also advanced in the last two decades and are strongly related to earlier peak appearance, and for multi-brooded species a longer flight period (Roy and Sparks, 2000). In the UK the first appearance of Peach-Potato aphid (Myzus persicae) in the UK advanced by 16 days with an increase of 1°C (Cannell et al., 1999). These analyses indicate that a 1°C increase in temperature advances first and peak appearance of most butterflies by 2-10 days.

Birds

Birds are monitored intensively by thousands of people. A lot of birdwatchers record the arrival and to a lesser extent departure of migratory birds. Furthermore, the timing of first singing, egg-laying, egg-hatching and moulting are recorded. As with plants and insects, the timing of these events is determined by climate variables like temperature and rainfall. Changes in the timing have been observed in the past decades. The recent change in timing of the arrival of many migratory birds, however, has not been as large as the changes recorded for plants and insects. According to Sparks and Menzel (2002) a temperature response in bird migration timing has been reported across Europe. An example of the change in recent times is provided by the arrival dates of the Sand Martin (Riparia riparia) in Essex, UK. This is now some 20 days earlier than it was 50 years ago, and a strong response to March temperature of four days per °C is apparent. This is greater than recorded for many bird species, and there is a suggested differential response between species that may lead to changed competition for resources. This was evident also in Poland, where the advance of short-distance (European) migrants was more marked than that for long-distance (African) migrants (Tryjanowski et al., 2002). In some other cases no clear trends in arrival dates have been found. The first arrival dates of the River Warbler (Locustella fluviatilis), for example, varied between 23 April and 10 May with no significant directional trend during the period 1963-2003 (Kaòušèák et al., 2004). A study of the relation between the arrival of 81 migratory birds at two Finnish bird observatories (1960-1999) and the North Atlantic Oscillation (NAO) concluded that there is a negative correlation between the NAO index and the arrival date. As a high NAO index is an indicator of mild and rainy winters in northern Europe, this means that mild winters result in earlier appearances. As the NAO index did not show a significant trend during the study period, no trends in arrival dates where found (Vähätalo et al., 2004).

Sparks et al. (2003) conclude that in many regions including the US state of Wisconsin, Russia and the UK, the majority of the bird life-cycle events have tended to become earlier. They present an example from the Essex Bird Reports in the UK which shows a trend towards earlier arrival over the last two decades of Whimbrel (Numenius phaeopus) and Hobby (Falco subutteo), which showed a significant trends towards earlier arrival of 39 and 12 days respectively. They note, however, that population increases might have contributed to the advance. In addition to observing the timing of arrival of migratory birds, the timing of egg laying is often recorded. A number of studies have demonstrated that the timing is changing too (Forchhammer et al., 1998, McCleery and Perrins, 1998, Crick and Sparks, 1999). The Blue Tit (Parus caeruleus) in the Netherlands advanced its egg-laying date by about 10 days since 1986 (Majoor et al., 2001). Both and Visser (2001) concluded that the Pied Flycatcher (Ficedula hypoleuca) advanced the timing of egg-laying by 7 days. A more detailed study of the breeding dates of 25 populations of Ficedula Flycatchers across Europe, studied over a long period, determined whether other environmental variables might have been the cause of the advance. The conclusion was that the advancement of egg-laying was stronger in areas where the spring temperatures were greater. Hence, climate change might cause an advance in breeding date (Both et al., 2004).

The observations made of the Pied Flycatcher by Both and Visser (Both and Visser, 2001) were part of a larger study of the impact of climate change on interaction between species. The study revealed that although the Pied Flycatcher advanced its laying date by 7 days, the main food source for its young, caterpillars of the Winter Moth (Operophtera brumata), appear 14 days earlier. Therefore there is now a timing mismatch, which rapidly reduces the ability of the Pied Flycatcher to breed successfully. The number of studies evaluated the occurrence of this kind of predator-prey mismatches because of a change in climate is very limited. With the enormous complexity of the food webs in natural systems, it is highly likely that many more problems will occur, although our lack of knowledge makes it difficult to quantify the problem.

Mammals

Mammals have also been the subject of phenological research, albeit to a much lesser extent than birds, insects and plants. Monitoring has focused on when hibernation begins and ends, and migration arrival and departure. Innouye et al. (2000), for example, report that marmots in Colorado are emerging from hibernation on average 23 days earlier than 23 years ago. This coincides with an increase in average May temperatures of about 1°C over the same time period.

The survival of caribou is determined by single climate events. Miller and Gunn (2003) studied the Peary Caribou (Rangifer tarandus pearyi) which is an endangered species in Canada. It has been in decline since 1961 when the total population consisted of 24,000 individuals. Sightings of Peary caribou were compared from two aerial searches, in 1993 and 1998, on Bathurst and its neighbouring islands in the western Queen Elizabeth Islands in the Canadian Arctic. The comparison suggested a near-total (98%) loss of Peary Caribou seen per unit of search effort. In summer 1993, 2400 caribou were counted during 33.8 hours of low-level helicopter searches. In contrast, in summer 1998, only 43 caribou were seen within the same area during 35.2 hours of low-level, helicopter searches. Widespread, prolonged and exceptionally severe snow and ice conditions from 1994-95 to 1996-97 probably caused the animals to die. Increasing snowfall is consistent with predictions for global warming in the western Canadian High Arctic. Future climate change may increase the frequency of years with unfavourable snow and ice conditions, which could prevent (or at least impede) recovery of Peary Caribou populations on the western Queen Elizabeth Islands, particularly to sustainable population sizes that would support subsistence harvesting.

Weladji and Holand (2003) studied the impact of climate change on reindeer. They concluded that the expected large climatic change in northern Europe and Scandinavia may lead to smaller, fewer calves, especially in regions where warm and snowy winters become more severe, as previously reported for red deer in Norway (Post et al. 1997) and Soay Sheep in St Kilda, Scotland (Forchhammer et al., 1998). This will affect conservation.

Aquatic species

Most phenological networks look at terrestrial plants and animals. However, changes in the timing of life-cycle events are also taking place in aquatic ecosystems. This is illustrated by amphibians. In the UK they have advanced their spawning 9 to 10 days earlier over a 17-year period (Beebee, 2002, Walther et al., 2002). Tryjanovsky et al. (2003) also concluded that in spawning dates of two anuran species (Rana temporaria and Bufo bufo) from western Poland (1978-2002) a trend towards earlier breeding was found, corresponding to an 8 to 9-day shift over the 25-year period. The advances are associated with increased temperatures in winter and early spring. As with other species groups, not all amphibian species show the same change and some do not change at all. According to Beebee (2002) this can be because climate has not changed in all sites where amphibians have been studied, or because of differences between species in reproductive strategies and cues.

Amphibians are partly dependent on air temperatures, so advance might be caused completely by a change in air temperature. This is not the case for fish, but phenological research on fishes is more difficult than with terrestrial species. In Estonia, the spawning dates of Pike (Esox lucius) and Bream (Abramis brama) have been studied. In 44 years of observation, the advance of spawning was 6 an 8 days respectively (Ahas, 1999).

Changes in the timing of fish-spawning also sometimes unexpectedly become visible. In order to protect cod in the North Sea, the European Commission restricted fishing in certain areas. After evaluation, it became clear that the timing of the rule, which was based on observations from the 1970s, was wrong; the timing of fish spawning had advanced. The spawning period had already half finished when the closure started. Moreover, the spawning areas had moved to the north in response to increased water temperatures (Rijnsdorp et al., 2002).

In the climate change indicator report by the European Environmental Agency (EEA ETC/ACC et al., 2004) phytoplankton biomass was presented as an indicator for the marine growing season. The biomass has increased considerably over the past few decades in parts of the north-east Atlantic and the North Sea. From the late 1940s to the 1980s, the majority of production was restricted to bloom periods in spring and autumn. However, production has significantly increased since the late 1980s during the winter and especially the summer season. Particularly high increases have been observed since the mid-1980s in the North Sea and west of Ireland between 52°N and 58 °N. During the 1990s, phytoplankton biomass increased in winter months by 97% compared to the long-term mean. Changes in annual phytoplankton biomass and the extension of the seasonal growing period already appear to have considerable impacts on overall biological production and the food web. Change in the seasonal timing of decapod larvae (as an example for zooplankton) over the period 1948–2000 shows a similar behaviour. Although there is considerable inter-annual variability of decapod larvae in the period 1948–2000, since 1988 the seasonal development of the larvae has occurred much earlier than the long-term average. The seasonal cycle was up to 4–5 weeks earlier in the 1990s than the long-term mean (EEA ETC/ACC et al., 2004).

Reptiles also have changed in the timing of their life cycle in response to temperature. Weishampel et al. (2004) examined 15 years of Loggerhead Sea Turtle (Caretta caretta), nesting patterns on the Atlantic coast of Florida, which is among the most important nesting area for this threatened species. The nesting date became earlier by roughly 10 days. This was significantly correlated with near-shore, May sea surface temperatures that warmed an average of 0.8°C over this period.

Sea turtles display strong sensitivity to climate change. Hays et al. (2003) reconstructed nest temperatures of a major green turtle (Chelonia mydas) at Ascension Island since 1855. The temperature of the sand varied around 3°C between different beaches. This variation has persisted for at least a century. Reconstructed nest temperatures varied, however, by only 0.5°C over the course of the nesting season, but differed for the individual beaches. Nest temperature strongly determines the sex: the coldest sites produced male offspring, while the warmer sites produce female offspring. The observed nest-warming trend up to 0.36 and 0.49°C for the last 100 years, which explains the observed sex ratio (Hays et al., 2003). Increasing temperatures reduce the number of male offspring and threaten the population.

2.3.2 Changes in distribution

Humans have the ability to live in almost any place on earth. The distribution of plants and animals, however, is limited to a continent, a country or maybe even a small region within a country. They are adapted to the environmental conditions which enable them to survive long enough to reproduce and maintain their populations. A large number of factors determine reproductive success: climate, environment (see previous chapter) and biotic conditions (e.g. presence or absence of competitors for space or nest sites). With a change in climate, all these factors will change. In order to survive, species have two options: adapt to the changes so they can continue to reproduce within a given area, or move to another area where the conditions are better. The question, however, is whether species are able to migrate to other areas. A tree will not be able to move to another area and can only depend on the successful distribution of its seeds to other areas that are more suitable.

Many ecological monitoring programmes have provided information on the location and size of the distribution area of species. In the last few years, several studies have analyzed observed changes in the distribution areas and tried to relate those changes to climate variables, exemplified below. They include both increases, changes, and decreases in distribution areas (including expansion into new areas) and the decrease in population numbers. The main conclusion is that the recent changes in climate have had a significant impact on the distribution of plants and animals in both terrestrial and aquatic systems.

Plants

The EEA climate change indicator report (2004) presented changes in plant distribution as one of the indicators. It concluded that in recent decades a northward extension of various plant species has been observed in Europe which is likely to be attributable to increases in temperatures (Ad-Hoc Technical Expert Group on Biological Diversity and Climate Change, 2003, Parmesan and Yohe, 2003). Many Arctic and alpine tundra communities are affected. The density of trees and shrubs increased (Molau and Alatalo, 1998). In western Europe, thermophilic (warmth demanding) plant species have become more abundant compared with 30 years ago (van Oene et al., 2001). In the new version of the Dutch flora, 41 new plant species have been added this year (Appendix 1). These species are located in at least three places in the Netherlands, and they have survived three generations. An additional 87 new plants are nominated for the next list as they have been frequently observed. Despite the increase in abundance of thermophilic plants, a remarkably small decline in the presence of traditionally cold-tolerating species has been observed (van Oene et al., 2001).

Endemic species have been replaced by other species in the mountain regions of Europe due to a number of factors, including climate change. Higher temperatures and longer growing seasons associated with climate change appear to have created suitable conditions for certain plant species that have migrated upward, and which now compete with the endemic species (Gottfried et al., 1994, Grabherr et al., 1994). The net effect on species richness varies from region to region and even within single regions. While richness has increased in some places, it has declined in others. In the Alps, for example, evidence exists that climate warming over the past 60 years may have encouraged spruce and pine species in the sub-alpine region and sub-alpine shrubs on summits (Theurillat and Guisan, 2001). The net effect is an increase in species richness in 21 out of 30 summits in the Alps compared with 50 to 100 years ago. Similar trends have occurred in

the Pyrenees, Scandinavia, Bulgaria and the Urals (EEA ETC/ACC et al., 2004).
Similar changes in mountainous areas have been observed in other continents. In the Olympic Mountains of Washington state, sub-alpine forest has invaded higher-elevation alpine meadows, partly in response to warmer temperatures (Peterson et al., 1994). In Alaska, comparison of photographs taken in 1948-50 with others taken in 1999-2000 of the area between the Brooks Range and the Arctic coast show an increase in shrub in tundra areas, and an increase in the extent of spruce forest along the treeline (Sturm et al., 2001). The increased vegetation is attributed to increasing air temperatures, on average 1°C per decade over the last three decades. In the Argentine Islands, the populations of two native Antarctic flowering plants increased rapidly between 1964 and 1990, coinciding with strong regional warming over the Antarctic Peninsula. The Antarctic Pearlwort (Colobanthus quitensis) population increased fivefold while Antarctic Hairgrass (Deschampsia Antarctica) increased by a factor of 25. The unusually rapid increases are attributed to warmer summer temperatures and/or a longer growing season, which enhance the plant's ability to reproduce (Fowbert and Smith, 1994).

Lichen and moss flora

It is expected that species with a high migration capacity have the ability to quickly change their geographic distribution. Recent changes in the Dutch lichen flora as well as changes in the moss flora are very clear examples. Since the end of the 1980s, particularly warm temperate species with a (sub-) Atlantic or Mediterranean distribution pattern have been increasing. Species with a boreo-montane distribution have been decreasing (van Herk et al., 2002, van Herk and Siebel, 2003).

Fungi

Just like lichens, fungi can quickly expand their distribution range if conditions are favourable. Plicaturopsis crispa, a small fungi that lives on dead branches and trunks of various deciduous trees, had a typical southern distribution in Europe and was until recently completely absent in the lowlands of western Europe. At the end of the 1980s the first observations were recorded (RIVM et al., 2003). Since then, the population expanded strongly and became abundant in many locations far to the north and west of the original range. This dramatic increase can only be explained by a lack of severe winters in recent decades.

Birds

Compared to plant studies, relatively few studies have been focused on changes in the distribution area of birds. Comparison of breeding distributions of birds in the UK for two periods (1968-1972 and 1988-1991) showed that the northern margins for many species had moved approximately 19 kilometres northwards. The range shift occurred during a period when central England's temperature warmed by about 0.5°C over the last century, and the 10-year period 1988-1997 was the warmest on record (Thomas and Lennon, 1999).
Many more studies have focused on increases or decreases of bird populations. Veit et al. (1996) studied the 90% decline in Sooty Shearwater (Puffinus griseus) between 1987 to 1994 in the California Current System. This decline seemed inversely correlated with the 0.8°C rise in seasurface temperatures. They demonstrates that the decline of Sooty Shearwaters is not a localized phenomenon, but linked to large-scale changes in ocean currents and consequent changes in food supply.
Other birds benefit from increase in temperature. The survival of some European

bird species wintering in Europe increases between 2% and 6% per 1°C rise in winter temperature, depending on species (EEA ETC/ACC et al., 2004). This effect is considerable particularly because of the increase in winter temperatures. The correlation between bird survival and winter temperature has been observed for many species, such as the Grey Heron (Ardea cinerea), Common Buzzard (Buteo buteo), European Cormorant (Phalacrocorax carbo), Song Thrush (Turdus philomelos) and the Redwing (Turdus iliacus). The higher survival rate clearly affects population, but the effect is less obvious because of other factors determining population dynamics, such as productivity.

Penguins are also considered to be sensitive to changes in climate. The reduction of ice also has severe consequences for several species of penguins in Antarctica (Barbraud and Weimerskirch, 2001, Croxall et al., 2002). Recent changes in these seabird populations reflect regional climate change. Increased snowfall reduces hatching success. Additionally, the melting of the sea ice and the consequent decrease in extent changes the abundance and distribution (Loeb et al., 1997) of the krill for which penguins forage. Adequate food availability has declined strongly in the region. Many large penguin colonies have been rapidly declining over the last decade and are the cause of extreme concern.

The Adélie Penguin (Pygoscelis adeliae), for example, is found only where sea ice persists well into spring in the sea ice zone that surrounds Antarctica (Ainley et al., 2001). For most of the last 20,000 years, populations have been increasing and colonizing new areas to the south, as suitable nesting habitat has been exposed by slowly retreating ice sheets. More recently, during the last 50 years, colonies of the Adélie Penguin have been declining and even disappearing altogether from the west coast of the northern Antarctic Peninsula and offshore islands such as the South Shetlands. This is the northern part of the range of the species. Air temperature records for the last 50 years reveal a marked warming which has been particularly evident in winter. By contrast, warming in the southernmost part of the Adélie Penguin's range has loosened rather than melted the sea ice. This has coincided with increases in breeding colonies, though the rates of change have slowed recently (Ainley et al., 2001). Adélie Penguin populations have shrunk by 33% over the past 25 years in response to a decline in their winter sea ice habitat.

Amphibians

Amphibian populations are declining around the world (Alford and Richards, 1999). This has received considerable attention from the media and scientists. Climate change is only one of the many factors that is believed to have contributed to the decline. Other factors are radiation, predation, habitat modification, environmental acidity and toxicants, disease and interactions among these factors. The changes have been quite dramatic. In Costa Rica, for example, twenty of 50 species of frogs and toads in a 30-km2 study area, including the locally endemic Golden Toad (Bufo periglenes), disappeared following synchronous population crashes in 1987 (Pounds et al., 1999, Pounds, 2001). The results of the studies by Pounds et al. indicate that these crashes probably belong to a constellation of demographic changes that have altered communities of birds, reptiles and amphibians in the area and are linked to recent warming. The changes are all associated with patterns of dry-season mist frequency, which is inversely correlated with sea surface temperatures in the equatorial Pacific, and has declined dramatically since the mid-1970s. Also in Puerto Rico, three frog species (Eleutherodactylus karlschmidti, E. jasperi, and E. eneidae) are presumed to be extinct and eight populations of six different species of endemic Eleutherodactylus frogs are significantly declining at elevations above 400 metres. Burrowes et al. (2004) have monitored 11 populations of eight frog species for several decades in Puerto Rico. They focused on climate change and diseases as the potential cause for the decline. Their analysis of weather data indicates a significant warming trend. They found a strong correlation between years with extended drought periods and frog decline. The 1970s and 1990s, the extinction periods, were significantly drier than average.

Marine species

In the section on phenology we gave several examples of changes in timing of life cycle events in marine systems. In addition, the distribution area of species is changing rapidly in marine ecosystems. RIVM (2003), for example, presents monitoring data of a population increase of the Scaldfish (Arnoglossus laterna) and the Lesser Weever Fish (Echiichthys vipera) along the Dutch coast. These species occur from the Mediterranean Sea to southern Scandinavia but were rare in the North Sea. Beare et al. (2004) analyzed trawl data from Scottish research vessels over the last 75 years. They clearly showed that catches of the warm water pelagic species, Anchovy (Engraulis encrasicholus) and Sardine (Sardina pilchardus), increased suddenly after 1995. All these increases correlate well with the increase in temperature since the end of the 1980s.

Rappé (2003) described some remarkable observations of marine coastal organisms including autochthonous crabs and shrimps, molluscs and aliens of Belgium. Populations fluctuate during the last two decades following severe or mild weather conditions. They disappear after harsh winters and come back more rapidly than in the past. Some offshore species are stranded or extirpated more often. Species new to the area turn up and establish themselves. These observations are believed to be mainly triggered by changes in oceanographic or climatic conditions, luring or forcing southern species into the North Sea and its coastal waters. There are similar examples along the American coasts as well (Parmesan and Galbraith, 2004).

Increasing evidence is found that every part of the whole food web in marine systems is undergoing significant changes (EEA ETC/ACC et al., 2004). An important basis of the food chain is zooplankton. Some zooplankton species have shown a northward shift of up to 1000 kilometres, in combination with a major reorganization of marine ecosystems. These shifts have taken place south-west of the British Isles since the early 1980s and from the mid 1980s in the North Sea (Beaugrand et al., 2002). In contrast, the diversity of colder temperate, sub-Arctic and Arctic species has decreased. Furthermore, a northward extension of the ranges of many warm-water fish species in the same region has occurred, indicating a shift of marine ecosystems towards a warmer north-eastern Atlantic. An invasion of warm-water species into the temperate areas of the northeast Atlantic has also been observed. For example, the cold-temperate Calanus finmarchicus copepods are now rapidly replaced by the warm-temperate Calanus helgolandicus.

Most of the warm-temperate and temperate species have migrated northward by about 250 kilometres per decade, which is much faster than the migration rates expected in terrestrial ecosystems (Parmesan and Yohe, 2003).

Coral reefs are the most diverse marine ecosystem and embrace possibly millions of plant, animal and protist species (Hoegh-Guldberg and Fine, 2004). They have become one of the clearest indicators of climate change’s ecological impacts. Mass coral bleaching - the loss of the dinoflagellate symbionts from reef-building corals - and mortality has affected the world’s coral reefs with increasing frequency and intensity since the late 1970s.

Mass bleaching events, which often cover thousands of square kilometers of coral reefs, are triggered by small increases (1 to 3oC above mean maximum) in water temperature (Hoegh-Guldberg and Fine, 2004). The temperature regimes of corals used to be very stable, covering a range of 3°C between minimum and maximum (Smith et al., 2001).

During recent El Niño events, water temperatures in many tropical waters have increased by over 5°C, which resulted in massive bleaching events of up to 95% in shallow waters off countries like Sri Lanka, India, Kenya, Maldives and Tanzania . The loss of living coral cover (16% globally in 1998, an exceptionally warm year) is resulting in an unspecified reduction in the abundance of myriad species (Hoegh-Guldberg and Fine, 2004).

Furthermore, it is expected that corals on the northern hemisphere will also migrate to northern areas in response to the increases in temperature. This has been observed by Precht and Aronson (2004). Both the Staghorn Coral (Acropora cervicornis) and Elkhorn Coral (Acropora palmata) are now expanding their range northward along the Florida Peninsula and into the northern Gulf of Mexico.

Insects

Many invertebrate species have been observed for very many years in a row. A large study of changes in the distribution area of 35 butterfly species in Europe by Parmesan et al. (1999) concluded that 22 of them had shifted their ranges northwards by 35-241 kilometres. This is consistent with a 0.78°C warming over the past century. In the Netherlands, the Comma Butterfly (Polygonia c-album) has expanded from the southern part of the Netherlands in 1980, to the whole of the Netherlands, including the Wadden Islands in the north of the country, by 2000 (van Swaay, 2003). Since the very warm summer in 2003 there have also been many reports of the Swallowtail (Papilio machaon) in the northern provinces of the Netherlands. The northern distribution area of this species was previously limited to the southern part of the country. In addition, of other Lepidoptera, the Microlepidoptera species have undergone significant changes in distribution area that can be attributed to climate change (Ellis et al., 1997). In California, the Edith's Checkerspot Butterfly has been disappearing from the lower elevations and southern limits of its range (Parmesan, 1996).

One range change that is currently becoming a societal problem is the northward expansion of the Oak Processionary Caterpillar (Thaumetopoea processionea). After the first observation in 1991 in the southern part of the Netherlands, the species advanced its distribution range to the middle of the Netherlands. The species requires warm conditions and originates in southern and central Europe. The caterpillars are a concern to human health because of their stinging hairs that can irritate the skin and bronchial tubes (Moraal et al., 2002).

That insects have the ability to quickly respond to changes in climate is illustrated by the enormous northward expansion of the Mountain Pine Beetle (Dendroctonus ponderosae) in Canada in the latter half of the 20th century. Logan and Bentz (1999) have projected that the species will expand its distribution in response to increases in temperature. Data from the Canadian Forestry Centre show a significant increase in infestations in areas that were historically climatically unsuitable for the beetle. The Mountain Pine Beetle population has doubled yearly in the last few years. It killed pine trees across about two million hectares of forest in British Colombia in 2002 alone. The beetle's range has been limited mainly to the southern half of British Colombia by cold winter temperatures and summers too cool for the beetles to complete their development in a single year (Anonymous, 2003). These large-scale pest infestations have large economic impacts on the forestry sector.

The number of invertebrate species is very large and often they are not included in monitoring programs. The existing monitoring programmes are providing increasingly convincing information. Kleukers and Reemer (2003) comprehensively studied a substantial part of the Dutch fauna (Table 2). In total 1331 terrestrial species of Apidae (honeybees and stingless bees), Asilidae (robber flies), Carabidae (ground beetles), Formicidae (ants), Mollusca (snails and slugs), Odonata (dragonflies), Orthoptera (grasshoppers) and Syrphidae (hoverflies) were studied. They focused on 339 species of which the northern border of their distribution ranges run through the Netherlands. No less than 101 species have expanded their range to the north in the 20th century. They were mainly dragonflies and molluscs. In total 63 species contracted their range and retreated southwards (especially many species of bee). The species possessing expanding ranges are mainly species of disturbed and cultivated habitats. The declining species are mainly those restricted to more undisturbed nature reserves. The Carabidae are an exception.

Table 2 **Trends of southern invertebrate species in The Netherlands. Increase, stable and decrease means respectively that the northern border moved north, did not change, or moved south (source: Kleukers and Reemer, 2003).**

Species group	Decrease	Stable	Increase
Dragonflies (20 species)	10	30	60
Bees (85 species)	38	51	11
Ants (3 species)	33	67	0
Ground beetles (78 species)	15	48	37
Robberflies (6 species)	0	67	33
Molluscs (28 species)	0	50	50
Hoverflies (54 species)	15	26	59
Locusts (15 species)	27	53	20
All groups (293 species)	22	44	34

A useful indicator of climate change-induced distribution shifts is the Wasp Spider (Argiope bruennichi). This species is also moving to the north in Europe. In 1980 the spider was found in the southern part of the Netherlands and it has now moved up to the central part of the Netherlands. In addition to the higher temperatures, the spider benefits from the increase of grass species in peat and heath vegetation (van der Linden, 2000, 2004).

Diseases

The changes in temperature, precipitation and species distribution also have had a direct impact on the distribution area of many vector-borne diseases like lyme disease (Lyme borreliosis), malaria and dengue fever. The EEA ETC/ACC et al. (2004) state that an increase in cases of tick-borne diseases per year has been observed since the 1980s in the Baltic countries (Sweden, Finland, Poland, Latvia, Estonia and Lithuania) as well as the central European countries (Switzerland, Germany, the Czech Republic and Slovakia). In Sweden, ticks expanded their northern distribution extensively between 1980 and 1995. During this period, northern areas with newly-established tick populations had less severe winters and more summer days. The chances of surviving winter for both ticks and host animals increased, as did the length of the vegetation season. These changes imply easier access to food for host animals and longer periods of activity for ticks. However, it is not clear yet how many of the 85,000 cases of lyme disease reported annually in Europe are attributable to temperature increases over the past decades (EEA ETC/ACC et al., 2004). Although tick-related diseases cause health problems in Europe, at the global scale malaria and dengue fever are having much larger impacts. In Mexico, for example, dengue fever has spread from its former elevation limit of 3,300 feet (1,006 metres) up to 5,600 feet (1,707 metres). The same upward movements of these diseases is happening in Colombia, Indonesia and Kenya. The increase in distribution range has caused the death of thousands of people in areas where population had previously been unexposed to these diseases.

Mammals

The larger mammals often have a position at the top of the food chain. Therefore, they are very vulnerable to changes in the trophic levels below them. Furthermore, they often require large nature areas with a large amount of suitable space to maintain a viable population. They are also sensitive to a large number of indirect impacts of climate change. For example, in Khabarovsk, Russia, fires fuelled by drought and high winds threatened the nature reserves where the only remaining Amur Tigers live.

Seals will also potentially be negatively affected by increasing temperatures. Stirling et al. (2004) recorded an unusually warm period with rain, not snow, in early April 1999 along the coastline at the end of the Hall Peninsula on the south-eastern Baffin Island, Nunavut. In contrast, long-term meteorological data collected nearby indicated that the air temperatures for the month of April are normally 10-20°C cooler than the recorded averages. Periodic warming to near freezing, probably due to the maritime influence of nearby open water in Davis Strait, occurs in this area in late March and early April, but not usually to the degrees observed now. During this warm period, they found slumped roofs over some Ringed Seal (Phoca hispida), birth lairs and others that had collapsed. Newborn pups were left lying on the bare ice, subject to thermoregulatory stress and vulnerable to significantly increased predation by polar bears and Arctic Foxes (Alopex lagopus). Stirling et al. (2004) concluded that if the climate continues to warm in the Arctic, it is likely that rain will be more widespread during early spring. This removes the protection by birth lairs and exposes young ringed seal pups to predation. This affects seals and the polar bears that depend on them for food.

The Polar Bear (Ursus maritimus) is also often mentioned as being extremely vulnerable to climate change. Its habitat is decreasing rapidly. In spring the bears wander onto the ice to hunt seals through and feed their pups. With the earlier ice break-up, this becomes increasingly difficult and they more frequently remain on land and visit or invade local fishing villages, where they become a nuisance (Hansell et al., 1998, Kerr, 2002). Decreased weight in adult polar bears and a decline in birthrate since the early 1980s have been attributed to the earlier spring break-up of sea ice, which have shortened the spring seal hunting season by two weeks. Derocher et al (2004) analyzed all these impacts on polar bears. They state that in the short term, climatic warming could improve bear populations and seal habitats in higher latitudes if currently thick perennial ice is replaced by annual ice, making it more suitable for seals. However, a cascade of impacts beginning with reduced sea ice will be lead to reduced storage in fat tissue. This will result in lowered reproductive rates because females will have less fat to invest in cubs during the winter fast. As sea ice thins and becomes more fractured and labile, it is likely to move more in response to winds and currents. Polar bears will need to walk or swim more and thus use greater amounts of energy to maintain contact with the remaining preferred habitats. All polar bears show behavioural elasticity, but given the rapid pace of ecological change in the Arctic, the long generation time and their highly specialized nature, it is unlikely that they will survive as a species if the sea ice disappears (Croxall et al., 2002).

Summary

The above examples show that recent changes in climate have caused significant phenological and distributional changes everywhere in the world. These changes have altered and will further alter many interactions between species (e.g., predation, pollination, and competition). The change in timing of events and in distribution varies considerably from species to species and from region to region. Long-term monitoring series clearly show a large interannual variability in timing, but simultaneously also prove that many species directly responded to extreme weather events which never happened before. Such response is not expected, assuming only gradual climate change (cf. Leemans and Eickhout, 2004). Such extreme events will definitely determine the development of local populations and species.

The changes observed should be seen in the context of a global mean average increase in temperature of 0.7 °C. The changes are already considerable and in some cases devastating. One might wonder what might happen next if the global warming continues beyond, for example, 2°C. Plant and animal species are not only confronted with climate change but also with other environmental change, including habitat loss and the response of other species (including humans). Such complex interactions will be difficult to comprehend completely. Projections of future impacts will therefore remain strenuous.

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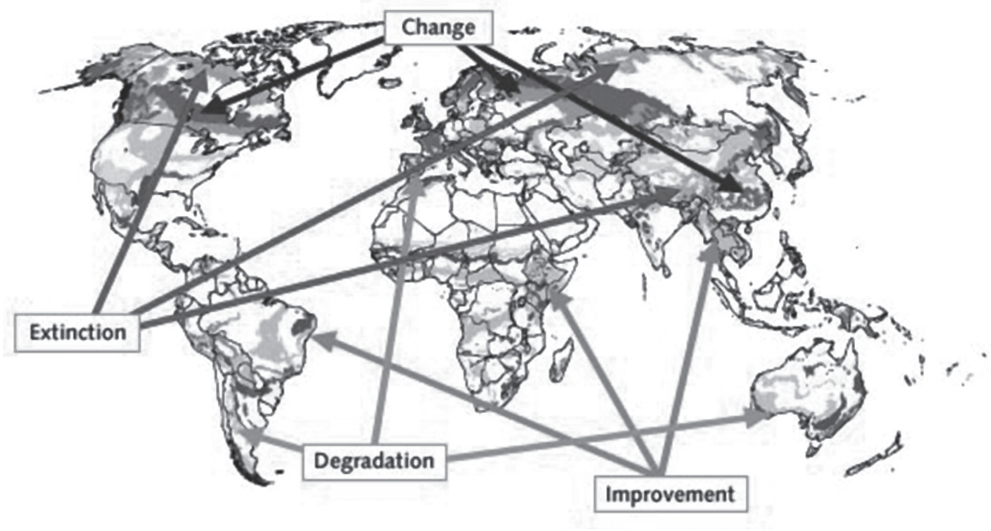
3. Are the observed changes a sign that things are getting worse?

The IPCC (2001) concluded that “recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems.” Their map (Figure 9), however, reflected few of the abundant changes everywhere documented in the preceding sections. The ecological impacts of climate change are now observed everywhere and some unexpected changes occurred. This conclusion is supported by our assessment and several other recent compilations of climate-induced responses (Roos et al., 2003, Root et al., 2003, Parmesan and Galbraith, 2004). All these studies show similar trends for many different species, ecosystems and regions.

Figure 9 **The changes in large-scale ecosystems or biomes with am equilibrium global vegetation model and a change in global mean temperature of 3°C (after Leemans and Eickhout, 2004).**



The question that immediately arises is “Were these changes expected to happen so fast and with such a magnitude?” To answer this question we have to evaluate how future impacts of climate change are determined.

3.1 Assessing future impacts of climate change on ecosystems

Many of the quantitative ecological impacts assessments completed over the last decade or so have used two components. First, numerical scenarios for future atmospheric trends and climate change were produced. Second, these scenarios were used to drive a model to describe possible responses to climate change. Applying this approach is relatively straightforward and potential impacts and vulnerabilities of different systems are established. Before 2000 climate change was not considered a major threat. Only boreal forests and tundras were then considered sensitive to it (e.g., Sala et al., 2000). Therefore, few researchers attributed ecological changes to the obviously ongoing responses to climate change because non-climatic influences often dominate local, short-term biological changes. The attribution to climate change of observed changes, however, still remains questionable, mainly because the predominant use of just correlative approaches (Parmesan and Yohe, 2003).

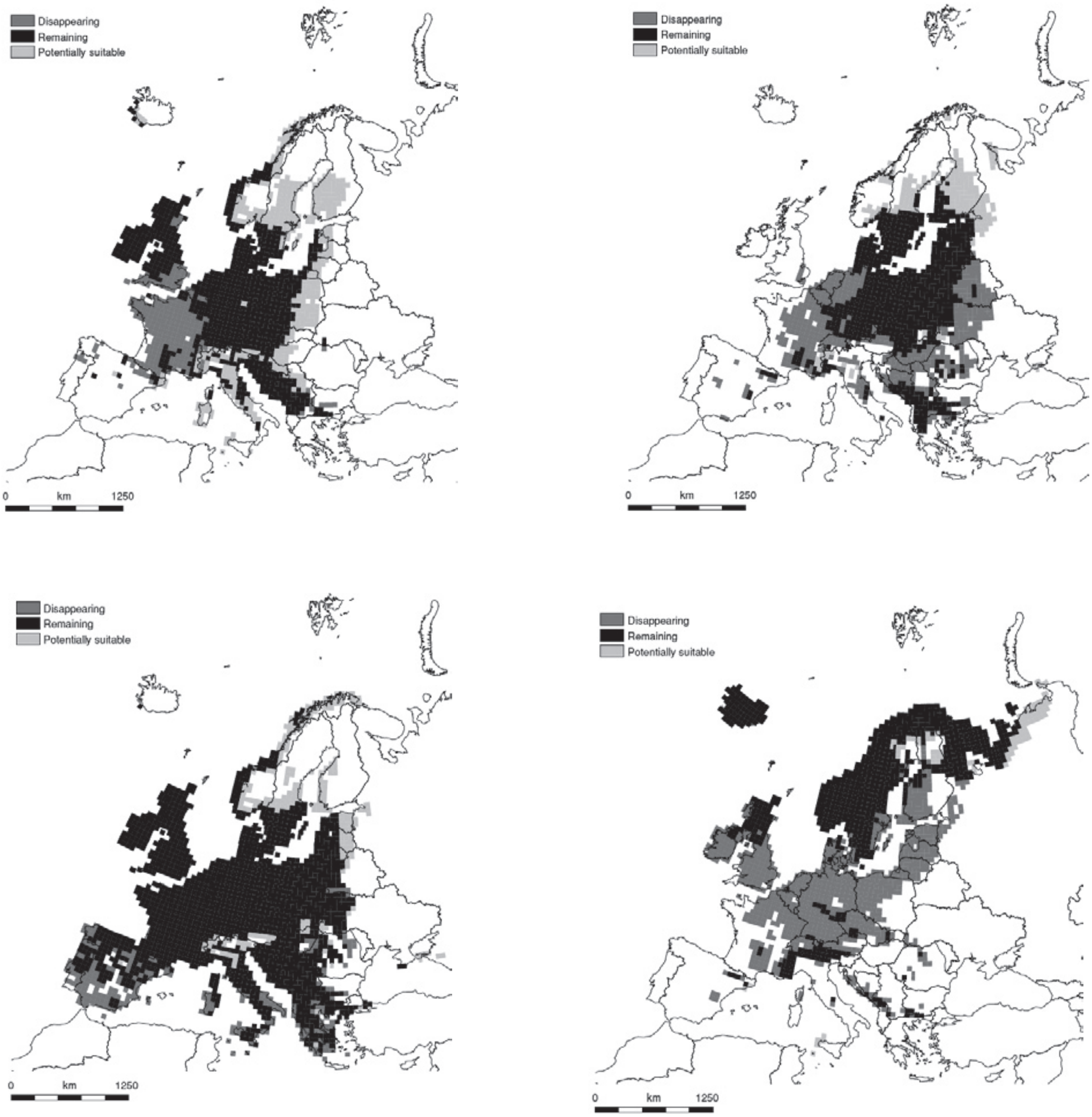
Most future impact assessments are done for doubling CO2 concentrations. In most scenarios this only occurs beyond 2050. Climate change scenarios, derived from advanced global dynamic climate models, are combined with current climate to obtain more realistic temperature and precipitation patterns. Climate is generally defined as long-term monthly or seasonal means, the so-called climatic normals: average weather for a period of 30 years (e.g. 1961 to 1990) (see, e.g., Leemans and Cramer, 1991, New et al., 1999). Thus this approach only depicted gradual changes throughout the seasons and ignored extreme events of shorter duration. Additionally, in presenting the results, only the differences (i.e. the impacts) were highlighted. The traditional approach resulted in a very static assessment of impacts. These studies did not emphasize the rate of change, but only indicated the magnitude, yet it was changing conditions, not static ones, that encompassed the critical questions.

However, despite these obvious limitations, the majority of impacts assessments appearing in the literature over the last two decades used such static and inappropriate approaches. However, better models and tools were not yet available. Emanuel et al. (1985) were among the first to use this approach. They applied the Holdrige life-zone classification and showed that climate change would have large impacts on the distribution of ecosystems. They concluded that about 35% of all the world's ecosystems would change in a climate with double the CO2. Their pioneering result can still be compared favourably with recent studies based on more advanced models (e.g. Cramer and Leemans, 1993, Tchebakova et al., 1993, Malcolm and Markham, 2000, van Minnen et al., 2000, Bachelet et al., 2001, Leemans and Eickhout, 2004) (cf. Figure 9). Of course, the more recent studies have added more spatial detail, used dynamic models, more realistic species and ecosystem responses, and more comprehensive climate scenarios, but the magnitude of change of recent studies is still very similar to the earlier ones.

More recently, transient climate scenarios that depict a year-to-year change (but still on monthly climate variables) have been applied (e.g. Cramer et al., 2001, Sitch et al., 2003, Leemans and Eickhout, 2004). These models respond to some of the inter-annual variability of a monthly mean climate change. During the first decades simulated, the models show little response, then an accelerated response and at the end of the 21st century a levelling off. Still, the simulated impacts are comparable with the equilibrium approaches both in direction and magnitude. The only advance that some of these models have made is evaluating the transient response of CO2 uptake and release (e.g. Cramer et al., 2001, Lucht et al., 2002). Some phenological features are explicitly simulated by these more dynamic models. Leafing, for example, is a function of plant-specific temperature threshold functions (e.g. when spring temperatures increase over 5°C), which causes simulated plant growth to follow changes in growing seasons.

Leemans and Eickhout (2004) used a simple transient scenario approach and

Figure 10 **The projected changes in the species ranges with the Euromove model for Dryopteris dilatata (upper left), Scleranthus perennis (upper right), Ranunculus bulbosis (lower left) and Botrychium lunaria (lower right)**



comprehensive biome model to calculate whether vegetation can adapt to the simulated changes over a century. Grasses, for example, disperse quickly, while tree populations disperse much more slowly (van Minnen et al., 2000). A warming of 1°C in 2100 is equivalent to a long-term rate of change of 0.1°C per decade. At this rate, only 50% of the impacted ecosystems may be able to adapt. With increasing rates of warming, the adaptation capacity rapidly declines. At a rate of warming of 0.3°C per decade, only 30% of the vegetation can adapt. Then, forests are especially threatened. Further shifts lead to degraded ecosystems and negative impacts dominate. Unfilled habitats in ecosystems will be filled rapidly by opportunistic 'generalist' species (Solomon and Leemans, 1990, Dukes and Mooney, 1999, Lake and Leishman, 2004). As a consequence, invasive species will even become even a larger threat to biodiversity under climate change.

The analysis by Leemans and Eickhout (2004) shows that one can approximate the risks for dangerous climate change (cf. the objective of UN-FCCC) but not precisely

determine its features. One of the problems with these approaches, however, is the coarse aggregation of the analysis. Generally, between 15 and 30 biomes are distinguished globally, all with a large extent. Changes start to occur at biome margins and only affect whole biomes after extremely large changes in climate. Using such highly-aggregated models conceals much smaller scale but still relevant impacts.
Some analyses have used advanced species-based models instead of plant type-based biome models (e.g. Huntley et al., 1995, Bakkenes et al., 2002, Thomas et al., 2004, Thuiller et al., 2004)). Generally the distribution of species is empirically derived by regressing climate variables and species abundance. These studies show species specific responses to climate change. This supports the assumption that biomes do not respond as unique entities but species population probably do (Figure 10). This approach shows many more subtle impacts in many more regions than just along margins of biomes. In fact, Thomas et al. (2004) indicated much larger adverse impacts using species than Leemans and Eickhout (2004) did using biomes. This means that most of the studies evaluated by the IPCC (2001) probably underestimate projected future impact levels. Impacts are thus likely more rapid, diverse and widespread than those depicted in traditional impact assessment.

Most of the changes that we observed over the last decade are consistent with a warming climate. However, many of the changes that we are experiencing occur much faster than indicated with the traditional climate scenario–model impact studies. For example, Leemans and Eickhout (2004) simulate that only 5% of all land-based biomes are affected with a 0.5°C increase in temperature compared to pre-industrial temperatures. The impact levels of Thomas et al. (2004) are a few percentage points higher. Such an increase in temperature occurred, nonetheless, over the last few decades and these authors' model could therefore be a realistic validation exercise to compare to observed changes. The observed changes indicated that all species, not just a small percentage, respond initially, especially when phenology is considered. Additionally, many species have already shifted their ranges, the most extreme being a few new Dutch lichen species from the tropics. (van Herk et al., 2002). These species possess almost no dispersal limitations. The overall impression is that the observed responses are more widespread and appear more swiftly than scenarios and models suggest.

3.2 Why are ecological impacts occurring so rapidly?

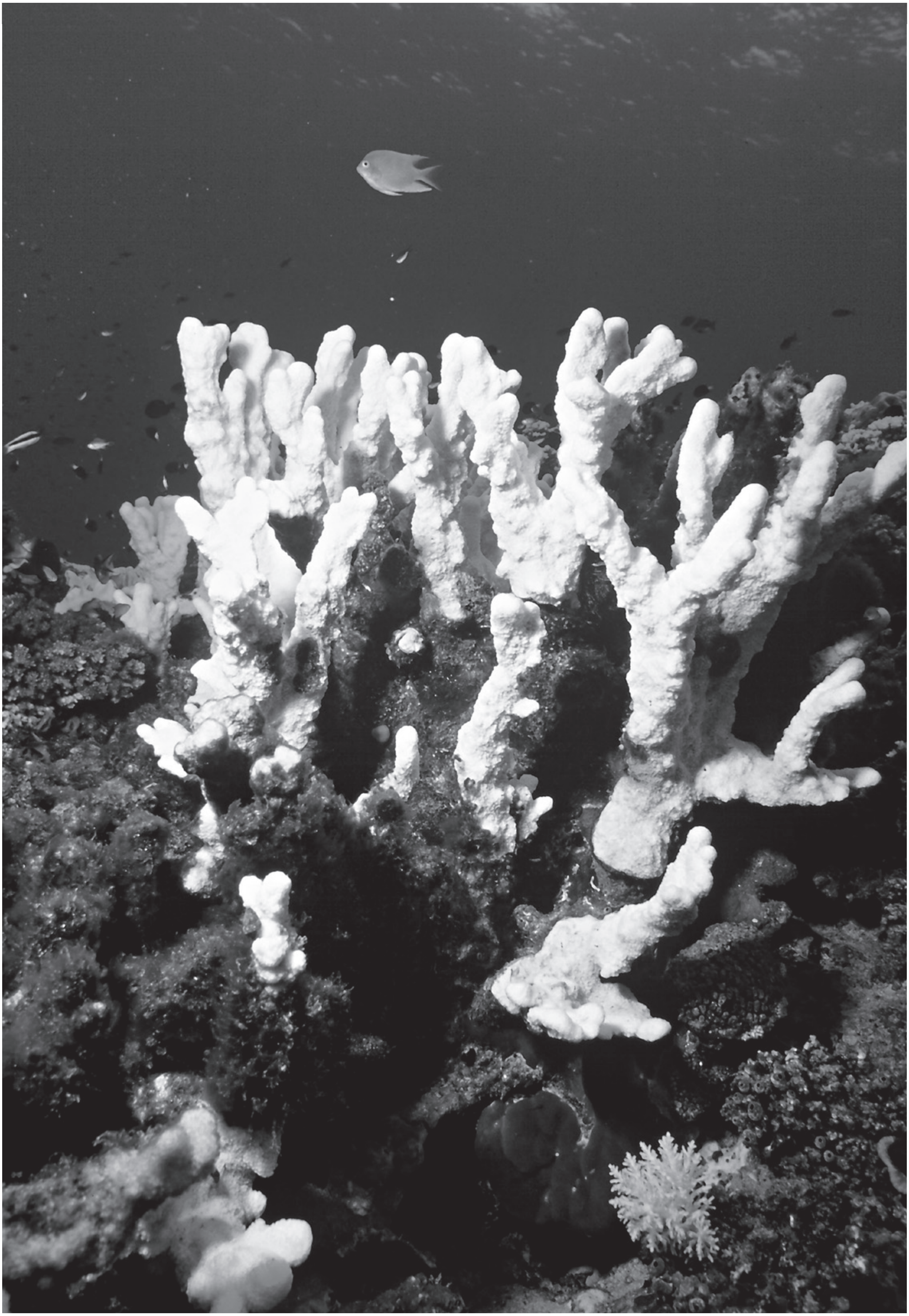
Species respond to changes in the environment in many different ways. Some of these responses are linear and predictable. Photosynthesis (an important component of plant growth), for example, ceases below a temperature threshold (generally 0°C), increases rapidly above the threshold until an optimum is reached, after which it declines again. Many other processes are more complex and involve interactions with other species (e.g. predator–prey), multiple thresholds, hysteresis (i.e. response initiation lags the forcing) and irreversible changes. Some of these responses could even be abrupt even when the forcing or changing factor in the environment only changes gradually. (e.g. Scheffer et al., 2001, Scheffer et al., 2002, Brovkin et al., 2003, Claussen et al., 2003). A rapid change in the ocean currents of the North Atlantic is such an example (Rahmstorf, 2002).
Generally, however, responses to extreme changes are much more apparent. The causal attribution is here also much more obvious. For example, forest fires that affect millions of hectares occur only when the amount of fuel (woody material and debris) and its dryness reach critical values. Fire is an abrupt change but reversible, at least over time scales from decades to centuries. An example of an irreversible change is the extinction of species. This can result from threshold effects and be accelerated when habitats become fragmented due to human activities. This process is highly non-linear, with little or no

decrease in populations until a critical levels of fragmentation are achieved, at which point extinction can rapidly and inevitably follow even in the presence of large scale efforts to rectify the damage. In all these complex situations, it is difficult and sometimes even impossible to unambiguously attribute responses to specific causes.

When we analyze the observed responses of the biota, most result from extreme climatic events. For example, the early budding and leafing of shrubs and flowering of bulbs in the Netherlands in February 2004 was clearly caused by unexpectedly high temperatures for that time of the year. Also the emergence of subtropical lichen species is clearly encouraged by more frequent hot and dry summers and mild winters. The recent analysis by Klein Tank (2004) demonstrating that extreme weather events contribute non-proportionately to recently observed climate change (rather than obvious changes in the climatic normal or long-term average), explains why ecological impacts are becoming so abundant over the last decade. Ecosystems respond most rapidly and vigorously to these large events especially.

Many have argued that the observed changes show that species and ecosystems are resilient and can thus easily cope with these climate changes. They respond effectively and continue to function. For example, coral reefs have revived after major bleaching events due to warmer surface water during an el Niño event. Unfortunately, it is not as simple as it seems. The continued warming trend pushes many species into conditions that they have never experienced. This increases stress and will eventually lead to degradation. Many models, however, show that many such stressed and degraded systems will be eventually replaced by better-adapted species and ecosystems. That may be true, but degradation is a generally fast process (days to decades), while recovery through growth and succession is a slow process (decades to millennia), and often constrained by habitat fragmentation, pollution and other human-induced stresses. This mismatch in time scales will lead to local die-backs and rapidly increasing extinction rates (Huntley et al., 1997). Additionally, opportunistic species with wide ranges and effective dispersal mechanisms will become more abundant, while specialist with narrow habitat requirements and long lifetimes (= slow growth rates) will decline. It will be impossible under such conditions of rapid climate change to uphold UN-CBD’s aim to reduce the rate of biodiversity decline significantly by 2010.

Unfortunately, extreme events have been neglected in the traditional impact assessments. That absence is an obvious reason for the apparent underestimation of current ecological impacts. The actual unfolding of climate change over the last decades and in the coming decades will provide most likely many more surprises. Species, communities, landscapes, ecosystems and biomes are much more sensitive and vulnerable than is commonly appreciated. With continued climate change over the coming decades, natural responses of species and ecosystems (cf. Article 2) will not be adequate for survival, and many ecosystems will rapidly become depauperated.



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4. Conclusions: many reasons for concern

The IPCC (2001) introduced several different reasons for concern while assessing the evidence for dangerous anthropogenic influences on the climate system (Smith et al., 2001). They indicate that above 2°C, risks rapidly increase. Although they explicitly mentioned that below that level, there already will be risks, they judged (at that time) that they would be acceptable. Their assessments used observed responses to estimate the risks at lower levels of warming. At that time, however, the impacts could not be unambiguously attributed to specific changes in climate, partly because such attribution was speculative by scientific standards (Parmesan and Yohe, 2003).

Our study uses recent observations on the character of the observed changes of local, regional and global climate. It is now well established that changes in climatic extremes (more heatwaves, more intense rain, different hurricane paths and intensity, etc.) have become more pronounced in the last decades than changes in the climatic 'normals'. Linking the observed changes in species and ecosystems with the changes in extreme weather events, we provide a consistent correlation of adequate forcing and response. With this new understanding, it is becoming obvious that traditional impact-assessment approaches are inadequate for precisely estimating the extent and magnitude of responses. They only provide the proper direction.

This study indicates that it is likely that the IPCC 'reason for concern' level of 2°C is actually too high. Even with small changes, there will be disproportionately large changes in the frequency and magnitude of extreme events and consequently unpredictable but devastating impacts on species and ecosystems with even a moderate climate change increase of 1 to 2°C.

Anthropogenic climate change will continue for many decades, likely even for centuries. We are venturing into the unknown with increasingly unique climate, and its associated impact could be quite disruptive. Defining tight climate protection targets and subsequent emission reduction targets is becoming, more than ever, a must. Given the wide recognition that human-induced climate change is a serious environmental and development problem, adequate measures are needed to reduce emissions of greenhouse gases and to reduce the vulnerability of different sectors and ecosystems to climate change. Based on current scientific understanding of the response of species and ecosystems, we suggest that efforts be made to limit the increase in global mean surface temperature to maximally 1.5°C above pre-industrial levels and limit the rate of change to less than 0.05°C per decade.

The maximum of 1.5°C tightens the climate protection targets of 2°C by the EU and the Ad-Hoc Technical Expert Group on Biological Diversity and Climate Change (2003) considerably. This is necessary, however, because impacts are more widespread, threaten delicate species interactions, and are triggered by the more rapidly occurring changes in extreme events. It thus comprehensively combines IPCC's reasons for concern 'Risks to unique and threatened systems" and "Risks from extreme climate events' (Smith et al. 2001). That ecosystems and species more strongly respond to changes in extreme events causes an additional reason for concern. Swart et al. (1998) already argued that beyond a warming rate of 0,05°C per decade the adaptation capacity of ecosystems becomes severely restricted. Although we support their argument, it is well established that rapid climate change will disproportionally lead to more extreme events. This is also what is observed in recent weather records. Together, this makes a strong argument for limiting the rate of change to maximally 0.05°C per decade.

About the authors

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Prof. Dr. Rik Leemans leads the Environmental Systems Analysis group (www.dow.wur.nl/esa/) of Wageningen University. He co-chairs the Response Option Working group of the Millennium Ecosystem Assessment (www.millenniumassessment.org). He has served as a lead author on all three IPCC Assessment Reports. Previously, he was a senior scientist and project leader of the National Institute of Public Health and the Environment (RIVM), and professor of integrated land-use modelling at Wageningen University.
His early studies at Uppsala University (Sweden) emphasized the successional dynamics and structure of forests. In his subsequent research position at the International Institute of Applied System Analyses (IIASA) in Laxenburg, Austria, he developed several widely-used environmental databases and simulation models to assess the impacts of climate change on ecosystems. Since then his research has evolved into modelling global land-cover patterns and land-use change and climate-change impacts. All these aspects were integrated in RIVM's IMAGE 2 model, which he coauthored. This global model explicitly simulates causal chain of climate change and environmental responses, and is broadly used to support (inter)national environmental assessments and development of greenhouse gas policies.

Ir Arnold van Vliet

Ir Arnold van Vliet is a biologist at the Environmental Systems Analysis group of Wageningen University and at the Foundation for Sustainable Development. Since his Biology study at Wageningen University he specialized in monitoring, analyzing and forecasting the ecological impacts of climate change on spatial scales ranging from global to local. He initiated and coordinates the Dutch phenological network De Natuurkalender (http://www.natuurkalender.nl/). He is vice-chair of COST Action 725, which aims to establish a European phenological data platform for climatological applications (http://www.cost725.org/) and he coordinated the European Phenology Network, which aims to increase efficiency, added value and use of phenological monitoring and research in Europe in the context of global climate change.

Appendix: Newly added plant species to the Standard list of the Dutch Flora.

New plant species, which are added to the official standard list of the Dutch flora, published in September 2004. These plant species share two criteria: They are observed in three different localities and have survived for at least three generations. The plant species with the attribute ‘will be added’ are also observed in The Netherlands but do not yet comply with the location and reproduction criteria. They are therefore nominated for the next standard list.

Trivial Dutch name	Scientific name	Attribute
Aarereprijs	Veronica spicata	will be added
Akkerwikke	Vicia sativa subsp. Segetalis	Added
Anna Paulownaboom	Paulownia tomentosa	will be added
Balkanvergeet-mij-nietje	Brunnera macrophylla	will be added
Behaarde struweelroos	Rosa caesia	Added
Beklierde heggenroos	Rosa tomentella	Added
Beklierde heggenroos	Rosa tomentella	Added
Berijpte viltroos	Rosa sherardii	Added
Beverneltorkruid	Oenanthe pimpinelloides	Added
Blauw kattenkruid	Nepeta mussinii	will be added
Blauwe monnikskap	Aconitum napellus (s.l.)	will be added
Bleek cypergras	Cyperus eragrostis	will be added
Boogmispel	Cotoneaster sternianus	will be added
Bosogentroost	Euphrasia nemorosa	Added
Bossalie	Salvia nemorosa	will be added
Bottelroos	Rosa villosa	Added
Brandpastinaak	Pastinaca sativa subsp. Urens	Added
Brede dovenetel	Lamium confertum	Added
Breed pijlkruid	Sagittaria latifolia	will be added
Chinese naaldaar	Setaria faberi	will be added
Citroenmelisse	Melissa officinalis	Added
Dalmatiëklokje	Campanula portenschlagiana	will be added
Dessertbladen	Malva verticillata	will be added
Donzige klaproos	Papaver atlanticum	will be added
Doorwaskervel	Smyrnium perfoliatum	will be added
Draadfonteinkruid	Potamogeton filiformis	Added

Trivial Dutch name	Scientific name	Attribute
Driebladvetkruid	Sedum sarmentosum	will be added
Eendagsbloem	Tradescantia virginiana	will be added
Fazantenbes	Leycesteria formosa	will be added
Fijn venushaar	Adiantum raddianum	will be added
Frans walstro	Galium parisiense	will be added
Fransje	Schoenoplectus x flevensis	Added
Galega	Galega officinalis	will be added
Geel duizendblad	Achillea filipendulina	will be added
Gekield druifkruid	Chenopodium schraderianum	will be added
Gele ribes	Ribes odoratum	will be added
Gevlamde fijnstraal	Conyza bonariensis	will be added
Grijs kattenkruid	Nepeta x faassenii	will be added
Groot nagelkruid	Geum japonicum	will be added
Hanendoorn	Crataegus crus-galli	will be added
Heggenroos	Rosa corymbifera	Added
Hoge amarant	Amaranthus rudis	will be added
Hoge dravik	Anisantha diandra	will be added
Hoge fijnstraal	Conyza sumatrensis	Added
Hondsroos	Rosa canina (s.s.)	Added
IJle kropaar	Dactylis polygama	Added
IJle lamsoor	Limonium humile	will be added
Kale gierst	Panicum dichotomiflorum	Added
Kale struweelroos	Rosa dumalis	Added
Karpatenklokje	Campanula carpatica	will be added
Klein fakkelgras	Rostraria cristata	will be added
Klein struisgras	Agrostis hyemalis	will be added
Kleinbloemige roos	Rosa micrantha	Added
Kleverige alant	Dittrichia viscose	will be added
Knobbelklaverzuring	Oxalis dillenii	Added
Knopkroos	Lemna turionifera	Added
Kogelduizendknoop	Persicaria capitata	will be added
Kraagroos	Rosa agrestris	Added
Kruipkattenstaart	Lythrum junceum	will be added
Kruipklokje	Campanula poscharskyana	will be added
Kruishyacint	Scilla massartiana (x)	Added
Kustwolfsmelk	Euphorbia portlandica	will be added
Laurierkers	Prunus laurocerasus	will be added
Lijsterbesspirea	Sorbaria sorbifolia	will be added
Lintvaren	Pteris cretica	will be added
Loganbes	Rubus loganobaccus	will be added
Mariëtteklokje	Campanula medium	will be added
Marjoleinbekje	Chaenorhinum origanifolium	will be added
Monnikskruid	Nonea lutea	will be added
Muurzeepkruid	Saponaria ocymoides	will be added
Oosterse klaproos	Papaver pseudoorientale	will be added
Oosterse plataan	Platanus orientalis	will be added
Piramideklokje	Campanula pyramidalis	will be added
Pluimgipskruid	Gypsophila paniculata	will be added
Prachtrozenkransje	Anaphalis margaritacea	will be added

Trivial Dutch name	Scientific name	Attribute
Prikneus	Lychnis coronaria	Added
Ribbelbies	Schoenoplectus mucronatus	will be added
Rijncentaurie	Centaurea stoebe	Added
Rimpelige mispel	Cotoneaster rehderi	will be added
Rivierduinzegge	Carex ligerica	Added
Rode ribes	Ribes sanguineum	will be added
Rood herderstasje	Capsella rubella	will be added
Rotsschildzaad	Alyssum saxatile	will be added
Roze berberis	Berberis aggregata	will be added
Ruige fijnstraal	Conyza bilbaoana	will be added
Ruwe viltroos	Rosa pseudoscabriuscula	Added
Schijnegelantier	Rosa columnifera	Added
Schijn-els	Clethra alnifolia	will be added
Schijnheggenroos	Rosa subcollina	Added
Schijnhondsroos	Rosa subcanina	Added
Schijnpapaver	Meconopsis cambrica	will be added
Slaapkamergeluk	Soleirolia soleirolii	will be added
Slanke ogentroost	Euphrasia micrantha	Added
Smal venushaar	Adiantum diaphanum	will be added
Spaanse dravik	Anisantha madritensis	will be added
Spaanse hyacint	Scilla hispanica	will be added
Steentijmereprijs	Veronica acinifolia	will be added
Stekelkamgras	Cynosurus echinatus	will be added
Stijf ijzerhard	Verbena bonariensis	will be added
Stijve aardpeer	Helianthus rigidus	will be added
Texaanse ganzenvoet	Chenopodium berlandieri	will be added
Trompetboom	Catalpa bignonioides	will be added
Tweekleurig springzaad	Impatiens balfourii	will be added
Tweenervige zegge	Carex binervis	will be added
Valse zandzegge	Carex reichenbachii	Added
Vierrijige ogentroost	Euphrasia tetraquetra	Added
Viltroos	Rosa tomentosa	Added
Vlokkige toorts	Verbascum pulverulentum	will be added
Vroege krokus	Crocus chrysanthus	will be added
Walstroleeuwenbek	Linaria purpurea	will be added
Waterteunisbloem	Ludwigia grandiflora	Added
Welriekende ganzenvoet	Chenopodium ambrosioides	will be added
Wigbladige roos	Rosa elliptica	Added
Wilde kool	Brassica oleracea subsp. oleracea	Added
Wilgbladige mispel	Cotoneaster salicifolius	will be added
Witte esdoorn	Acer saccharinum	will be added
Zijdeplant	Asclepias syriaca	Added
Zilverkruiskruid	Senecio cineraria	will be added
Zilverstruisgras	Agrostis scabra	will be added
Zuid-Afrikaanse gierst	Panicum schinzii	Added
Zwart peperboompje	Daphne laureola	will be added
Zwarte wikke	Vicia sativa subsp. nigra	Added

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WWF Climate Change Campaign

Global warming and climate change pose a serious threat to the survival of many species of plants and animals and the well-being of people around the world.

The programme has two aims:

- By 2010 the world has made significant progress to stay below a 2 degree C increase in global average temperature (in comparison to pre-industrial levels), and
- 50 countries are implementing adaptation strategies in key Ecoregions/biomes and sectors of their economies on the basis of national plans, for the reduction of vulnerability of climate change.

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