Plants and climate change: which future?

With Foreword by Wangari Maathai

BGCI
Plants for the Planet

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By Belinda Hawkins, Suzanne Sharrock and Kay Havens

"All flesh is grass." Isaiah

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BGCI

Plants for the Planet

Botanic Gardens Conservation International (BGCI)

Linking more than 800 botanic gardens and other partners in some 120 countries, BGCI forms the world's largest plant conservation network. From grass-roots action to global policy development, BGCI operates at all levels to achieve plant conservation, environmental education and development goals. We aim to ensure that plants are recognised as one of the world's most important natural resources, providing essential ecosystem services and underpinning all life on Earth. Our mission is to: "*mobilise botanic gardens and engage partners in securing plant diversity for the well-being of people and the planet*".

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For more information about BGCI and its activities, please contact: Botanic Gardens Conservation International, Descanso House, 199 Kew Road, Richmond, Surrey, TW9 3BW, UK. Tel: +44 (0)20 8332 5953, Fax: +44 (0)20 8332 5956, email: info@bgci.org, www.bgci.org.

Foreword

In my childhood, I lived in a land abundant with shrubs, creepers, ferns and trees. Food was plentiful, nutritious and wholesome, people were healthy and strong and there was always enough firewood to cook with. Through my life I have watched the indigenous forests of Kenya being continuously encroached upon for the commercial production of timber, charcoal production and human settlements. In many parts of the world the story has been the same and the natural abundance of plant diversity is being destroyed. Today we are also faced with global food shortages and declining water supplies.

Our disregard for the negative impact of our actions on the environment has directly contributed to climate change. The Intergovernmental Panel on Climate Change (IPCC) estimates that during this century, global temperatures will rise between 1.8° and 4°C, and perhaps by as much as 6.4°C. Scientists also tell us that Africa will be hit hardest by climate change. Melting of ice and snow on the highest mountains, unpredictable rains and floods, subsequent crop failures, prolonged droughts, and rapid desertification, among other signs of global warming, are already visible in Africa. Many Africans are still largely poor and live in rural environments where they will find it difficult to adapt to the impact of climate change. We are called to take action and avoid destruction of the environment and subsequent disruption of human economies and well-being.

This report attempts to demonstrate the linkages between plant diversity and climate change and why it is crucially important to care for the world's natural plant diversity. Forests such as the Congo, the Amazon and the huge forests in southeast Asia, all major repositories of plant diversity, provide livelihoods for millions and play a major role as carbon sinks.

Plant diversity provides a buffer against the effects of climate change, and a source of raw materials for adaptation. Looking after our forests – and other forms of natural vegetation - is a crucial step. Understanding, explaining and valuing our plant diversity are other vital tasks – so often undertaken by botanic gardens and promoted by BGCI. The experience I have had working with the Green Belt Movement for the last thirty years shows that it is possible to mobilise literally millions of individual citizens in every country to plant trees, prevent soil loss, harvest rain water and practice less destructive forms of agriculture. Climate change is one of the critical issues of our times and we must all act urgently as individuals or collectively to care for our green world.

Wangari Maathai
Nobel Peace Laureate

"When we plant trees, we plant the seeds of peace and seeds of hope."

Executive Sumary

There is unequivocal evidence that the Earth's climate is warming at an unprecedented rate. The majority of informed scientists agree that this is the result of the increase of greenhouse gases in our atmosphere, directly caused by human activities. The effects of climate change are geographically inequitable, varied and unpredictable with potentially devastating and unplanned-for consequences, both for global plant diversity and ultimately for human survival.

Plants are of particular importance as they are major regulators of global climate and are the keystone of the carbon cycle. The uptake of carbon dioxide (CO_2), one of the principle greenhouse gases, during photosynthesis is the major pathway by which carbon is removed from the atmosphere and made available to animals and humans for growth and development. Forests are especially important in this regard, acting as major carbon sinks by soaking up CO_2 and storing it as biomass and in soils. Conversely, the ongoing destruction of tropical rainforests, which today continues at around 13 million ha/yr, is a major source of CO_2 emissions.

Plant diversity underpins all terrestrial ecosystems, and these provide the fundamental life-support systems upon which all life depends. Ecosystems are composed of species assemblages and it is clear that individual plant species within ecosystems will react differently to changing climatic conditions. Some species will stay in place and adapt to new conditions, others will move to new locations and some species will become extinct. This will result in changes in species compositions and ecosystem structure, and possible loss of essential ecosystem services.

Models of future plant distributions indicate that a temperature rise of 2-3°C over the next hundred years could result in half the world's plant species being threatened with extinction. Species such as alpine and island endemic species with 'nowhere to go' are already of grave conservation concern. Loss of plant species will disproportionally affect the rural poor, many of whom rely on wild plant resources for their livelihoods.

Agro-ecosystems face many of the same threats from climate change as species in natural systems. The negative impacts of climate change on agriculture (reductions in yield, shifting crop growing zones, increased pests and diseases) are likely to be most severe in tropical Africa and south Asia, where an additional 75 million people or more could become at risk of hunger. The most food insecure people will be those most affected by climate change.

The responses of plants to changing environmental conditions are complex and not well understood. However, the intimate linkages illustrated in this report between climate, plant diversity and human livelihoods, highlight the need for urgent attention to be focused on plants and their conservation.

The Global Strategy for Plant Conservation (GSPC) adopted in 2002 by 188 countries as part of the Convention on Biological Diversity (CBD) provides a relevant framework – promoting actions necessary to maintain ecosystems as carbon sinks and as reservoirs of genetic and species resources as a safeguard for the future. It has also set international targets for the conservation of threatened plants both *in situ* and *ex situ* and for promoting education and awareness about plant diversity. While it is important that every effort is now made to ensure that the GSPC targets are achieved by 2010, the profound shift in environmental parameters brought about by climate change requires renewed and re-focused activities. This report identifies a number of additional actions that should be undertaken as an urgent priority. These include: a greater focus on the conservation of tropical forests; encouragement of agro-forestry and tree planting; using native species for land restoration; the collection and sharing of baseline data on plant distributions and current and future threats; the development of an internet-based information service on plants and climate change; climate change public awareness campaigns relating to the importance of plant diversity; and the development of mechanisms for the sharing of relevant skills and information.

The GSPC has united governments, botanic gardens and other conservation agencies in taking coordinated action to save the world's plant diversity. As the links between plant diversity and climate change are becoming more clearly demonstrable and understood it is essential that the momentum for plant conservation is increased. Action to save plant species from extinction must be stepped-up to ensure the future of life on earth.

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Acronyms and abbreviations

&	and
%	per cent
°C	degrees Centigrade
°F	degrees Farenheit
AGCM	atmospheric general circulation models
AR4	Fourth Assessment Report of the IPCC
BAU	business as usual
BGCI	Botanic Gardens Conservation International
C	carbon
C3	3-carbon compound
C4	4-carbon compound
CABI	CAB International
CAM	Crassulacean acid metabolism
CBD	Convention on Biodiversity
CDM	Clean Development Mechanism
CH_4	methane
CI	Conservation International
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
cm	centimetre
CO	carbon monoxide
CO_2	carbon dioxide
CoP	Conference of the Parties
CPF	Collaborative Partnership on Forests
CPCS	China Plant Conservation Strategy
CWR	Crop Wild Relatives
DEFRA	Department for Environment, Food and Rural Affairs (UK)
ECCM	Edinburgh Centre for Carbon Management
EU	European Union
FACE	Free air carbon dioxide enrichment
FAO	Food and Agriculture Organization
FSC	Forest Stewardship Coucil
FZB	Zoological-Botanical Foundation in Rio do Sul
GBIF	Global Biodiversity Information Facility
GDP	gross domestic product
GHG	greenhouse gas
GNP	gross national product
GPP	gross primary production
GPPC	Global Partnership for Plant Conservation
GSPC	Global Strategy for Plant Conservation
GVMs	global vegetation models
ha/yr	hectare per year
H_2O	Water
IPG	International Phenological Gardens
IPA	important plant area
IPCC	Intergovernmental Panel on Climate Change
ISSC-MAP	International Standard for the Sustainable Wild Collection of Medicinal and Aromatic Plants
ITTO	International Tropical Timber Organization
IUCN	World Conservation Union
km	kilometre
km/yr	kilometre per year
LIDET	Long term intersite decomposition experiment
LPJ	Lund–Potsdam–Jena Dynamic Global Vegetation Model
m	metre
MDGs	Millennium Development Goals
MA	Millennium Ecosystem Assessment
N	nitrogen
N_2O	nitrous oxide
NEP	net ecosystem production
NPP	net primary production
NGO	non-governmental organisation
NO_x	nitrogen oxides
NTFPs	non timber forest products
O_3	ozone
OGCM	ocean general circulation models
PFT	plant functional type
ppm	parts per million
PRECIS	providing regional climates for impact studies
REDD	reducing emissions from deforestation and degradation
SANBI	South African National Biodiversity Institute
SCRI	Scottish Crop Research Institute
spp.	species
sq km	square kilometre
sq m	square metre
UK	United Kingdom
UKCIP	UK Climate Impacts Programme
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USDA	US Department of Agriculture
US$	US dollars
UVB	Ultraviolet or B rays
VOCs	volatile organic compounds
WHO	World Health Organisation
WWF	World Wild Fund for Nature

Introduction

In 1896, the Swedish chemist Svante Arrhenius predicted that a doubling of atmospheric carbon dioxide (CO_2) would increase global temperature by 3-6 degrees Centigrade (ºC).

Over 100 years later, the large majority of informed scientists now agree that the rapid climate change which we are increasingly observing and recognising, *is* the result of the increase of CO_2 in our atmosphere, and that ultimately this has come about because of the development of human civilisation. Humankind's ability to alter the chemistry of the atmosphere and thereby change global climate thus now compares with the natural swings in climate found in the geological record extending back in time over millions of years (Press, 2008).

Research also indicates that our climate will not necessarily change smoothly this time, and that the intensity and forcings of climate change on the environment and society could, at least on a regional basis, be abrupt and nonlinear with potentially devastating and unplanned-for consequences (Schellnhuber, 2006; MacCracken, *et al*., 2007). Indeed, the increased incidence of droughts, flooding and extreme weather events around the world is now an observable reality, attributable to climate change.

In the light of this, growing millions of people agree with the science-based consensus that urgent action is required to address anthropogenic greenhouse gas (GHG) emissions, particularly CO_2 as a by-product in the production of energy.

Nevertheless, developed countries are reluctant to give up their energy intensive prosperity, while developing countries see no justification for forsaking their aspirations for the same. Our world stands at a crossroads.

Against this backdrop, it has only recently become widely accepted that *biological* processes can control and steer the Earth's climatic systems in a significant way. Healthy terrestrial ecosystems constitute a major player in this respect because they can both release and absorb greenhouse gases, as well as control exchanges of energy and water (Heimann & Reichstein, 2008). Whilst CO_2 plays a critical role in maintaining the balance of conditions necessary to all life (Flannery, 2005) the very character of land surface, whether it is hardwood forest or grassland, is determined to a large extent by climatic forces.
The interaction between the carbon cycle and climate is therefore crucial to life as we know it.

Looking closely at this interaction we find that, through the uptake of CO_2 during photosynthesis, it is *plants*, in their boundless variety, that are the keystone of the carbon cycle. By harnessing the energy of the sun, they begin the chains of biomass production that enable all things to exist and grow.

Plants are arguably the single most important group of organisms in shaping the habitats and determining the physical environments that all other species require for survival, and as such significantly influence total biodiversity richness. Furthermore, vegetation and soils together contain about three times as much carbon as the atmosphere (Royal Society, 2001). Plant responses to climatic changes are therefore of enormous importance, since they determine to a large extent primary productivity, ecosystem structure, soil composition and potential carbon sequestration. In turn, climate change will also have a fundamental effect on soil properties and processes, and a direct impact on water resources.

Recent studies predict that climate change could result in the extinction of up to half the world's plant species by the end of the century (Bramwell, 2007). Such mass extinctions will have catastrophic effects for humanity. And yet, up to now, plants have been largely neglected in the climate change debate. This report sets out to address this imbalance by explaining the importance of plants in relation to climate change, describing the impacts of climate change on plant survival and highlighting the fundamental importance of maintaining plant diversity for the future of people and the planet.

A report of this nature was first called for by a group of experts meeting to discuss the impact of climate change on plant diversity in Gran Canaria in 2006. A specific recommendation of the meeting was that research findings on climate change and plant diversity should be compiled into a baseline report for wide dissemination. This report is the result of a desk-based study on plants and climate change. It includes input from international experts and presents a synthesised overview of the present state of knowledge about the complex relationships that exist between plants, climate and human livelihoods. The report includes a series of recommendations and actions that are required to prevent widescale loss of plant diversity under future climate change scenarios and will form the basis of an information service, which will be used to guide future policy and plant conservation actions.

"*The fate of humanity in the light of climate change, and of all known species, is inseparable from the fate of plants*" (Gran Canaria Group, 2006). We must understand the story they are telling.

1 An overview of current climate change

Summary

There is unequivocal evidence that the Earth's climate is warming at an unprecedented rate. Temperature increases are geographically inequitable. Some regions, particularly at high altitudes and latitudes, are warming more than other areas. Other climatic effects, including prolonged droughts in arid and semi-arid regions, increased flooding in mid to high latitudes, and more extreme weather events are also increasing. Sea levels are rising. Climates are changing more rapidly than species can adapt and there is a high risk of mass extictions of biodiversity as the planet warms. There is very good evidence that human activities that increase the concentration of greenhouse gases (GHGs) in the atmosphere are driving climate change.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) stated that: "*continued GHG emissions at or above current rates would cause further warming and induce changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century. For the next two decades a warming of about 0.2°C per decade is projected for a range of emission scenarios. Afterwards, temperature projections increasingly depend on specific emission scenarios.*"

In other words, the future world climate depends on us and our ability to curb GHG emissions.

Key points

- CO_2 is one of the principle GHGs driving climate change.
- Global atmospheric CO_2 is increasing due to human activity, particularly the burning of fossil fuels, deforestation and agriculture.
- Uptake by plants is the major pathway by which CO_2 is removed from the atmosphere. Approximately 50% of our emissions are currently removed this way, but the ability of vegetation to act as a sink is decreasing and in some areas, vegetation may switch to become a source of CO_2.
- Plants convert CO_2 to complex carbohydrates (such as glucose) through the process of photosynthesis.
- The photosynthetic pathway is the major route by which carbon, the principle element within our bodies, is made available to animals and humans.
- Plants therefore form the basis of the carbon cycle. They are major regulators of the global climate and underpin all life on our planet.

1.1 Our warming planet

The climate of our Earth has always changed. Ice ages have come and gone and life, in its infinite variety, has evolved and persisted. That the climate system is currently warming at an unprecedented rate is unequivocal:

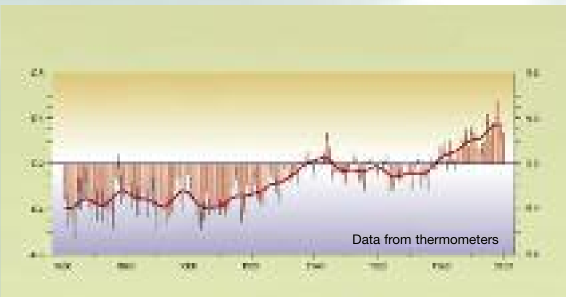
- **Global average temperatures** have risen by on average 0.74°C over the past century (1906 to 2006) with the warming rate for the last 50 years nearly twice that of the last 100 years (IPCC, 2007).
- 11 of the past 12 years (1995 to 2006) rank among the 12 **warmest years** in the instrumental record of global surface temperature since 1850 (IPCC, 2007).
- **Ocean temperatures** have increased to depths of at least 3000m (Manning, 2007). In fact, the recent warming of the Western Equatorial Pacific has bought its temperature to within <1°C of its maximum in the past million years (Hansen *et al*., 2006).
- Average Arctic temperatures are rising at almost twice the global rate, a phenomenon that is known as the '**Arctic amplification**' (Graversen *et al*., 2008). Parts of the Arctic have warmed by 2-3°C since the 1950s (Pew Centre, 2007). In Alaska, northern Siberia and the Antarctic peninsula winter temperatures have risen by 4-5°C since the 1950s (Epstein & Mills, 2006).
- **Warming is geographically inequitable**, with temperature increases greater at higher altitudes, and some parts of the globe actually cooling. Further, winters are warming more than summers (Saeterdsal *et al*., 1998) and nights are warming more than days (Peng *et al*., 2004).

Figure 1.1: Variations of the Earth's surface temperature over the last 140 years and the last millennium (IPCC, 2001a).

Variations of the Earth's surface temperature for:

the past 140 years (Global)

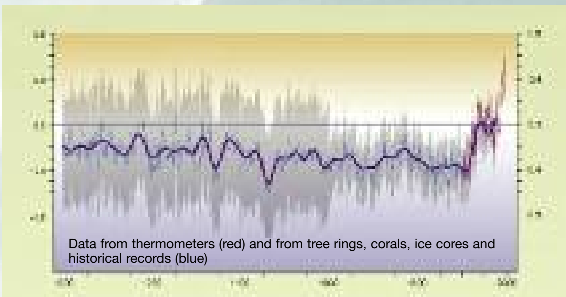
Departures in temperature in °C (from the 1961-1990 average)



The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (red line).

the past 1,000 years (Northern Hemisphere)

Departures in temperature in °C (from the 1961-1990 average)



Additionally, the year by year (blue) and 50 year average (solid line) variations of the average surface temperature of the Northern Hemisphere for the past 1,000 years are shown.

1.2 Results of temperature rise

- In 2006, models predicted an **ice-free Arctic** in summers by 2040 (Holland *et al*., 2006), a condition that has not existed for at least a million years (University of Arizona, 2005). In 2007, research indicated that this will happen as soon as 2013 (Maslowski, 2007). It has become apparent in recent years that the real, observed rate of summer ice melting is now starting to run **way ahead of models**. Melting ice masses (over land) will contribute to sea level rise and the release of carbon and methane, long locked in ice. The loss of reflective ice and snow cover will exacerbate temperature rise via the albedo effect, whereby vegetation soaks up heat. Feedbacks such as this could become the dominant mechanism underlying future temperature amplification (Graversen *et al*., 2008).
- Over most of their ranges, **cumulative loss of glacier mass** is currently occurring ubiquitously and uncharacteristically rapidly (Manning, 2007) with increasing rates of ice loss since the mid-1980s (UNEP, 2007a). For example, the Vernagtferner glacier in the European Alps lost almost 30% in area and more than 50% in mass between 1912 and 2003. Projections of glacier retreat in the Himalayas (based on IPCC scenarios) suggest that increases in the mean annual temperature for High Asia in the range of 1-6°C (low to high estimate) by 2100 are likely to result in a decline in the current coverage of glaciers by 41-84%. The Himalayan mountain ranges are known as the 'water towers' of Asia, since the glacier-fed rivers originating from the mountains comprise the largest river run-off from any single location in the world. Changes in these influence water resources, agriculture, infrastructure, livelihoods, biodiversity and cultures and would affect the lives of about 40% of the world's population (UNEP, 2007a).
- **Global average sea level has been rising** (expanding due to warming by absorbing climate heat plus added to by melting glaciers) by approximately 3mm per year since 1993 (UNEP/GRID-Arendal, 2007). Two villages on the Pacific island state of Kiribati have already been evacuated due to rising seas since 2000 (WWF, 2006). Higher ocean levels are already contaminating underground water sources in Israel and Thailand, in various small island states in the Pacific and Indian Oceans and the Caribbean Sea, and in some of the world's most productive deltas, such as China's Yangtze Delta and Vietnam's Mekong Delta (UNFCCC, no date).

1.3 Droughts and fires, floods and storms; other climatic changes

Though global warming is the aspect of climate change that attracts the most attention, we are also seeing coherent changes in aspects of the climate system other than temperature:

- **Arid and semi-arid regions** such as the Sahel, the Mediterranean and south Asia are becoming drier. In Africa's large catchment basins of Niger, Lake Chad and Senegal, total available water has decreased by 40-60% (UNFCCC, no date) with **prolonged droughts** predicted to increase across the region (Fischlin & Midgely, 2007).
- Conversely, atmospheric water content is increasing globally and **mid to high-latitudes are becoming wetter**. Where precipitation has increased there have been disproportionately more frequent heavy precipitation events in some regions (eastern parts of North and South America, northern Europe and northern Asia (Manning, 2007). For example, the monsoon-based flooding of Bangladesh in 2004, which left 60% of the country under water (UNFCCC, no date). In August 2007 more than 17 million people in India, Pakistan, Bangladesh and Nepal were affected by monsoon rain and floods (BBC, 2007a). Figures are even higher for China, where 119 million people were affected (BBC, 2007b) and where natural defences have been weakened by environmental degradation.
- **Extreme weather events** such as heat waves, wildfires, storms and flash floods are expected to increase. From 1987 to 1998, the average number of climate-related disasters was 195. From 2000 to 2006, the average was 365, representing an increase of 87% (UN, 2007).
- The number of category 4 and 5 hurricanes has almost doubled in the past 30 years (Emmanuel, 2005). In 2004, Brazil was hit by the first hurricane ever recorded in the South Atlantic (Climate Institute, 2007). Similarly, **economic losses** due to extreme events have increased by more than 30 times over the past three decades to an estimated US$43 billion a year in the 1990s (Boyd & Roach, 2007).
- Further, **storm intensity has increased** on average and is expected to continue increasing (Adger *et al*., 2005). Hurricane Katrina, which hit the USA Gulf Coast in 2005, displaced one million people (Epstein & Mills, 2006). Once the initial disaster is over, **secondary disasters** follow, such as poor resettlement plans, ongoing disabilities, homelessness and harassment in camps (Worldwatch Institute, 2007). Regardless of other factors, extreme events are enough to cause a great loss within a short time (Bhandari, 2007).

1.4 The impacts of these changes

The combined aspects of current climate change have played a part in:

- **Observed climate-induced changes** in at least 420 physical processes and biological species or communities (UNFCCC, no date). Of more than 29,000 observational data series from 75 studies that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (IPCC, 2007). Ecological responses to climate change were already clearly visible back in 2002 (Walther *et al*., 2002). Six years later and at least one species, the golden toad (*Bufo perglenes*) of Costa Rica, has gone extinct directly due to climate change with a third of the world's amphibian's under threat of extinction from climate change (Stuart *et al*., 2004; Bosch *et al*., 2006). The risk of **mass extinctions** is increasing (McLaughlin *et al*., 2002; Thomas *et al*., 2004; Malcolm *et al*., 2006; Sekercioglu *et al*., 2008). Pygmy possums, penguins, caribou, monarch butterflies, migratory songbirds, polar bears, trout, coral reefs and arctic foxes to name but a few are all at the verge of extinction due to global warming (Barbraud & Weimerskirch, 2006; Mahat, 2007; Stirling & Derocher, 2007). Plant extinctions have been less well documented but are predicted to increase dramatically – see Chapter 5.

- The **spread of malaria** to higher altitudes, for example in the Columbian Andes, 7,000 feet above sea level. Currently, up to 75% of malaria cases occur in children and over 3,000 children die each day from malaria (McMichael *et al*., 2003).
- Over 150,000 **deaths** (taking into account only a subset of the possible health impacts) in the year 2000 (McMichael *et al*., 2003) including 55,279 from extreme temperatures worldwide from 2000 to 2005 (Dow & Downing, 2007). For example, the August heat wave in 2003 caused the death of almost 15,000 people in France (Canouii-Poitrine *et al*., 2005).
- The acidification of the ocean, due to CO_2 absorption, affecting the ability of shellfish to form carbonate shells (IPCC, 2007) and of marine animals to extract dissolved oxygen from water (WWF, 2008).
- A significant decline in the diversity of bees and of the flowers they pollinate, for example in Britain and the Netherlands over the last 25 years, providing a worrying suggestion that declines in some species may trigger a **cascade of local extinctions** amongst other associated species and potentially lead to **ecosystem collapse** (University of Leeds, 2006).

1.5 The causes of these changes

After 8,000 generations of *Homo sapiens*, it is at least 90% certain that global warming is caused by human activities (IPCC, 2007) with joint attribution also demonstrated statistically (Root *et al*., 2005).

The principal GHGs, which are essential to life by reducing the loss of heat to space, are water vapour (H_2O), CO_2, methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Likewise, an excess of GHGs can raise the temperature of the planet. We are increasing the concentration of GHGs in the atmosphere, principally by fossil fuel combustion, forest burning and agriculture.

- The global atmospheric CO_2 concentration ranged from 180-300 parts per million (ppm) over the past 400,000 years and varied roughly within a 270-290ppm over the last 1000 years (Barnola *et al*., 2003).
- The pre-industrial concentration of CO_2 in the atmosphere was 280ppm (Dow & Downing, 2007). Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (IPPC, 2007).
- Concentrations of greenhouse gases in 2005 were 430ppm (Stern, 2006).
- Currently, atmospheric levels of CO_2 are rising by over 10% every 20 years (UNFCCC, no date). Today, using the IPCC's formula, they are 459ppm (Monbiot, 2007). The lowest projected increase is for a concentration of over 520ppm by the end of this century (Dow & Downing, 2007).

Box 1.1 Climate change definitions

Climate is defined as the average 30-year weather patterns of a region (World Meteorological Association, no date). We do not need to be able to predict exact weather conditions to be able to understand average climatic trends.

Climate *change* constitutes three main variables; elevated carbon dioxide (CO_2), altered rainfall patterns and temperature ranges.

Dangerous climate change was legally introduced as a term in 1992, when the United Nations Framework Convention on Climate Change (UNFCCC) called for stabilisation of GHGs to prevent dangerous anthropogenic interference with the climate system. The Convention suggested that such a level should be achieved within time frames 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 a sustainable manner.

Though scientific knowledge is insufficient to point to a single 'safe' GHG concentration, it has been suggested that the most serious consequences of climate change (i.e. dangerous climate change) might be avoided if global average temperatures rise by no more than 2°C above pre-industrial levels. Any temperature rise above this would significantly increase risks of irreversible feedback mechanisms that could produce runaway climate change. GHG emissions of 550ppm would very likely raise temperatures above that level, and so an appropriate precautionary approach would aim to stabilise emissions as far below 550ppm as possible (Schellnhuber, 2006). A 2006 study by Lowe *et al*. (2006) showed that even with stabilisation at 450ppm, 5% of modeled scenarios led to a complete and irreversible melting of the Greenland ice sheet.

In 2006, the Stern Review calculated a 77-99% chance of a 2°C rise before 2035 and at least a 50% chance of exceeding 5°C during the following decades. We are rapidly approaching this mark.

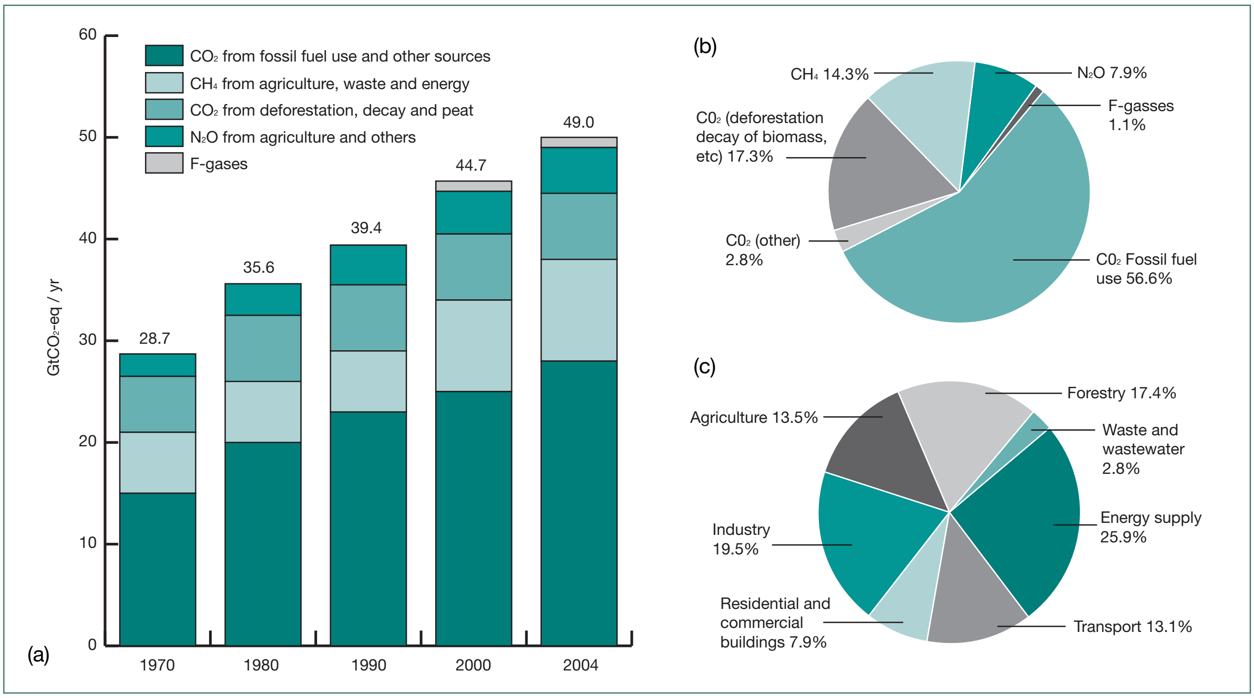


Figure 1.2 - (a) Global annual emissions of anthropogenic greenhouse gases (GHGs) from 1970 to 2004. (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (forestry includes deforestation) (IPCC, 2007).

Box 1.2 Feedback mechanisms

Different parts of the climate system interact with each other. Positive feedbacks tend to amplify the variability of climate whereas negative feedbacks provide stability. For example, warmer water stores less dissolved CO_2, which then remains in the atmosphere and is hence a positive feedback. In some interactions, the effect is reduced (a negative feedback), such as increased cloud cover due to increased ocean evaporation.

Though the global climate system is generally stable, it is a balance that is dynamic and constantly adjusting to forced perturbations. A change in any one part of the climate system will have much wider consequences as the initial effect cascades through the coupled components of the system. For example, the destruction of a forest will affect the balance of local surface energy, which in turn may modify local atmospheric circulation, effecting further climatic changes some distance away (Lovejoy & Hannah, 2005). Likewise, ice on the ocean has a huge effect on the local air temperature, as air over ice or land can be much colder than air over water. Sea ice changes might therefore influence fast, extreme climate change.

1.6 Future emissions: future warming

Since the climate system does not respond immediately, we are committed to a certain degree of warming simply from past emissions. The minimum predicted warming for the next 100 years is more than twice the warming that has already occurred (UNFCCC, no date). Continued GHG emission at or above current rates (a 'business as usual' scenario) would cause further warming and induce many changes in the global climate system during the 21st century that are likely to be larger than those observed during the 20th century (IPCC, 2007).

For the next two decades warming of about 0.2°C per decade is expected. After that, projections depend on emissions scenario. Future global warming is likely to lie in the range 2.4-6.4°C, depending on the emissions scenario that we chose. Substantially larger values still cannot be excluded (IPCC, 2007). To put average global temperature measurements into context, it is only 5°C warmer now than in the last ice age (Stern, 2006).

What is more, over the course of this century, net carbon uptake by terrestrial ecosystems is likely to peak (before mid-century) and then weaken or reverse, thus amplifying climate change (Fishlin & Midgley, 2007). Carbon uptake (by land and sea) is currently at about 50%, meaning that the Earth soaks up about half of our GHG emissions. There is no guarantee that this 50% 'discount' will continue and there is some evidence that the ability of forests to soak up man-made CO_2 is weakening alongside temperature increase (Miller, 2008). The Earth system is able to self-regulate and adapt to changes, but only up to a certain point (Schleicher & Bubendorfer, 2005).

Box 1.3 Inequitable climate change

Geographically, climate change will impact the people of the world in very different ways. Though an all pervasive issue, it will largely cause the most harm, soonest, in developing countries, where people are least responsible for it and least able to cope. Greatest attention should be given to helping these countries to mitigate and adapt to current and future climate change impacts (Lane *et al*., 2005).

Climate change adaptation is increasingly seen as an issue of both human welfare (in the face of inevitably unfair distribution of these burdens (Müller, 2002)) and of security. It has been addressed as such by the UN Security Council, forecasting conflicts over scarce food, water and land as well as unprecedented rates of human migration (Purvis & Busby, 2004).

Since CO_2 emissions are linked to Gross Domestic Product (GDP), developing countries will also play a significant role in determining the success of multilateral climate change response regimes. There is therefore a discrepancy between responsibility for, and the sharing of, climate impact burdens.

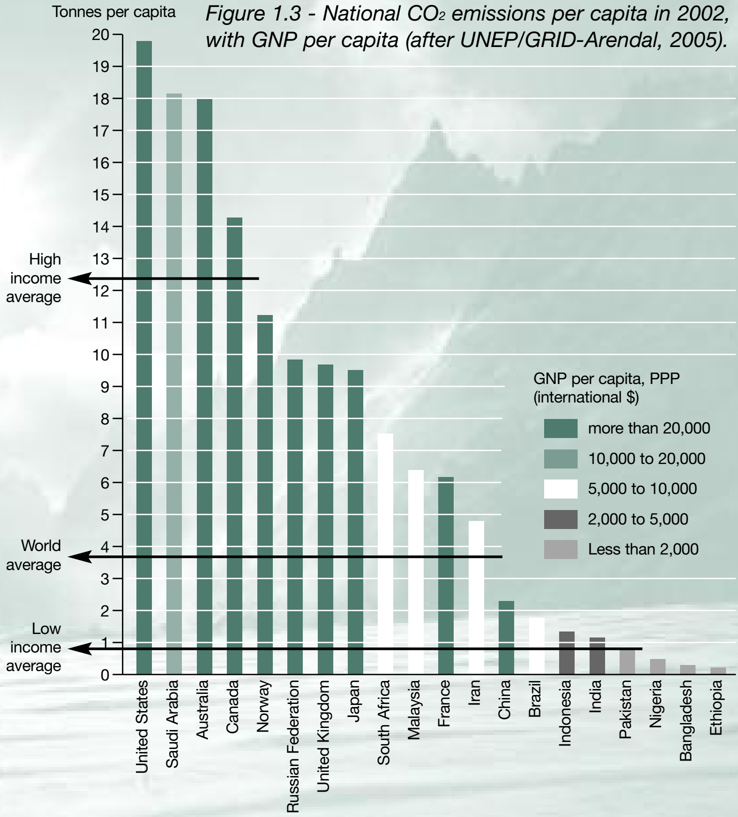


Figure 1.3 - National CO_2 emissions per capita in 2002, with GNP per capita (after UNEP/GRID-Arendal, 2005).

The rapidity of climate change and the mismatched adaptive capacity of species means that 20-30% of higher plants and animals are at high risk of extinction if the temperature rises by 1.5-2.5°C above present (Stern, 2006). Rises of 2-3°C may cause major (20-80%) loss of the Amazon rainforest and its biodiversity, 40-50% loss of endemic plants in South Africa and 50% loss of the rainforest in Queensland, Australia (Fishlin & Midgley, 2007).

1.7 Which future?

Plants can and do adapt to changes in their environment, with a classic example coming from the rapid evolution of heavy metal tolerance in plants on mine site tailings (Antonovics *et al*., 1971) and more recent examples coming from herbicide resistance in populations of weeds (Roy, 2004). However, plant adaptive responses to climate change are likely to be slower than plant responses to single pollutants, since adaptation to pollutants normally only involves one or two traits whereas adaptation to climate change is likely to involve many traits.

The fossil record indicates that in the past species have been able to adapt or move in response to climate change, but this has been dependent on a natural landscape. Further, from the perspective of the world's plant species, current changes in climate are occurring in the context of many other stresses such as pollution, land use change and population increase. Current observations reveal a climate that is more sensitive than anticipated, with changes occurring sooner and more intensely than predicted (Pew Centre, 2007).

Anthropogenically forced climate change is happening now, rapidly and may be the biggest threat to life as we know it. Actual *climates* are disappearing, not just habitats. Climate is the primary control of species distributions and ecosystem processes both now (Bickford & Laffan, 2006; Williams *et al*., 2007) and throughout history (Vincens *et al*., 1999). What differs now from history is the rate of change, the increasing frequency of extreme events and the fact that many of the changes in the environment are human-caused (Brooker, 2006).

Though uncertainties remain about the extent of changes the likely effects are:

- higher average land and sea temperatures;
- more rainfall globally from increased evaporation;
- more variability in rainfall and temperature with more frequent and more severe floods and droughts;
- rising sea levels from warming water and from melting ice masses;
- increased frequency and severity of extreme weather events, such as hurricanes;
- shifting ranges of vegetation species with cascade ecosystem effects;
- expanding range of pathogens, such as mosquitoes.

The extent of future climate change depends on what we do now. The smaller the climatic shift the more species are likely to be able to persist, and the greater the genetic diversity preserved. Biodiversity equals ability to adapt. Healthy ecosystems are more likely to be able to adapt to future climate change, and continue to provide us with ecosystem services vital to our own existence.

2 The physiological responses of plants to climate change

Summary

The diversity and distribution of the world's terrestrial vegetation is the product of a complex suite of interactions between individual plants and a multitude of climatic and environmental variables. Plants are major regulators of the global climate, and their collective responses to increased atmospheric CO_2 concentrations have clearly played an important role in mitigating climate change up to this point. The uptake of CO_2 by plants during photosynthesis is the major pathway by which carbon is stored.

In looking to the future, it is increasingly critical to understand how plants respond on a basic level to the changes imposed upon them by continued increases in atmospheric CO_2, as well as the cascade of climatic and environmental changes triggered by this increase. While plant responses to changes in single variables, such as CO_2 or temperature, are increasingly well-understood, we have only just begun to understand how the interaction of these changes impacts plants and their role in regulating the global climate. Recent discoveries reveal just how much remains to be learned while illustrating the many ways in which the world's plants can all-too-easily loose their ability to act as a global carbon sink, becoming instead yet another carbon source.

Key points

- Increased levels of CO_2 in the atmosphere can increase plant productivity, so long as no other factors (such as water) are limiting. However this is likely to be a temporary effect as plants acclimatise to the change.
- Increased levels of CO_2 may allow plants to become more water efficient (i.e. requiring less water for the same productivity). However, reduced water flow through the plant can reduce the cooling (air conditioning) effect of vegetation.
- Increased temperature can increase plant growth up to a limit, beyond which death occurs. Increased temperatures can also cause plant respiration rates to increase relative to photosynthesis, resulting in no net gain in biomass production and to plants even becoming a potential source of CO_2.
- Nitrogen availability limits plant growth and thus capacity to uptake carbon and benefit from increased CO_2.
- Nitrogen-fertilised soils emit nitrous oxide (N_2O), a greenhouse gas with more that 200 times the warming potential of CO_2.
- Individual species will react differently to changing environmental conditions, resulting in changes in species compositions and ecosystem structure.

2.1 Plants affect all life; climate affects all plants

Plants grow and develop in response to a range of stimuli but especially to the availability of CO_2, water and mineral nutrients, to temperature and to the quality and quantity of light. The distribution of different plant species, associations and vegetation types is thus controlled by a number of different climatic factors (such as annual and seasonal temperature, annual and seasonal precipitation, atmospheric CO_2 concentration) and their interactions (Maslin, 2004). Clearly, most of these stimuli will be affected directly or indirectly by climate change, in turn altering the cues which trigger plant life stages (Bisgrove & Hadley, 2002). One of the most pressing questions about future climate change is how it will effect terrestrial vegetation.

Box 2.1 Net primary production (NPP) and net ecosystem production (NEP)

Primary production occurs when chemical or solar energy is transformed to useable biomass. Most primary production on the planet occurs via photosynthesis, a process that allows plants to convert solar energy, water and CO_2 into useable carbohydrates, which can ultimately be used to produce plant tissue. Plants, as primary producers, are thus instrumental in removing CO_2 from the atmosphere and turning it into a product that stores the carbon, ultimately playing a key role in limiting CO_2 as a greenhouse gas in the atmosphere.

As the principal input of carbon into ecosystems, NPP is the net result of CO_2 fixation by photosynthesis and CO_2 loss by plant respiration. The product of NPP is organic matter, which accumulates first as living mater then decomposes, thus losing carbon by respiration. Rates of primary production and respiration are directly affected by temperature (normally increasing with warming).

NEP is the difference between gross primary production and total ecosystem respiration (including plants as well as other organisms in the ecosystem) and represents the total amount of organic carbon available in an ecosystem for storage or loss (Lovett *et al*., 2006). NEP and organic carbon accumulation rates are not always equivalent.

Climate change may also affect NEP and NPP by altering an ecosystem's moisture regime, nitrogen availability, and growing season length, among other things. From these, multi-step indirect effects may cascade and affect other ecosystem processes, for example litter quality. For many ecosystems, the indirect effects of a temperature increase on carbon balance are likely to be more important than the direct effects (Shaver *et al*., 2000).

2.2 Plant responses to rising CO_2

Box 2.2 Photosynthetic pathways

Land plants utilise one of three modes of photosynthesis: C3, C4 (so called because the CO_2 is initially incorporated into either 3-carbon or 4-carbon compounds) and CAM (Crassulacean acid metabolism, named after the plant family in which it was first found).

C3 photosynthesis is the oldest and most prevalent photosynthetic pathway (and it was all we knew about until a few decades ago). C3 photosynthesis is found in about 90% of all known land plants, including important crops like barley, wheat, tomatoes and cotton and most species of tree. This form of photosynthesis is the most efficient in climates not exposed to temperature extremes or drought. C4 and CAM photosynthetic pathways have evolved from the C3 pathway as adaptations to hot, arid conditions, as they result in more efficient uptake of CO_2 and more efficient use of water.

While only about 3% of all known plants (7,000-8,000 species) use the C4 pathway (including key crops like corn and sugar cane), they are common components of the tropical and subtropical grassland, savannah and marsh habitats, and collectively account for 20-25% of global primary productivity (Sage, 2005).

About 20,000 species utilize the CAM pathway (primarily cacti and other succulents). Most grow in arid ecosystems and collectively contribute relatively little to global net primary productivity but they are ecologically important in areas where relatively few plant species grow.

The main difference between all three pathways is that in C3 plants, Rubisco (the enzyme involved in the first major step of photosynthesis) is directly involved in the initial uptake of CO_2. In C4 plants, a different enzyme is used in the uptake of CO_2, enabling faster delivery to Rubisco for photosynthesis and thus less water loss through transpiration via open stomata. C3 plants are thus more efficient under cooler, moist conditions because they require less 'machinery' i.e. additional enzymes, while C4 plants are more efficient under conditions where CO_2 and/or water are limiting.

CAM plants are capable of surviving their arid habitats by limiting water loss and moderating CO_2 intake as the extremes of their climates dictate. For this, CAM plants usually only open their stomata to take in CO_2 at night, when temperatures are cooler and water loss is lower (C3 and C4 take in CO_2 during the day). The CAM pathway allows CO_2 to be collected at night and stored as an acid before being broken down during the day and delivered to Rubisco for photosynthesis. Some CAM plants can 'idle' in particularly arid conditions, and leave their stomata closed both day and night, saving precious water. When this occurs, oxygen (O_2) given off in photosynthesis is used for respiration and CO_2 given off in respiration is used for photosynthesis. This cannot go on indefinitely but does allow the plant to survive extreme dry spells (Fiero, 2006).

2.2.1. Increased growth

Photosynthesis by terrestrial vegetation accounts for about half of the carbon that annually cycles between Earth and the atmosphere. Most C3 land plants (i.e. most plants) respond to elevated CO_2 by increased net photosynthesis. It is generally accepted that this leads to an increase in growth and yield, conditions permitting.

The ability of plants to produce additional biomass in this context is one of the potential reasons that terrestrial plants have become increasingly greater carbon sinks over the past 50 years, keeping CO_2 build-up in the atmosphere at 40-50% of what it would otherwise be due to our emissions (Houghton, 2007).

C4 plants respond similarly to C3 plants but to a lesser degree and CAM plants hardly at all, because these photosynthetic pathways already function so as to minimise photorespiration.

2.2.2 Eventual acclimatization

Some studies indicate climate-driven increases in global net primary terrestrial production (Nemani *et al*., 2003). After eventual acclimatization to higher CO_2 however, short term photosynthetic response is decreased. This means that initial increases in growth and yield stop. In fact, long term exposure to elevated CO_2 leads to the accumulation of carbohydrates in the photosynthetic tissues of the plant and this in turn leads to a reduction in photosynthetic rates (Bisgrove & Hadley, 2002). Further, although CO_2 initially enhances plant growth rates, in some regions the larger effects of increased drought (also associated with climate change) will lead to lower growth overall.

2.2.3 Lower nutritional value

As well as this down-regulation of photosynthetic capacity, plants that do respond to elevated CO_2 produce tissue with lower nutrient concentrations (reduced leaf nitrogen (N) content). This may be because plants require less Rubisco

Box 2.3 Photorespiration

Photorespiration is an alternative but less efficient pathway by which plants build structure using Rubisco. Unlike photosynthesis however, photorespiration uses oxygen (instead of CO_2). Photorespiration occurs frequently, especially when stomata are closed to prevent water loss, therefore oxygen levels in the leaf are high and CO_2 levels are low.

This oxygenation reaction forms phosphoglycolate, which represents carbon lost from the photosynthetic pathway. Phosphoglycolate also inhibits photosynthesis if it is allowed to accumulate in the plant. The reactions of photorespiration break down phosphoglycolate and recover 75% of the carbon to the photosynthetic reaction sequence. The remaining 25% of the carbon is released as CO_2. Photorespiration thus reduces the rate of photosynthesis in plants by diverting energy from photosynthetic reactions to photorespiratory reactions and by releasing CO_2 (Parker, 2005).

The rate of photosynthesis can be stimulated as much as 50% by reducing photorespiration. Since photosynthesis provides the material necessary for plant growth, photorespiration inhibits plant growth by reducing the net rate of carbon dioxide assimilation. Therefore most of the beneficial effects on plant growth achieved by increasing CO_2 may result from the reduced rate of photorespiration in a high CO_2 atmosphere.

On hot, dry days however, stomata close to minimise water loss, and this favours photorespiration.

for photosynthesis (Hartwell Allen *et al*., 1996). Thus greater growth results in loss of nutritional quality (Sinclair *et al*., 2000). This has clear implications for herbivores as well as for decomposers (Vitousek, 1994) and for humans, when we consider the implications of nutrient content decrease of staple crops such as potatos (Fangmeier *et al*., 2002). As food quality decreases, more must be grown and consumed to obtain the same benefit.

2.2.4 Increased nitrogen needed

Additionaly, although increased CO_2 makes C3 plants grow larger initially, plants growing larger, faster need more nutrients, such as nitrogen (if available) with cascade effects on soil quality (Elstein, 2005).

2.2.5 Reduced stomatal density

Stomata are pores on the surface of leaves that can open and close to allow gas exchange between the plant and the atmosphere. In a single leaf, the stomatal density of some species decreases with increased CO_2, since either the opportunity for water conservation is of more importance than grasping benefits of rising CO_2 (Agrawal & Agrawal, 2000) or less stomata are needed to receive equivalent amounts of CO_2. Looking at herbarium records, there are indications that tree leaves collected from the time of the early industrial revolution have higher numbers of stomata than the present day (Bisgrove & Hadley, 2002). Other associated observed effects are an increase in leaf thickness and leaf area (Lawson *et al*., 2002).

2.2.6 Reduced transpiration

Plants in increased CO_2 environments frequently either open their stomata less widely or keep their stomata completely closed more often, therefore reducing plant transpiration (Betts *et al*., 2007). While this will help plants to efficiently utilise limited water resources (most water evaporation occurs via transpiration), this response may limit predicted increases in net primary productivity, and thus limit carbon storage opportunities. Additionally, transpiration is largely responsible for the ability of plants to cool their local climate. On a global scale, the loss of this cooling effect could be significant. Further, reduced transpiration may allow plants to extract less water from the soil, leaving more water at the land surface. A recent study equated this with river flow increases (Gedney *et al*., 2006), which themselves have impacts on the ability of aquatic systems to absorb carbon. Clearly, the indirect effects of plant responses to elevated CO_2 on ecosystem water, temperature and carbon balance could be significant.

2.2.7 Species specific responses

Whilst many species of plants acclimatise to elevated CO_2 relatively quickly; many others do not, if at all. Plants with growth strategies or photosynthetic pathways that allow them to take advantage of changing conditions in any given habitat will gain a relative advantage over those that do not. There is therefore enormous potential for effects at the plant community level. Species with rapid growth rates may be more responsive than slower growing species, and plants with a C3 pathway should gain more relative to those with a C4 pathway. This may cause shifts in entire habitats, including the predicted replacement of C4 dominated praries and savannas with C3 dominated forests under certain scenarios (see Case study 4.6). Within these responses there will also be genetic preferences and varying genetic adaptability of species/populations (Harte *et al*., 2004).

Case study 2.1
Toxicity response of poison ivy (*Toxicodendron radicans*) to elevated CO_2

Toxicodendron radicans is widely distributed and abundant in North America and also occurs in Central America, parts of Asia, Bermuda and the Bahamas. It has been introduced in Europe, South Africa and Australia and New Zealand, where it has become invasive. In the USA, contact with poison ivy is one of the most widely reported ailments at poison centres – approximately 80% of humans develop dermatitis upon exposure to the active allergenic compound, urushiol.

A six-year study at Duke University in the USA showed that increased CO_2 in an intact forest ecosystem increases photosynthesis, water use efficiency, growth and population biomass of *Toxicodendron radicans* and that the CO_2 growth stimulation exceeds that of most other woody species (Mohan *et al*., 2006). Additionally, under higher CO_2 the plants produced a more allergenic form of urushiol.

This study indicates that poison ivy will become both more abundant and more toxic in the future and adds to studies indicating that rising CO_2 may be responsible for the increased vine abundance that is inhibiting forest regeneration and increasing tree mortality around the world (see p. 37), with implications for long term carbon storage in old growth forests (Philips *et al*., 2002; Swaine & Grace, 2007).

2.3 Plant responses to temperature changes

The direct effect of warming on plants and ecosystems will be complex because temperature impacts virtually all chemical and biological processes. However, it is suggested that the direct effects of temperature changes are likely to be larger and more important than any other factor (Kehlenbeck & Schrader, 2007). In turn, changes in vegetation composition may have significant effects on the local heat balance (Berendse, 2005).

Additionally, plant tissue chemistry modifications caused by elevated CO_2 may affect responses to warming (Shaver *et al*., 2000). For example, by not using energy for evaporation (reduced transpiration) the temperature of both the plant (leaf surface) and its surroundings will increase. In this way the 'air conditioning' effect of plants is reduced, particularly during periods of water stress.

2.3.1 Faster growth

Though each plant species has its own characteristic response to temperature, in general, higher temperatures speed up growth and the rate of development of plants where other factors are not limiting. As temperatures rise, an optimum is reached followed by a (usually sharp) decline, where damage to plant tissue leads to the cessation of growth and ultimate death of the plant (Bisgrove & Hadley, 2002).

2.3.2 Too much heat

The drought in Europe in 2003 combined unusually high temperatures with water stress and reduced primary productivity by 30% (Ciais *et al*., 2003). If temperature increases too much, faster respiration may tip the balance towards plants becoming a CO_2 source. Whilst elevated CO_2 favours C3 plants, temperature rise may also effect habitat composition, since generally C3 plants are more sensitive to heat stress than C4 and CAM plants (Ehliringer *et al*., 1997).

2.3.3 Extended growing season

There are widespread examples of an extended growing season due to temperature rise and concomitant changes in key biological processes, including earlier budburst, delayed autumn leaf fall, and extended flowering. The early onset of spring across the northern hemisphere has been particularly well documented (Primack & Miller-Rushing, 2004; Schwartz & Reiter, 2000) with an observed advance in European spring/summer of 2.5 days per decade (Menzel & Sparks, 2006) and a two day delay in autumn (Bisgrove & Hadley, 2002).

2.3.4 Dormancy

Dormancy is a period of limited to no growth which enables plants to survive temporary climatic extremes, such as sub-zero winter conditions or prolonged drought. It has evolved to ensure that plants have no soft growing tissues that could be damaged by prevailing seasonal weather. Some species use temperature cues as a sign that it is safe to break dormancy in order to maximize growth during favorable climatic conditions. Where temperature changes, ability of plant species to successfully predict appropriate times for growth is altered. Development is impaired, resulting in the delay, abnormality or failure of flowers and fruits.

2.3.5 Unpredictable weather

For many species, certainly in the short term, it is not small differences in temperature that will affect them most, but rather the likelihood of sudden weather events, for example sudden frosts after periods of warmth (Kehlenbeck & Schrader, 2007). It is not just the magnitude of the change but the unpredictability of the change. Early onset of growth in response to mild weather combined with unexpected frosts is likely to cause significant damage to plants.

Case study 2.2
Early spring, late autumn

In Japan, cherry blossom festivals are hugely popular and culturally significant. Because of this, the flowering times of cherry blossom have been recorded for over a thousand years. From 1401 to the present time (a 606 year time span) there are records of the cherry blossom festivals for most years. The cumulative flowering record shows a six week range in flowering dates from as early as late March to as late as early May. Extreme flowering dates are scattered through this period. However, after approximately 1830 flowering times become progressively earlier. By the 1980s and early 1990s, average flowering times had become earlier than at any time previously during the entire flowering record (Primack & Higuchi, 2007).

At Kew in the UK an advance in flower opening has been observed since the 1980s, a subset of plants are flowering on average 8 to 19 days early. For example, the first daffodils opened at Kew on 16 January 2008, a week earlier than 2007, and 11 days earlier than the average for this decade for that type of the flower. Crocuses also set a record, flowering on 24 January, 11 days ahead of the decade average (Dugan, 2008).

Intense late summer heat delays the frosts which trigger chlorophyll in leaves to degrade, thus changing the colour of leaves. In New England in the USA the spectacular colours of autumn leaf change are projected to become duller. Some observations indicate that this is already happening.

Case study 2.3
Blackcurrants (*Ribus nigrum*) and frosts

Blackcurrants need a heavy frost to ensure their buds break evenly to produce an even ripeness in the fruit. Increasingly mild winters in England have led to a steep decline in blackcurrant harvests, fruit quality and juice yields. Two traditional varieties are expected to die out within 10 years due to climate change.

Several new varieties of the fruit have been developed that are more resistant to changing climate, but it takes roughly 16 years to develop a new strain (SCRI, 2008) and it will take several years for the new varieties to bear fruit.

Case study 2.4 Yellow birch (*Betula alleghaniensis*) and winter thaw

In eastern Canada, studies indicate that winter thaws and late spring frosts may partially explain the large scale decline of yellow birch. Winter thaws decrease the cold hardiness of the tree, thereby increasing vulnerability to frost. Winter thaws have also been shown to affect the xylem of the tree, making it harder for water to pass from the roots to the branches (Cox & Arp, 2001).

2.3.6 Snow

Snow insulates and protects plants from the harshest conditions of winter, such as freezing temperatures and desiccating winds. Shorter winters and less snow will potentially greatly increase the severity of temperatures experienced by some plants, particularly alpine species. This relatively overlooked aspect of global climate change is likely to be a critical factor affecting plant survival in some areas.

2.4 Plant responses to available water

Water is vital to plants and to all life. As with all climatic changes, plant responses depend very much on each species' unique adaptive mechanisms and on the interaction of several factors. However, precipitation changes are implicated in vegetation shifts, which, in turn, alters the abundance of associated species (Lovejoy & Hannah, 2005).

2.4.1 Water vapour

Water vapour is the most abundant GHG in the atmosphere. It is increasing in the atmosphere, not as a direct result of industrialisation (as in the case of CO_2), but as the result of feedbacks associated with climate change, such as plant transpiration. In general, rising temperatures mean more water is evaporated from the Earth's surface, increasing humidity. Since water vapour is a GHG, the more of it that is held in the atmosphere the more heat the atmosphere retains, thus warming. The warmer it gets, the more water vapour the atmosphere holds, and so on. As such, water vapour is a positive feedback to anthropogenic GHG emissions. Eventually however, atmospheric water vapour will condense into clouds. These reflect incoming solar radiation and may reduce warming. Though critically important, this aspect of climate change is still fairly poorly measured and understood.

2.4.2 Water stress

If water is in short supply in the soil because of drought, or does not fall during periods when plants most need it, plants will suffer from water stress. To deal with evaporative loss from prolonged water stress, a plant may limit leaf production and leaf surface area to reduce water loss, or close its stomata. Each response decreases the ability of the plant to carry out photosynthesis, with clear implications on net primary productivity and carbon storage, and can ultimately lead to plant death. Other indirect effects include altered flowering times (as stressed plants flower and set seed rapidly before dying), greater susceptibility to pests (Kehlenbeck & Schrader, 2007), and greater allocation of photosynthetic products to root growth to increase the probability of securing rare water resources (Bisgrove & Hadley, 2002). Additionally, whilst land management practices have decreased the incidence of wildfires, increased temperatures and decreased water availability are likely to lead to an increase of fires with associated carbon release (Houghton, 2007).

Case study 2.5 Effects of drought on growth of beech (*Fagus sylvatica*) trees

A study of *Fagus sylvatica* trees in Catalonia in Spain showed that populations of the species toward the southern limits of the species' distribution are increasingly limited by drought. Further, the region is expected to warm in the future. The study looked at annual growth levels over the past 50 years and found a rapid recent decline of southern range-edge populations, starting in approximately 1975. By 2003, growth of mature trees had fallen by 49% when compared with pre-decline levels. The decline is not seen in populations at higher altitudes, therefore it is likely that the effects of drought (less water, higher temperature) are impacting tree growth (Jump *et al*., 2006).

2.4.3 Waterlogging

Waterlogging occurs when soil becomes saturated with water (for example, after a flood), leaving no air spaces in the soil and depriving plant roots of oxygen, as well as preventing CO_2 being diffused away. With too much water, plant are unable to draw up soil moisture, leaves will wilt (Bisgrove & Hadley, 2002) and roots will rot, leading to plant mortality, literally by drowning. Plant species exhibit different tolerances to waterlogging, but this is also dependent on intensity, duration and at what stage in a plant's life cycle it occurs (Ricard *et al*., 2006). With increased precipitation and flooding, as predicted for parts of the northern hemisphere, it is likely that some species of plants will be affected by waterlogging.

2.5 Plant responses to tropospheric ozone (O3)

Tropospheric ozone (O_3) is a both a GHG and a pollutant, formed at ground level when nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs) from pollution, especially exhaust fumes, react with water and sunlight. Ground-level ozone causes more damage to plants than all other pollutants combined (Booker, 2005).

O_3 is transported long distances, so that rural concentrations can be higher than urban. Concentrations are highest on calm, sunny summer days but vary from place to place and day to day. Tropospheric O_3 levels are predicted to rise under IPCC scenarios for future population and consumption patterns. This is likely to affect both agriculture by reducing yields, as well as the natural plant communities that provide us with ecosystem services.

O_3 enters leaves through stomata and causes direct damage to internal cells as well as leading to decreased chlorophyll and increased pigmentation (Pleijel *et al*., 1999; Ljubeši & Britvec, 2005; Burkey *et al*., 2007). It has a corrosive effect on leaf surface and some species have been shown to increase the thickness of surface cell walls to protect against increasing O_3. O_3 has also been implicated as a cause of tree death (de Lourdes de Bauer & Hernández-Tejeda, 2007). Further, these effects will not act in isolation but as part of global change phenomena. For example, King *et al*. (2005) showed that exposure to even moderate levels of O_3 significantly reduced the capacity of NPP to respond to elevated CO_2 in some forests (birch, aspen and maple communities).

As well as causing changes in leaf biochemistry and physiology, high concentrations of O_3 cause plants to close their stomata, thus inhibiting photosynthesis, altering plant structure and development and suppressing biomass and yield (USDA, 2000). Reductions in growth and yields under increasing O_3 have been well illustrated. Though all species have unique tolerances to climate conditions, recent research on interactions within plant communities has shown that O_3 is impacting the composition of simple species mixtures (Thwaites *et al*., 2006).

Trophospheric O_3 is not to be confused with stratospheric O_3, which blocks harmful solar radiation. However, we are decreasing stratospheric ozone by the release of halocarbons. This decrease leads to an increase of the harmful effects of tropospheric ozone (Solomon *et al*., 2003) as well as increasing the amount of harmful UVB rays that reach the surface of the planet and which have an adverse impact on plant growth.

2.6 The nitrogen cycle in a changing climate

Nitrogen comprises 78% of the earth's atmosphere, but in its gaseous form is not useable by plants. Nitrogen is transformed into nitrates (the form that is taken up by plants) by the effects of lightning and by nitrogen-fixing bacteria. The carbon cycle is inextricably linked with the nitrogen cycle because carbon fixation depends on nitrogen containing enzymes. In a green leaf, the enzyme that is responsible for the first step in carbon fixation via photosynthesis is the nitrogen-containing protein Rubisco. It constitues about half the protein in leaves and is the most abundant protein on Earth (GANE, 2001).

2.6.1 Carbon-nitrogen-climate interactions

We do not fully understand how the availability of nitrogen will affect the capacity of Earth's biosphere to continue absorbing carbon from the atmosphere, and hence continue to help with the mitigation of climate change. A changing climate, a changing carbon cycle and changing human actions will affect the nitrogen cycle, itself a critical component of the Earth system, controlling primary production in the biosphere (Gruber & Galloway, 2008).

What is certain is that the nature of the nitrogen economy of an ecosystem is an important factor in determining responses to other environmental factors (Shaver *et al*., 2000) and *vice versa*. For example, there are indications of strong interactions between water and nitrogen, with nitrogen becoming more limiting under drier conditions (Heimann & Reichsten, 2008).

Though many of these responses are as yet unclear, what is apparent is that species-rich ecosystems are more likely to be able to adapt to changing nitrogen availability and the interactive effects of climate change than species-poor assemblages (Reich *et al*., 2001).

2.6.2 Nitrogen and plants

Nitrogen is essential for plant growth. It ranks behind only carbon, hydrogen, and oxygen in total quantity needed and is the mineral element most demanded by plants. Nitrogen uptake by plants stimulates productivity and enables the uptake of CO_2 from the atmosphere. Therefore, in many ecosystems, nitrogen availability limits plant growth and in turn carbon fixation. The response of plant biomass under elevated CO_2 will likely be constrained by the availability of soil nitrogen (Reich *et al*., 2005). It could be said that the nitrogen cycle thus ultimately controls the storage of carbon from the atmosphere.

With increasing climate change, plants may ultimately be able to store less carbon since they will be unable to glean sufficient nutrients from increasingly nitrogen-poor soils, made so by the initial increase in uptake due to responses to elevated CO_2. Though nitrogen availability and uptake is affected by several factors (drought stress for example) it has been shown that low availability of nitrogen progresively supresses the positive response of plants to elevated CO_2 (Gruber & Galloway, 2008). Soil nitrogen supply is therefore an important constraint on plant responses and carbon uptake (Reich *et al*., 2005).

2.6.3 Nitrogen and soils

Soils contain the world's largest near-surface reservoir of terrestrial carbon and so knowledge of the factors controlling soil carbon storage and turnover is essential for understanding the changing global carbon cycle. However, the relationship between nitrogen availability and soil carbon storage is complex and there remains considerable uncertainty in the potential response of soil carbon dynamics to the rapid global increase in reactive nitrogen (coming largely from agricultural fertilisers and fossil fuel combustion) (Neff *et al*., 2002).

Recent studies have documented increases in soil nitrogen leading to losses in the ability of soils to store carbon, perhaps due to accelerated rates of decomposition (Kahn *et al*., 2007; Sainju *et al*., 2008). This means that, despite how plants react to increases in nitrogen, any benefits in increased carbon storage may be lost if soils themselves become a carbon source.

2.6.4 Added nitrogen

Since low nitrogen limits plant growth, nitrogen can be added to soils. In agriculture this is common practice, but is limited in wild areas, for example forests. Although the production and industrial use of artificial nitrogen worldwide has enabled increased food production, it has also led to other problems associated with nitrogen deposition, such as eutrophication and acidification. Currently, in many developed nations, the rate of atmospheric deposition of biologically active nitrogen is occurring at two to seven times the pre-industrial rates because of the combustion of fossil fuels and agricultural fertilisation. Deposition rates are expected to increase similarly over the next 50 years in the industrialising nations of Asia and South America. While small increases in nitrogen deposition may enhance plant growth and productivity, studies have shown that chronic increases may have detrimental effects on plant populations and species survival (Clark & Tilman, 2007).

Box 2.4 Eutrophication

Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth. This enhanced plant growth, often called an algal bloom, reduces dissolved oxygen in the water and can cause other organisms to die.

Nitrogen-enriched, fertilised soils emit two to ten times as much nitrous oxide (N_2O) (produced by the action of bacteria on soils) as unfertilised soils and pastures (Pretty & Conway, no date). N_2O is a direct GHG, whose molecules have a warming potential at least 200 times that of CO_2 and whose concentration in the atmosphere has increased by 8% since the industrial revolution. Nitrogen-enriched soils also increase NO_x concentrations, adding to trophospheric O_3 levels.

Although research focused on the environmental impacts of high rates of nitrogen addition has enabled better management of the problem, it has been strongly advised that the large scale use of nitrogen-based fertilisers be avoided (Royal Society, 2001).

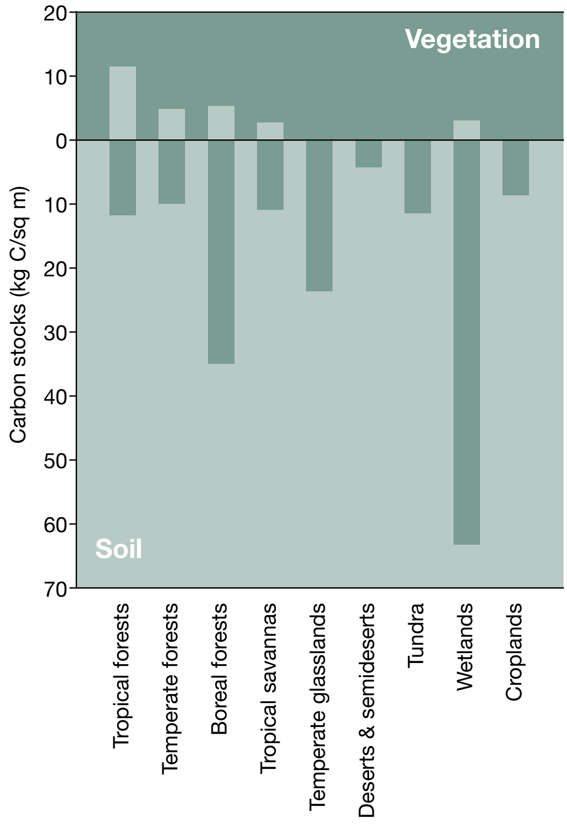


Figure 2.1 Carbon stocks in soil and vegetation: Mass of carbon stored in soils and vegetation per metre square for different terrestrial systems (kg C/sq m) (Royal Society, 2001).

Case study 2.6 Consequences of species-specific nitrogen strategies

In the Netherlands, an increase in atmospheric nitrogen deposition led to the accelerated accumulation of soil organic matter and an intial increase of the grass *Molinia caerulea* at the cost of the the dwarf shrub *Erica tetralix*. Due to high litter production and decomposition, *Molinia* increased soil N-mineralisation two-fold, which triggered a positive feedback, resulting in monospecific stands of *Molinia* and an unexpected rapid disappearance of wet heathland communities, including endangered species such as *Gentina pneumonanthe* and *Dactylorhiza maculata* (Berendse, 2005).

Box 2.5 – Decomposition and nitrogen

In a natural system, nitrogen release through decay controls the availability of nitrogen for the next generation of plant growth. However, decomposition (soil respiration) also releases more carbon annually than fossil-fuel combustion. While above-ground plant biomass production is relatively well documented from field measurements and satellite observations, the quantity of carbon that plants transfer below ground is not well known (Chapin & Ruess, 2001).

Equally, the symbiotic relationships and role of soil organisms and mycorrhizal fungi in regulating the responses of plants to climate change are not well understood (Brooker, 2006). Increased nitrogen uptake under increased CO_2 for example, may decrease available soil N for microbes, thereby slowing microbial activity and potentially increasing ecosystem carbon accumulation (Hu *et al*., 2000).

A ten-year Long-term Intersite Decomposition Experiment (LIDET) study involving 10,000 root and leaf litter samples distributed over 21 sites from the Arctic to the Antarctic and major ecosystem types inbetween showed that the rate of leaf and root litter decomposition was affected by temperature and moisture, with cold, dry regions showing the slowest rates and warm, moist tropical forests the fastest (Capos, 2007).

In general, soil respiration quickens with increased temperature, thus temperature rises mean increased release of soil carbon (Knorr *et al*., 2005). It is for this reason, together with the leaching effects of heavy rainfall, that there is very little organic matter in tropical soils, while high latitudes may host peat deposits with huge stores of carbon. (Hence with warming and melting, high-latitude permafrost becomes a CO_2 source).

2.7 Light levels

Changes in the amount and quality (direct or diffuse) of light can alter vegetation productivity and lead to further increases in air pollutants and ozone, with detrimental effects on primary production (Heimann & Reichstein, 2008). Higher light levels resulting from reduced cloudiness have been predicted for many habitats of the world. In Australia, changing shade levels have been shown to impact tree growth (Egerton *et al*., 1998).

The possibility of an extended growth season due to temperature increase, for example near continuous growth of lawns through winter months means that plants will also be growing at lower light levels and in shorter days than at present with possible consequences, for example on susceptibility to pest attack.

There is much to be understood, for example the mechanisms by which plants protect themselves from excess sunlight. An intriguing result of recent research found that increased sunlight on a plant's chloroplast membranes led to changes that protected it from the sun, and actually dissipated potentially harmful absorbed energy as heat (Ruban *et al*., 2007). This potential positive feedback loop joins a host of many others waiting to be explored in the global effort to understand the physiological responses of plants to climate change.

2.8 Methane (CH_4)

Methane (CH_4) is an important GHG because of its warming potential, which is some 21 times that of CO_2 (Schindell *et al*., 2005). It is generated naturally by the breakdown of organic matter by bacteria and has increased in the atmosphere (by 150% since 1750) (IPCC, 2001a) due to increases in landfills, livestock farming and rice cultivation. Vast natural reserves of methane exist, stored for example in wetlands and peatlands, on the ocean floor and in permafrost. It is a gas that has been implicated in past climate change and has important implications for future climate change scenarios.

A 2006 experiment showed plants to be emitters of methane under normal conditions and as such a source of methane previously overlooked. The experiment showed methane emissions increased with temperature, with emissions doubling for each 10°C rise in temperature (Keppler *et al*., 2005). Another experiment in the field in Venezuela verified these findings, and found an accumulation of methane, particularly at night (Crutzen *et al*., 2006). Though the mechanisms of methane production by plants are not known, if the findings are confirmed they would help explain the large plumes of methane seen from space above tropical forests, as well as the current decrease in the growth rate of global methane (i.e deforestation) (Lowe, 2006). However, another paper has disputed these findings (Dueck *et al*., 2007) and so plant methane fluxes remain uncertain.

Case study 2.7
Melting permafrost in Siberia

Western Siberia has warmed faster than almost any other region on the planet, with an average increase of 3ºC over the last 40 years. It is here, over an area covering a million sq km (the size of France and Germany combined) that frozen peatbog is melting and becoming a mass of shallow lakes, releasing CH_4 at a rate 5 times faster than expected. The western Siberian peatbog alone is estimated to contain some 70 billion tonnes of CH_4, a quarter of all the CH_4 stored on land surface worldwide (Walter *et al*., 2006). Considering the warming potential of CH_4, this has frightening implications for the rate of global warming.

2.9 An interaction of impacts

Terrestrial plants have the ability to act as carbon sinks with increasing atmospheric CO_2 concentrations. However, the interaction of multiple climatic and environmental factors will determine when and where (or if) terrestrial plants are able to store excess carbon, and will therefore play a key role in shaping the current and future climate of the globe. Individual species will react differently, leading to changes in species composition and ecosystem structure. The smaller the temperature rise the more likely viable plant complexes will be able to adapt and continue to support all other life.

Case study 2.8 Effects of elevated CO_2 plus unseasonal freezing on *Ginkgo biloba* (Maidenhair tree)

Elevated CO_2 has the capacity to influence the freezing temperatures of plant tissues. A study exposed *Ginkgo biloba* saplings to elevated CO_2 for five years. Leaf freezing temperatures and recovery times of photosynthetic apparatus were measured. Results showed that leaves of the Maidenhair tree, an ancient species which is now endangered in natural habitats, became more susceptible to freezing at higher temperatures under elevated CO_2 and that recovery was negligable, suggesting that an early season 'freezing injury' could persist into the growing season, limiting carbon fixation and tree survival (Terry *et al*., 2000).

3 Observing and predicting plant responses to climate change

Summary

Understanding the effects of climate change on plant species and communities is a fairly recent conservation concern, but requires long-term data sets. Some such data sets exist, such as long-term phenological records for a few plant species, but analysis can be hampered because data collection protocols and species selection generally were not set up to answer contemporary questions. Similarly, experimental approaches can be prohibitively expensive and lengthy, so research in this field relies heavily on modeling. Models can be used for predicting responses of single species, multi-species assemblages, global vegetation patterns, and climate or hardiness zones. Models are only as good as the data and assumptions on which they are built and are continually improving as we refine and test them using data from past climate changes. While it remains important to scrutinise climate change predictions adequately, the scientific debate must not divert us from taking timely and appropriate action on both mitigation and adaptation.
The extent of global change is still IN OUR HANDS and scientific rigour should not replace action.

Key points

- Observations such as earlier bud burst and longer growing seasons confirm that the behaviour of plant species is changing in response to climate change.
- Observations also show changes in species distributions over the past 30 years.
- Predictions of future plant species ranges are critical for conservation planning, but can only be obtained through modeling.
- Models must be treated with caution as they do not take into account local situations, such as plant-to-plant interactions, dispersal ability or plant adaptability to changing environments.
- Lack of data on existing plant distributions is a further limitation to modeling approaches.
- Experimental approaches which assess the climatic tolerances of species can help to overcome some of the limitations of modeling.

3.1 Past climates

Studies of past climates can elucidate how quickly and in what way certain vegetation types may respond to climate change. In Colombia in the 1950s for example, pollen analysis was undertaken on a sediment core from the Andes. More recent regional studies have contributed to this analysis to create a detailed fossil pollen history of the past 1.4 million years for the high plain of Bogotá. The paleobotanical record indicates wholesale changes in vegetation type (from forests to shrubby subparamo to grassy paramo according to cold events) as well as intricate movements of individual taxa, such as *Alnus* and *Quercus* species. The strength of the pollen record of these species indicate temperatures and likely local floras (Bush, 2005).

Though the evidence for global carbon cycle-climate interactions on the timescale pertinent to current climate change (i.e. decades) is scarce as compared to fossil, tree ring and ice core data, it is certain that climate change over the past 30 years has produced shifts in the distributions and abundance of species (Thomas *et al*., 2004; Root *et al*., 2005; Parmesan, 2006).

3.2 Phenology

Phenology is the study of the timing of natural events, especially in relation to climate. These events include flowering and leafing dates, and those of insect appearance and bird migration. As well as changes in distribution and abundance, plants exhibit diverse phenological responses to the various aspects of climate change. Observations of these responses have been well documented for centuries, often by citizen scientists passionate about recording the first signs of spring as a mark that the long winter is over (Parmesan, 2006). Other data on phenological responses comes from the phenological records collected over the decades by dedicated individuals or institutionally (for example by the International Phenological Gardens (IPG) network in Europe) from individual botanic garden phenological and meterological records and from agricultural records. Because of the tight links between the seasons and agriculture, there are long records of planting and harvest dates which can be compared to relevant climatic data.

Phenology has taken on new importance in relation to climate change, since temperature changes and consequent effects on seasonality have direct effects on the development of plants. Furthermore, the undeniable advances in spring have proved to be useful in demonstrating to a wide audience that the natural world is already responding to climate change, despite the relatively modest warming so far experienced (approximately 0.7°C (IPCC, 2007)).

3.3 Field experiments

Clearly, from a scientific viewpoint there is growing evidence that species are responding to increasing climatic changes. Evidence suggests that species may be locally adapting to changes (Tryjanowski *et al*., 2006) but raises questions about the rate of adaptation of species and whether species will respond at the same rate. Observed wild and cultivated species data is thus accompanied by mechanistic research and field experiments, used to study the physiological tolerances of species.

Studies are also attempting to understand the implications of plant physiological changes at a larger level. For example, stomatal responses to climate change have been well documented; less clear is how reduced stomatal conductance at the leaf-level will translate to changes in ecosystem transpiration (Bernacchii *et al*., 2007), or how C3 and C4 grasses will respond to CO_2 enrichment (Chen *et al*., 1996).

Box 3.1 Observing climate change effects on plants

Between 1851 and 1858, on almost every spring morning, the naturalist Henry David Thoreau made observations about numerous plant and animal species, meticulously recording his seasonal observations. From October 18th 1857: "*The huckleberries in Conatum appear to have been softened and spoilt by the recent rain for they are quite thick still on many bushes. Their leaves have fallen. So many leaves have now fallen in the woods that a squirrel cannot run for a nut without being heard*." These records have been consolidated and combined with other records in a study at Boston University to reveal phenological shifts. The highbush blueberry for example is blooming some two weeks earlier than it did 150 years ago (Primack & Miller Rushing, 2004; Nickens, 2007). A similar pooling of observations was made by Walther *et al*., in 2005, who continued with a 50-year observed study (Iverson, 1944) on *Ilex aquifolium* (holly) showing an increased range as well as a north or northeast shift.

Another study based on observations has shown that the palm *Trachycarpus fortunei* is expanding its range northward to form the world's most northern wild palm population in southen Switzerland and northern Italy. This is thought to be because of changes in winter temperatures. Palms in general, and particularly *T. fortunei*, are significant bioindicators for present day climate change (Walther *et al*., 2007).

In IPG gardens genetically identical trees and shrubs are planted in order to make phenological comparisions. Cloned species are planted in uniform gardens and subject to observations such as: beginning of leaf unfolding, May shoot, beginning of flowering, first ripe fruits, autumn colouring and leaf fall. Between 1959 and 1998 more than 65,000 observations of 23 different plant species were collected, enabling large-scale, standardised comparisons about the timing of different developmental stages of plants (European Phenological Gardens, no date).

Wide scale public participation in observing phenology ('citizen science') is increasingly occuring and very useful. For example, Project BudBurst, piloted by Chicago Botanic Garden, USA, in 2007, is a national field campaign designed to engage the public in the collection of important climate change data and how it is affecting American plant species. From April to June a total of 913 phenological events were reported from 26 states. The project asked for observations of 60 broadly distributed wild and cultivated species, widespread and easily identifiable. In 2007, thousands of people participated, over 60% of them children, demonstrating a clear interest by members of the public and feeding into scientific programmes of work. The project website now runs year round (Chicago Botanic Garden, 2007).

Box 3.2 Experiments

Azorella selago is a keystone species across the sub-Antarctic. A field experiment to determine the effects of reduced rainfall (a direct effect of climate change) and increased shading (a predicted indirect effect of climate change, via enhanced growth and wider distribution of competitors) showed that plant structure changed in response to these variables. Over the course of the experiment, persistent direct and indirect effects were observed (increased stem mortality, accelerated autumn senescence) with negative implications for the species and therefore the ecosystem functioning (le Roux *et al*., 2005).

An experiment in Colorado in the USA looked at the effect of elevated CO_2 on native shortgrass prairie species. Chambers were infused with either air containing 360ppm of CO_2 or with air containing 720ppm of CO_2. Among the 34 plant species exposed to the higher amount of CO_2 the study showed a 40-fold increase in aboveground biomass of *Artemisia frigida*, a widespread shrub. The CO_2 -induced enhancement provides evidence that CO_2 may be contributing to the shrubland expansions that have been reported over the past 200 years. This may be because woody plants have a photosynthetic pathway more responsive to elevated CO_2 than the grasses they are displacing (see Chapter 2). The decline of grasslands may have implications for availability of suitable grazing areas for domestic livestock (Morgan *et al*., 2007).

In Spain, a reduction in soil moisture is predicted. To test the implication of this, *Quercus ilex, Arbutus unedo* and *Phillyrea latifolia* trees were subject to artificial drought for seven years. This was done using plastic strips and ditches to intercept rainfall and exclude runoff. The experimental drought reduced flower and fruit production in *Q. ilex* by 30% and 45%, respectively. Reductions in flower and fruit production were not significant in *A. unedo* and were not observed in *P. latifolia*, with implications for future plant community composition (Ogaya & Peñuelas, 2007).

3.4 Modeling

Accurate estimates of species' responses and climatic tolerance limits can be obtained by experiments (See Box 3.2), but they are expensive and time consuming. Therefore much of the assessment of current and future climate change distribution impacts is done by means of comprehensive, carbon cycle-climate models, which are getting more and more complex each year. Indeed, climate change scenarios are themselves based on complex models. Current models contain at least a million lines of code, but computing power is such that years of model time can be simulated in a day. This means that simulations can be run many times over with slightly different values to parameters.

3.4.1 Global models

Global climate models or atmospheric general circulation models (AGCMs) have their origin in weather prediction and are based on the mathematical principles of thermo and fluid dynamics (Stute *et al*., 2001; Meehl *et al*., 2005). They break the globe (including the atmosphere) into a series of grids, horizontally and vertically. The more grids, the higher the resolution of the model and the more small-scale climate features it can represent – therefore the best model is the one with the most grids. Of course, this means more parameters, more calculations to be run and more model run time. There is generally a need to compromise between resolution and computing power, and to project climate centuries in the future, either very powerful computers or less complex models are required (Met Office, no date).

AGCMs are coupled with ocean general circulation models (OGCMs), to include aspects of ocean circulation such as the El Niño southern oscillation, vertical mixing etc. as well as sea ice. To these couplings, carbon cycle and biosphere processes are added, such as global vegetation models (GVMs).

Ensembles of models are run with slightly different parameters, for example, a difference in wind speed of 1% over a certain region, or a different emissions scenario. Running many ensembles creates probability densities of likely scenarios. Recent models, which include increasingly interactive representations of the terrestrial carbon cycle show regions becoming a source of CO_2 under certain scenarios, further amplifying climate change (Cox *et al*., 2004).

3.4.2 Regional models

Local climate change is hugely influenced by local features, such as mountains or forests, yet these are not represented by the coarse resolution of global models. However, local projections are critical for regional impact and adaptation studies and preparations. A regional climate model called PRECIS (Providing Regional Climates for Impact Studies) has been developed by the Hadley Centre in the UK that runs at high resolution for shorter periods of time. Typically, PRECIS models (with a horizontal resolution of 50km, 19 levels in the atmosphere and four levels in the soil) are nested in an AGCM, providing locally specific predictions.

Case study 3.1
An example of model complexity

The Lund–Potsdam–Jena Dynamic Global Vegetation Model (LPJ) is a prominent model that combines process-based, large-scale representations of terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges. The model includes feedback through canopy conductance between photosynthesis and transpiration and interactive coupling between these processes and other ecosystem processes such as resource competition, tissue turnover, population dynamics, soil organic matter and litter dynamics and fire disturbance. Since global vegetation models cannot simulate all plant species, they are aggregated into plant functional types (PFTs). In the LPJ model ten PFTs are differentiated by physiological, morphological, phenological, bioclimatic and fire-response attributes. Resource competition and differential responses to fire between PFTs influence their relative fractional cover from year to year. Photosynthesis, evapotranspiration and soil water dynamics are modelled on a daily time step, while vegetation structure and PFT population densities are updated annually (Stich *et al*., 2003). Although PFTs bridge the gap between plant physiology and community and ecosystem processes (Díaz & Cabido, 1997), a criticism of this approach is that most PFTs encompass the full spectrum of plant migration rates. Migration processes span scales of time and space far beyond what can be confidently simulated in dynamic global vegetation models (Neilson *et al*., 2005).

Case study 3.2
PRECIS modeling in East Africa

East Africa has a complex regional climate, affected by, for example, the Indian Ocean circulation systems, the African rift and Ethiopian highlands and the existence of large lakes. It is also a region predicted to be particularly vulnerable to climate change and variability, namely flooding and drought. Of course, localised water resources, namely groundwater for potable water and rainfall for agriculture, are massively important to rural populations and will be impacted by climate change.

Taking these unique local considerations into account, a local PRECIS model coupled with soil moisture balance and groundwater recharge models, has provided critical information necessary for local climate change impact assessments (START Project, 2006).

3.4.3 Using models to predict species range shifts

There are many ways of modeling but one of the most popular for predictions of species shifts in response to climate change is bioclimatic envelope modeling. Here, observed species distributions are correlated with environmental variables to approximate the ecological requirements of a species (Araújo & Pearson, 2005). Assessments of the future ranges of a species are developed by applying this data to selected climate change scenarios.

Case study 3.3 Single species modeling

Purshia subintegra, or Arizona cliffrose, is an endangered endemic shrub known from just four populations in the Sonoran desert in Arizona in the USA. Models show that populations will be increasingly endangered under increasing aridity. The fine scale of the modeling illustrates where the highest extinction risk or potential refugia may occur, which can guide human conservation intervention (Maschinski *et a*l., 2006).

In South Africa, several Proteaceae species' ranges were modeled in order to inform protected area management. Species were classified according to the spatial scale of movement exhibited in the model. For example, 'stay-at-home' species (*Serruria glomerata*) have substantial overlap in current and future ranges. 'Neighbourhood movers' (*Serrurria bolusii*) have ranges that may be accommodated within a single large protected area, and 'cross-country movers' experience range shifts on a large scale that would require land between protected areas ('corridors') to enable migration (*Serruria linearis*) (Hannah & Hansen, 2005). Other studies in the region show that fewer than half of species modeled showed overlap between current and projected ranges. Therefore transport and establishment in novel ranges and conservation landscape linkages are of critical importance (Midgely *et al*., 2003; Bomhard *et al*., 2005; Araújo, 2006).

Fagus sylvatica, the European beech, is particularly sensitive to drought and flooding. In southern Germany, where it is an important forest species, hot and dry summers are predicted, alongside periods of heavy rain in spring and autumn causing flooding events. Models show the species exhibiting reduced growth and reduced competitive capability, especially at range extremes (Geßler *et al*., 2007).

Evern more starkly, *Virola sebifera*, a tree found in Central and South America, is used medicinally to treat skin conditions and fevers. It's entire current distribution is predicted to become climatically unsuitable by 2050 (Thomas *et al*., 2004).

3.4.4 Using models to predict pathogen behaviour

Climate change affects plants in natural and agricultural ecosystems throughout the world and will also affect plant disease epidemics.

In the UK, a weather-based disease forecasting model was combined with a climate change model predicting temperature and rainfall under high and low carbon emissions for the 2020s and 2050s. Multi-site data collected over a 15-year period were used to develop and validate a model forecasting severity of Phoma stem canker epidemics on oilseed rape.

This was combined with climate change scenarios to predict that epidemics will not only increase in severity but also spread northwards by the 2020s (Evans *et al*., 2008).

3.4.5 Modeling groups of species

At a regional scale various but still relatively few assessments of the threat of climate change to plants have been made. One such study is the assessment of projected future climatic conditions on 1,350 European plant species. Using current distribution maps, and based on the IUCN (World Conservation Union) system for categorising threat (see p.41), more than half the species become vulnerable or committed to extinction by 2080 based on the effects of climate change alone. The impacts of land-use on the threat status of species are considered likely to be overridden by the impact of climate (Thuiller *et al*., 2005).

- Similarly, Bakkenes *et al*. (2002), used climate data from 1990 to 2050 to determine the climate envelopes for about 1,400 European plant species. The climate envelopes were applied to projected climate. For each European grid cell the model calculated which species would still occur. On average, 32% of the European plant species that were present in a cell in 1990 would disappear by 2050. Though individual plant species responses were diverse, the areas in which 32% or more of the 1,990 species will disappear takes up 44% of the modeled area.

- Fleming & Svenning (2004) looked at the possible consequences of two climate change scenarios on a representative sample of forest herbs in Europe. Even under the mild scenario (less warming) moderate to large range losses (a 17-61% reduction in total climatic suitability for 75% of the 26 species) was shown. The range centres are projected to move strongly towards the northeast for most species, with migration rates of on average 2.1km/yr and 3.9km/yr (for each climate scenario respectively) required. This is a particular problem for forest herbs, the majority of which are poor dispersers existing in forest fragments.

- For Africa, the results of a comprehensive modeling study suggest that the distribution ranges of 90% of plant species will decrease by 2100. On average, species lose almost 50% of their climatically suitable habitat by that year and up to 26% may lose their entire climatically suitable habitat (Lovett, 2007) (see p.34). In sub-Saharan Africa, areas of suitable climate for 81-97% of 5,197 plant species were projected to decrease in size and/or shift location, many to higher altitudes. 25-42% were projected to lose all of their area by 2085 (McLean *et al*., 2005).

3.4.6 Strengths and weaknesses of the bioclimatic approach

Critisms of the bioclimatic approach include the fact that there are many other factors, other than climate, that play a part in species distributions, such as plant to plant interactions and dispersal ability. They also assume that species are faithful to their biome, and do not consider plant plasticity. Therefore their results should be interpreted with caution, since their specific accuracy is reliant to a large degree on the spatial scale at which they are applied (Pearson & Dawson, 2003; Heikkinen *et al*., 2006; Hijmans & Graham, 2006).

Some comparisons of models reveal that the type of model used, even with a common data set can have dramatic effects on predicted range shifts and extinction rates. Therefore model-averaging approaches may have the greatest potential for predicting range shifts. For example, a comparison of nine models applied to South African plant species showed that the predicted distribution changes varied from a 92% loss to a 322% gain for one species (Araújo & New, 2006). The limitations of modeling are thus highlighted by the fact that different models tend to provide different predictions of species distribution or biodiversity under similar scenarios of environmental change. However, where applied with wide ecological knowledge, accurate distribution data and appropriate temporal scale, bioclimatic models allow consideration of how climate change may affect plant (and all) species and provide estimates of potential changes thus highlighting areas on which to focus attention (Soberón & Townsend Peterson, 2005).

As discussed, the main requirements of bioclimatic modeling are good environmental data at the correct scale (such as rainfall and temperature) and accurate distribution data (Vargas *et al*., 2004). However, information on the distribution patterns of biodiversity is spatially unevenly distributed, much like biodiversity itself. This is an important impediment to conservation.

Küper *et al*. (2006) looked at collection records of 5,873 plant species in sub-Saharan Africa, with a view to analyzing the availability of distribution data suitable for the mapping of plant diversity. They found that only for a few, well known centres of plant diversity were comparatively many data collection records available and that several areas were very data poor. For example, for the Guinean montane forests and the north-western Congolian lowland forests, the study predicted much higher species richness than were currently documented.

Case study 3.4 Model testing

Climate change predictions derived from models are highly dependent on assumptions about feedbacks between the biosphere and atmosphere. Modeling plant responses to climate change is therefore problematic. However, models can be tested against past climates ('hindcast'), as well as compared against each other and tested against field observations.

In the 1990s, model research showed that climate models successfully simulated the patterns of 20th century climate change *only* when anthropogenic effects were included, thus strengthening the evidence that it is humans who have caused recent climate perturbations. Models are also tested against proxy measurements, such as ice core or tree ring data, and have been shown to successfully reproduce climatic conditions from as long ago as 9,000 years (Scaife *et al*., 2007).

Dynamic crop-growth models for *Triticum aestivum* (spring wheat) were tested in the field, using simulated scenarios of CO_2 concentration (Free Air Carbon Dioxide Enrichment (FACE)) and water availability. Models can be evaluated using measures of crop phenology, aboveground dry matter, grain yield and evapotranspiration. In this case, the model did not simulate the accelerated crop phenology, indicating the need to include stomatal effects in models (Tubielo *et al*., 1999).

In China, Gao *et al*. (2004) compared the behaviour of two suites of models (biogeochemical and leaf photosynthesis models) against field data of 11 plant species in the semi-arid Loess Plateau of northern China, including trees, shrubs, grasses and crops (i.e. C3 and C4 species). The results suggest that the biogeochemical models explained on average 66% and 82% of variations in observed net photosynthesis rates for C3 and C4 plants respectively and the leaf photosynthesis models explained 72% and 76% of variations, suggesting that the models performed similarly to each other and simulated field results relatively successfully.

Box 3.3 Plant plasticity

Plants are able to adapt and grow in a wide range of environments. The different responsive adaptations of plant species to changing environments (plant plasticity) leads to differences in species growth rates and productivity.

3.5 Modeling plant hardiness zones

Climatically, many species have the potential for a much broader range than they actually exhibit. They are limited because of other factors, such as competition (McKenney *et al*., 2007a). This raises the question of plant plasticity as an important consideration in the interpretation of plant distribution predictions. Little is known about the extreme tolerances of most species i.e. the conditions in which species *could* exist, not just where they are plotted as occurring. One source of further data in this respect are the world's botanic gardens, which frequently grow plant species in environments far removed from their native ranges.

Plant hardiness zones are the geographical zones in which plant life is capable of growing, and are normally based on the extreme minimum temperature of the zone. Traditional plant hardiness zones do not consider other climatic variables, such as heat levels, soil moisture or snow cover for example, which all effect whether a plant can be grown in an area. Nevertheless they provide a useful guide, and a way of comparing zones across the globe. In terms of climate change, comparisons of current and past plant hardiness zones indicate how plants may be affected by temperature changes (though these are limited by the complex nature of plant responses to climatic variables other than temperature). For example, in 2006, the National Arbor Day Foundation released a hardiness zone map for the USA based on climate data from 1990 to 2005. When compared to the 1990 US Department of Agriculture's (USDA) hardiness zone map, approximately half of the country had warmed one hardiness zone.

Case study 3.5
Plant hardiness zones in Canada

In Canada zones have been developed based on seven different climate variables including average winter minimum temperatures, rainfall in January, maximum wind gusts and also snow cover. The use of several variables is an attempt to better reflect the complexity of plant responses to more than just temperature. A recent update of the Canadian zones suggested zone increases in much of western Canada but relatively little change or even lowering of the zone values in parts of eastern Canada (McKenney *et al.*, 2007a; 2007b). This in fact is consistent with what is known about climate change in Canada; temperature increases are much more pronounced in the west than the east.

The complexity of mapping plant distributions and potential changes due to climate change has spurred on a North America-wide project called 'Going Beyond the Zones' (McKenney *et al*., 2007a; 2007b). This work provides a web-based approach to better quantify the climatic tolerances and map the possible consequences of climate change on thousands of individual plant species across both the United States and Canada. Planting zones and/or species ranges are expected to shift northward hundreds of kilometres and in many cases species suitable habitats shrink by more than half. It is clear that there will be significant stresses on the climate habitat of many species over the course of this century if IPCC climate change scenarios are even roughly correct.

3.6 The need for models

The interaction of processes in nature is complex and the importance of stochastic events is large. Predictions of future changes in species distributions are therefore complicated but of major importance in planning ahead.

Models are critcal for conservation planning, because they highlight focus areas and illustrate the need for action. Although modeling is limited by the quality of data it is based on, such as the environmental tolerances of plants, they provide the best information we presently have.

Though it is important to scrutinise climate change predictions adequately, the scientific debate must not divert us from taking timely and appropriate action. Meta analyses of independent studies confirm the clear consensus that 20th century global warming has already affected the Earth's biota (Parmesan, 2006). The extent to which this continues is up to us and represents the greatest challenge humanity faces.

4 Plant community interactions

Summary

It is clear that different plant species will respond differently to climate change. Some species will stay in place but adapt to new climatic conditions through selection or plasticity. Other species will move to higher latitudes or altitudes. Some species may become extinct. Because of this, plant community composition will be reorganised, new communities will emerge and others will be lost. One of the biggest concerns of this community reshuffling is the disruption of food webs and co-evolved mutualisms, such as the relationships between a plant and its pollinator or seed disperser. If species that rely on each other no longer co-occur in the same time or space, both may be driven to extinction. Diseases, pests, and invasive species may spread into new ranges putting more pressure on fragile communities. Maintaining biodiverse communities will become an even greater conservation priority.

Key points

- Plant species are reacting differently to changing environmental conditions. We can therefore expect climate change to induce a reassortment of species within plant communities. The consequences of these changes are largely unknown, but are likely to be significant.

- Disruption in the synchrony between plants and pollinators is already affecting food security, nutrition and agriculture, as well resulting in a decline of the numbers of pollinators themselves.

- Bluebells, an emblematic spring flower in the UK, are facing increasing competition from other common wild plants, as warmer springs encourage the earlier growth of these species.

- Globally, the cost of damage caused by invasive species has been estimated to be US$1 trillion per year; close to 5% of global GDP. Climate change is likely to exacerbate the problem as 'weedy' species increase and threaten the survival of native species.

- Many food chains are dependant on synchrony between species along the chain. Early bud burst for example can deprive caterpillars of their preferred food and lack of caterpillars will have a consequent impact on the food supply for bird species.

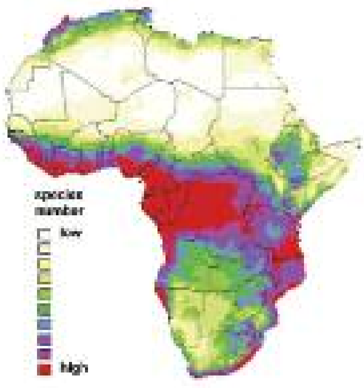
4.1 The importance of interactions

So far, it is clear that climate change is exerting distinct physiological impacts at the scale of individual plant species. This is variable according to species type, genotype and the unique set of adaptations that each has (Shaver *et al*., 2000).

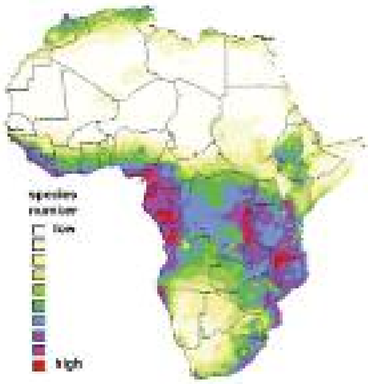
Since responses to climate change are species specific, these varying effects will have important implications for species interactions, leading to a reorganisation of existing communities rather than a synchronous shift of whole vegetation units (Walther *et al*., 2002; Root & Schneider, 2006).

Plant to plant interactions effect both resource availability and habitat structure and play an important role in mediating the responses of natural systems (Brooker, 2006).

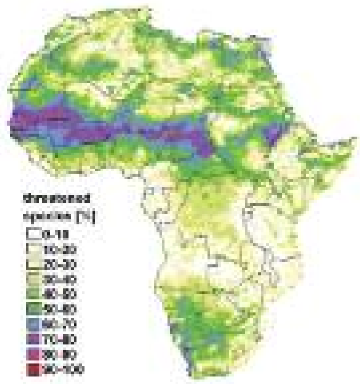
Case study 4.1 Climate change: predicted decrease in plant species diversity by the year 2100



recent plant diversity



predicted plant diversity by the year 2100



proportion of threatened species per area

Conclusions

- the geographic ranges of 90% of all species may decrease in average to about 50% of their recent range;
- some areas may lose up to 80% of all species, in particular in the Sahel region;
- up to 25% of all species may go extinct by the effects of climate change (Sommer *et al*., 2006).

4.2 Past and future vegetative shifts

In the past there have been major changes in the distribution of plant species brought about by climatic change. In turn, past climatic conditions have had a major influence on the current distribution of vegetation. Cooling climates towards the end of the Tertiary (approximately 65 million to 1.8 million years ago) for example, resulted in large assemblages of plant species from warm temperate and subtropical circumboreal regions retreating southwards to refugial areas of warm wet conditions. These areas of plant refugia are in east Asia, south-eastern North America, western North America and southwest Eurasia (the Caucasus region) and are known as Tertiary relict floras. Tertiary relict floras are of great biogeographical interest because they show disjunct distributions of genera that were able to migrate along former land bridges between continents. They are also centres of plant diversity with a disproportionate number of globally threatened species.

Under changed climate, it is likely that new plant assemblages will be formed (community scale) and that carbon and water cycling may change (ecosystem scale) resulting in altered functions and services (Vohland *et al*., 2007). In short, climate change will alter plant distribution, will influence the diversity of species, will influence ecosystem stability, and will therefore influence services required for life (Bakkenes *et al*., 2002).

Further, in some areas, the relationship between climate change and vegetation is not reversible; this suggests that once an ecological threshold has been crossed, a return to similar climatic conditions does not guarantee a similar reversal in vegetation (Maslin, 2004).

4.3 Plant-to-plant interactions

Plant-to-plant interactions play a key role in regulating the composition of communities and ecosystems because they impact resource availability and habitat structure - but they can in turn be impacted by external drivers, such as nutrient availability. Since we are currently experiencing unprecedented rates of change of many environmental parameters, plant-to-plant interactions are an important part of the mechanisms governing the response of plant species and communities to these drivers and to climate change. When and to what extent these interactions play a key role is still not fully understood but interactions have a considerable modifying effect on environmental niches.

4.3.1 Competition

Competition is a central component of ecological theories, principly determining the diversity and dominance of species within plant communities. Very subtle changes in soil moisture levels, light levels and nutrient levels can make the difference between a plant dominating its surroundings or being eliminated. It could be said that a plant's survival will thus depend on competition, rather than its inate response to climate change. For example, an experiment with five common UK roadside species showed that, when grown in monocultures, all responded positively to increased spring warming. However, when grown in mixtures the benefits of warming were only observable in a subset of species (Dunnett & Grime, 2001).

The effect of competition also depends on the severity of the environment. In environments favourable for plant growth, competition plays a significant role, in less favourable environments it is less important because of the increasing role of adverse environmental conditions (Brooker, 2006). Increasing productive capacity in arctic and alpine environments may therefore lead to an increasing role for competition. Further, when a plant is transported to a new environment it could be 'released from enemies' and thus develop new competitive ability.

4.3.2 Facilitative plants and plant complementarity

Facilitative interactions between plants (such as the nurse plant effect, where a mature plant provides shelter for establishing seedlings) can play an important role in regulating the composition of some plant communities. In French alpine communities increased altitude was associated with an increased frequency of facilitative interactions (Choler *et al*., 2001). Such interactions can promote the survival of plant species in environmental conditions that would otherwise be too stressful, thus expanding their realised niche. Increasing severity, for example in Mediterranean-type ecosystems may lead to an increasing need for facilitation (Brooker, 2006).

4.4 Plant/pollinator and plant/pathogen interactions

The timing of seasonal activities has advanced for many species in response to climate change (Root *et al*., 2005; Parmesan, 2006). Whilst this illustrates that species are adapting to climate change, not all species are responding. Where there are tightly coupled relationships among species, phenological changes are particularly important. If the phenology of a species is shifting at a different rate to that of the species that make up it's environmental conditions, this will lead to a mismatch, a 'decoupling'. The consequences of this may be severe for species survival (Visser & Both, 2005).

4.4.1 Pollinators

Some plant/pollinator pairs in a particular area are likely to respond to the same environmental cues and may react similarly to climate change. But other pairs may use different cues, the pollinator emerging in response to air temperature for example, while the plant flowers in response to snow melt (Lindsey, 2007). With the synchrony of plants and pollinators being disrupted, there will be obvious consequences. There is also some evidence that elevated

Case study 4.2 Competition and the bluebell (*Hyacinthoides non-scripta*)

The bluebell is a bulbous spring flowering plant that is popularly thought of as Britain's national flower. Its fragrant bell-shaped flowers stand upright when they are in bud, but hang downwards when fully open. When growing en masse in woodlands they create a beautiful haze of blue colour. Although the bluebell is widespread in Britain, it is globally threatened, and British populations represent 25-49% of the world's total.

During periods of cold weather, spring flowers such as bluebells have already started the process of growth by preparing leaves and flowers in underground bulbs in summer and autumn. They are then able to grow in the cold of winter or early spring by using these resources stored in their bulb. Other species - such as cow parsley (*Anthriscus sylvestris*) or dandelions (*Taraxacum officinale*) are more temperature dependent, and require warm weather before they are able to germinate and grow. With the warmer springs induced by climate change, bluebells will lose their 'early start' advantage, and be outcompeted by temperature sensitive plants that start growing earlier than in the past (BGCI, no date).

To exacerbate the problem for *Hyacinthoides non-scripta*, the Spanish bluebell *Hyacinthoides hispanica* is more vigorous than the native species and proving able to outcompete the native species. *H.hispanica* also readily crosses with *H.non-scripta*, producing a fully fertile hybrid; *H.hispanica x non-scripta*, further threatening the genetic integrity of the indigenous species (Pilgrim & Hutchinson, 2004).

CO_2 influences nectar production and secretion, and that increased UVB rays may effect flower production – these will all have repurcussions for plant and pollinator reproductive success (National Research Council, 2007).

Depending on the degree of the variation in responses, the consequences could range from subtle to dramatic. Pollinator declines could affect many basic ecosystem services, food security and nutrition, agriculture and wild plant availability. The economic value of pollinators is thought to be between $US40 billion to $US100 billion a year worldwide and should not be underestimated (BGCI, 2006).

Bees are incredibly important pollinators. In the USA in 2000, it was estimated that the agricultural value attributable to honey bees was US$14.6 billion (Morse & Calderone, 2000). However, bees are responsive to changes in temperature, and have been emerging from hibernation earlier because of warmer winter weather. In the UK, they have been sighted on average two to three weeks earlier than in the 1970s and 80s (Woodland Trust, 2004). Unfortunately, when colder spells follow, the bees die, with clear implications for food chains, plant pollination and food security.

4.4.2 Pests and pathogens

It is likely that climate change will alter the stages and rates of development of plant pathogens, as well as modifying host resistance, resulting in changes in the interactions between the two (Garret *et al*., 2006).

Insects have short life cycles, high mobility, and high reproductive potential which means they can quickly take advantage of and adapt to new climatic conditions and expand their ranges. Temperature is expected to have significant effects; increasing winter survival, extending the summer season and possibly influencing life-cycle duration, population density and distribution (Kehlenbeck & Schrader, 2007). Milder winters mean pests will have a 'head start', whilst increased temperatures in spring mean pests become active sooner, for longer and with shorter intervals between generations.

Diseases are also impacted. Warming winters result in greater availability of surviving host material, and increased temperatures may increase rate of spread and the incidence of exotic diseases. For example, more severe outbreaks of downy mildew on grape harvests are predicted under climate change (Salinari *et al*., 2006). Further, changing microclimates – for example, that created by an increase in plant density as a result of elevated CO_2 (more humid microclimate) may favour plant pathogens.

Increased concentration of nutrients in cell sap due to reduced water supply might mean that pests that feed on this may increase more rapidly. On the other hand, consumption of plants by pests might increase due to decrease in the nutritive value of leaves (See Section 2.2.3).

Case study 4.3 Proteaceae and sugarbirds

Two Sugarbird species in South Africa are highly dependent on Proteaceae flowers, and leave their territories only during the dry season when flowers are absent. Their entire life cycles are adapted to those of the plants. Species within the Proteaceae family however, are predicted to face range contradictions and extinctions and be especially vulnerable to aspects of climate change such as increased fire frequency. In turn, sugarbirds are important pollinators of proteoids. If the birds' own temperature tolerances force them away from the flowers the plant-pollinator link may be broken. In this way, both sugarbird populations are detrimentally affected but plant populations will also likely reduce (Simmons *et al*., 2004).

This combined with increased insect outbreak may increase light penetration through the foliage canopy, effecting competition among plants. Additionally, an increase in the rate of fall of nutrient-rich litter would stimulate nutrient uptake and the redistribution of nutrients within plant tissues (le Mellec & Michalzik, 2007).

Other climate change-stimulated structural changes to plants will impact host resistance. For example, elevated O_3 can change the chemical composition of leaf surfaces, which alter surface properties, which alter the ability of pathogens to attach to leaf surfaces (See section 2.5).

Case study 4.4 Pests and pathogens

This is an area of uncertainties, reliant on several limiting factors (Garret *et al*., 2006).

For aphids, one of the most important natural controls is raindrops, which dislodge the aphids or damage their feeding parts. It is not known whether lower summer rainfall will reduce this control mechanism or whether less frequent but heavier rainfalls will increase it (Bisgrove & Hadley, 2002).

One experimental study on the long-term effects of elevated CO_2 on the evolution of the pathogen fungus *Colletotrichum gloeosporioides* on *Stylosanthes* spp. demonstrated that host resistance under elevated CO_2 was linked to pathogen aggressiveness (Chakraborty *et al*., 2002).

Outside of the laboratory, the effects of climate change on crop pests are already being felt in some areas. Reduced incidence of frosts led to an increase in the tropical grass webworm in New Zealand causing severe damage to pasture grasses. Citrus canker, a highly contagious bacterial disease favouring heat and heavy rain has been spread by hurricanes to citrus crops throughout Florida in the USA and bean leaf beetle, which affect soyabean crops by spreading bean pod mottle virus, have migrated from the southern USA to the central and northern Midwest (UNEP, 2006).

4.5 Factors effecting plant communities

In some cases, plant responses to climate change will disrupt community processes. For example, in non-fragmented Amazon forests over the last 20 years of the 20th century, liana dominance relative to trees has increased by 1.7-4.6%, thought to be a response to elevated CO_2. Lianas enhance tree mortality and suppress tree growth. Their rapid increase implies that the tropical terrestrial carbon sink provided by forest trees may shut down sooner than predicted (Philips *et al*., 2002).

4.5.1 Invasive species

Invasive species are those which have been introduced into an environment (often accidentally) in which they did not evolve. As such they usually have no natural enemies to limit their spread. They are usually species with high reproductive rates, fast growth rates and good dispersal mechanisms. Invasive species are typically good at establishing themselves in new habitats, where they thrive, to the detriment of native species. The characterisitics that make a species a good 'invader' are also those that will enable a species to adapt to climate change fast enough to survive i.e. most of the species which have shown rapid evolutionary response to climate change have short generation times.

Invasive species already constitute a major driver of environmental change and are a significant concern for the conservation and management of natural and managed areas. They threaten native biodiversity, change ecosystem functioning and have an economic cost, due for example to crop losses and the controling of pests and diseases (Millennium Ecosystem Assessment (MA), 2005). The global cost of controlling invasive species has been estimated to be US$1 trillion (CABI, 2007). In the USA alone, the cost is estimated to be $120 billion a year, with 100 million acres suffering invasive plant infestations (Nature Conservancy, no date).

Climate change brings the likely increase of alien invasive species, or 'weedy' plants (Kriticos *et al*., 2003; Middleton, 2006) as well as increasing the probability that 'sleeper weeds' may become invasive (Kriticos & Filmer, 2007). New niches will become available as less tolerant species die, and may be readily dominated by invasive species. Increasing disturbances due to extreme events could also have a detrimental effect on indigenous populations and create windows for successful invasions (Ward & Master, 2007). Invasive species go on to alter ecosystem dynamics such as fire regimes, either increasing the frequency or the intensity of fires (Mooney & Hobbs, 2000). Bufflegrass (*Penisetum cilare*) in South America for example has invaded landscapes and fuels fires that native species are unable to withstand (Nature Conservancy, no date).

Biodiverse rich communitites are more resiliant to invaders, since diverse communities use resources more fully, leaving fewer niches for potential colonists to exploit. This is the theory of 'biotic resistance' first proposed by Elton in 1958. He predicted that should trends in the loss of biodiversity persist, "*the eventual state of the biological world will become not more complex but simpler and poorer. Instead of six continental realms of life, there will only be one world*." Unique assemblages of plants and animals would thus be replaced by widespread alien species that can coexist with humans, such as rats, starlings and carp (Ricciardi & MacIssac, 2008).

Case study 4.5 Invasive species

The water fern (*Azolla* spp.) is an invasive plant species, widely introduced globally via ship's ballasts, for example in the Caspian sea (Global Invasive Species Database, 2005). The species provides a haven for mosquito larvae in Africa. Similarly, the water hyacinth (*Eichhornia crassipes*) originates from the Amazon but now threatens native biodiversity globally. Its growth rate is among the highest of any plant known; the species is able to double its mass in 12 days and can grow faster than it can be cleared. These species form dense mats that cover thousands of hectares, preventing sunlight and water from getting into the water and choking out other species. This results in a loss of livelihood (fishing), decrease in available water and even a threat to power generation. The Akosombo Dam in Ghana is under serious threat from the water hyacinth (Sarpong, 2004).

Acacia nilotica has been declared a weed of national significance in Australia. Though introduced to provide shade for sheep it causes significant damage to cattle production by reducing pasture production. In terms of the environment, the species increases soil erosion and water loss through transpiration. *A.nilotica* has vast potential distribution and actively expands its range. Climate change will likely increase areas at risk of invasion (Kriticos *et al*., 2003).

4.5.2 Disturbance and ecological succession

Ecological succession is the process of colonisation of a landscape by species until equilibrium is reached. Primary succession is the colonisation of an area where vegetation has not been present – for example stabilising grasses on newly formed dunes, followed by shrubs, able to colonise the stabilised dune. Secondary succession occurs after a disturbance has occurred. Disturbance is a temporary change in average environmental conditions brought about by an event, such as a fire, insect outbreak, flooding or storms, as well as human-induced disturbance, such as deforestation. As well as profound immediate effects, disturbance has long-term impacts, based on the severity, frequency and cumulative impacts from interactions between disturbances. For example, increased drought stress (from climate change) may lead to increased frequency of and magnitude of pest and disease outbreaks (disturbances). An increase in defoliation by pests may then lead to an increase in the likelihood of wildfire (a disturbance), by increasing the volume of dead tree matter, which acts as fuel for fire.

Disturbance is necessary for ecological succession to occur, whereby different species may fare better in the post-disturbance conditions. As such, natural disturbance is necessary for biological diversity. It is also thought that biodiversity is highest when disturbance is neither too rare nor too frequent (Connell, 1978). However, more frequent disturbances are predicted under future climate change scenarios, particularly the increased incidence of forest fires (Dale *et al*., 2001; Goetz *et al*., 2007).

Case study 4.6 Disturbance in Africa

Africa, like other continents though perhaps to a greater degree, is characterised by ecosystem control through disturbance, such as fire and grazing regimes. Changing disturbance regimes will interact with climate change in important ways to control biodiversity, for instance through rapid, discontinuous ecosystem 'switches.'

For example, changes in the grazing and fire regime during the past century are thought to have increased woody-plant density over large parts of southern Africa. Fire-maintained ecosystems, often C4 grasslands, regenerate from fire quickly. After a fire, there are high levels of light, nutrients and water – it is CO_2 that is the limiting factor for woody plant growth. Under elevated CO_2, tree density may further increase in savannas, thus disrupting a species-rich ecosystem which also contains many endemic species (Bond *et al*., 2003).

Ecosystem switches are accompanied by species shifts and even species extinction. Even subtle changes in species composition of rich ecosystems such as forests will impact biodiversity resources. Although much larger scale ecosystem switches, such as forest to savannah or shrubland to grassland, clearly occurred in the past, the geographical range shifts required to preserve biodiversity into the future will be strongly constrained by habitat fragmentation (IPCC, 2001b).

4.5.3 Migration

It is accepted that, as in the past, plants will have to migrate in order to persist. In essence following the environmental niches to which they are uniquely adapted.

McLachlan *et al*. (2005) looked at the migrations of *Fagus grandiflora* (American beech) and *Acer rubrum* (red maple) during the last glacial period (10 to 20,000 years ago) and estimated that they were of an order of magnitude slower than those required for current climate change. However, the species *did* persist, and this might be through an ability to maintain low-density populations for long periods of time (Pearson, 2006).

Under current climate change scenarios, it has been suggested that migration speeds in the region of 300-500km a century will be required. This is beyond even exceptional examples in the fossil record of 100 to 150 km a century (Maschinksi *et al*., 2006). It is therefore likely that, for most plant species, climate change may outstrip a population's rate of migration (Hewitt & Nichols, 2005; Neilson *et al*., 2005).

Generally, the poleward shift of whole taxonomic groups is suggested (Parmesan, 2006). However, terrain must permit migration. For example, a species cannot move from one mountain top to another through a valley, or from one moist area to another through a dry patch. There are now substantially more barriers to migration than in previous climatic shifts and this will have a *huge* impact on migration opportunities.

Further, it is likely that different species will migrate at different rates, resulting in changes in the composition of plant communities. However, studies of pollen, seeds and other fossils from the last glaciation regularly show species living in combinations unknown today. Known to paleoecologists as no-analog communities (nothing like them exists in the present world), they arose from odd combinations of climate variables that don't exist today. There is growing evidence that climate change is pushing us towards a no-analog world where the plant communities of the future will look very different from those of today. The important issue will be whether or not these new communities are able to function and to continue to provide the services provided by today's ecosystems.

4.5.4 Food chains

Given the complex interplay between organisms, food chains are vulnerable to climate-based disruptions. Aspects discussed earlier in this report filter down the food chain, for example the predicted decrease in the nitrogen content of plants leads to reduced nutritive value to insects and herbivores and necessitates increased consumption, if this is an available option.

Adaptations are needed from both plant and herbivore to perform well under different conditions, and the adaptive capacities of these remain uncertain. Further, within food chain couplings there may be an asymetry of dependence. Márquez *et al*. (2004) found that disperser species richness exerts a greater influence on fleshy-fruited plant species richness than the other way round, highlighting the importance of dispersal for colonisation by plants.

Animals responding to temperature and plants to daylength is another great mismatch that will cause problems under accelerated climate change (Flannery, 2005). In fact, for many species, the primary impact of climate change will be through effects on synchrony of that species' resources. More crucial than any absolute change in timing of a single species is the disruption in timing of life cycles (Parmesan, 2006). In 2005, Visser and Both reviewed 11 species' interactions and found that seven out of 11 responded differently enough to climate change that they were losing synchrony by the end of the studies.

A classic example of the disruption of food chains is Visser and Holleman's 2001 study of oaks (*Quercus robur*) and winter moths (*Operophtera brumata*). The study indicated that the response of moth egg hatching and oak bud burst to temperature were asynchronous in recent warm springs, because of an increase in spring temperature without a decrease in the incidence of freezing spells in winter (i.e. temperature changes in one period changing in a different way from temperatures in another period).

The timing of egg hatch is strongly selective to bud burst, because if the eggs hatch prior to bud burst the caterpillars will starve, and if hatching occurs after bud burst the caterpillars must eat less digestible leaves due to an increase in leaf tannin concentration in older leaves. This in turn affects pupae weight, with consequences for multitrophic levels, such as the availability of food for birds.

For migratory species using climate cues for migration, changes in the timing of parts of a species' life cycle could cause significant harm. For example, a species may not find food at its destination (Robinson *et al*., 2005).

5 Plant species at risk

Summary

In an era of rapid climate change, species have three basic alternatives, they can: 1) migrate to appropriate environmental conditions; 2) adapt to the new environmental conditions; or 3) become extinct. In a changing environment, 'weedy' species with fast generation times and wide ecological tolerances are more likely to adapt or migrate quickly and are more likely to flourish. Conservative species with specific habitat requirements or long generation times are more prone to the threat of extinction. At present an estimated one-quarter of vascular plant species are under threat in the wild. With predicted temperature increases, changing hydrological cycles and other factors of climate change, as many as half of all plant species may be lost over the next century. This is a catastrophic scenario given the fundamental importance of plants to life on earth. As yet there is a lack of published information on plant extinctions directly due to climate change but with baseline information now being collected on the distribution, threat status and ecology of various plant groups, monitoring schemes can be established. Plant species restricted to high-risk habitats, including montane, island or coastal habitats are likely to be the first casualties of climate change. Plant conservation action needs to be increased *now* to ensure that options are available for the future.

Key points

- Recent models, based on a temperature rise of 2-3°C over the next 100 years, suggest that up to half of the world's plant species will be threatened with extinction. Levels of extinction will be directly related to the extent to which we limit global warming.
- Species that are already under threat will become rarer and more likely to become extinct.
- Alpine plants are one group particularly at risk. Such species tend to have a narrow habitat tolerance and grow in marginal habitats. Many alpines exhibit relict distributions and have migrated to highlands since the last Ice Age.
- Other species with 'nowhere to go' and which are already of grave conservation concern, include island species such as the 300 endemic tree species from Jamaica as well as 70 threatened plant species that are confined to the cloud forests of Cuba.
- 10% of the world's tree species are threatened with extinction. This is of particular relevance as trees facilitate significant carbon storage and play a crucial role in the carbon cycle.

5.1 Every species matters

Climate change will place pressure on the natural range and survival of wild populations of plants. Species that are already rare will become rarer still. The existence of many species in the wild will be threatened because many are restricted in range, and because environments will change faster than most plant species can adapt. Levels of species loss will be directly related to the extent to which we can limit global warming.

The survival of many plants in the wild is threatened by a wide variety of factors. As well as climate change - habitat loss, the spread of invasive species and the over-exploitation of valuable species are major causes of the loss of both species diversity and the decline of individual plant species. These threats rarely act in isolation but combine in different orders of magnitude in different geographical locations and impact on species in different ways depending on their biology and ecology. Assessments of the conservation status of plant species began around 40 years ago and a significant body of information has built up. Measurements of threat take into account factors such as rate of decline of populations, past, ongoing or predicted, or restricted area of distribution and condition of the habitat.

5.2 The IUCN Red List of Threatened Species

The system of categorising threat to species that is used as a global standard is the application of the IUCN Red List Categories and Criteria (IUCN, 2001). Basically, these are;

- **EXTINCT (EX)** - A taxon is Extinct when there is no reasonable doubt that the last individual has died.
- **EXTINCT IN THE WILD (EW)** - A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range.
- **CRITICALLY ENDANGERED (CR)** - A taxon is Critically Endangered when the best available evidence indicates that it meets any of five criteria for Critically Endangered and it is therefore considered to be facing an extremely high risk of extinction in the wild.
- **ENDANGERED (EN)** - A taxon is Endangered when the best available evidence indicates that it meets any of the five criteria for Endangered and it is therefore considered to be facing a very high risk of extinction in the wild.
- **VULNERABLE (VU)** - A taxon is Vulnerable when the best available evidence indicates that it meets any of the five criteria for Vulnerable and it is therefore considered to be facing a high risk of extinction in the wild.
- **NEAR THREATENED (NT)** - A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.

At present there are 8,447 plant species recorded as threatened in the 2007 IUCN Red List, of which 5,643 are tree species. This figure is not representative of the total number of plant species threatened at a global scale but rather an indication of the number that have been assessed using the current categories and criteria. Progress in Red Listing for plants using the IUCN Categories and Criteria and meeting the full documentation requirements is widely acknowledged to be unimpressive. This should not delude us into thinking that all is well with plants. There are many national and regional lists of threatened plants that indicate the decline of species.

A review of the IUCN Red List in 2004 noted that;

"*As yet few species have been identified as being threatened on the IUCN Red List specifically owing to climate change. However there are many examples of the effects of climate change on species from around the world, which taken together, provide compelling evidence that climate change will be catastrophic for many species*" (Baillie *et al*., 2004).

One example of a plant species where changing climate has already been noted as a threat is a species of dragon tree, *Dracaena ombet*. In the Elba Mountains of Egypt, populations of this endangered species are in decline, particularly so over the last 10 years. Surveys have shown that this decline is occurring (and has accelerated) at the lower and middle elevations of the species range, with unhealthy trees, no sign of any new generation and widespread tree death between 450-850m. At higher altitudes, the *Dracaena* woodland in general is healthy. It seems likely that the main cause of the decline in extent and quality of *Dracaena* woodland is the gradual drying up of the area of southern Egypt. As well as extreme drought to contend with, *Dracaena ombet* occurs only at a high elevation between 450-1,450m in this area and is dependant on moisture from mists and cloud which come from the Red Sea to the east. Local people have described the extent of this cloud coverage as diminishing over the years (Ghazaly, 2007).

Case study 5.1 Plant Red Listing in Cuba

Island floras are rich in endemic species which generally have restricted distributions and are under a high degree of threat. Cuba for example has a very rich flora with 7,020 vascular plant species of which 50% are endemic to the island. The main threats to the flora are habitat loss, fires, agricultural and forestry development and mining. Recently 1,414 taxa have been evaluated using the IUCN Red List Categories and Criteria including 1,089 plant species that grow only on the island. Of the recorded endemic species; 21 are extinct, and 1,006 are threatened with extinction. 191 of the threatened endemic plants are tree species. With changing climatic conditions the wild populations of these globally threatened species are likely to be placed under more severe stress. The 70 threatened species that are confined to high altitude cloud forest are potentially most at risk as temperatures increase (Iturralde *et al*., 2005).

5.3 Vulnerability traits

As noted by Téllez *et al*. (2007) most species have only a few alternatives in the face of climate change. They can:

- migrate to appropriate environmental conditions;
- adapt to the new environmental conditions; or
- become extinct.

Evidently, it is expected that the intrinsic capacity of each taxa or group of taxa to respond to climate change will result in different behaviours. The Gran Canaria Declaration II (Gran Canaria Group, 2006) provides a list of taxa that may be most significantly impacted by climate change. These are:

- taxa with nowhere to go, such as mountain tops, low-lying islands, high latitudes and edges of continents;
- plants with restricted ranges such as rare and endemic species;
- taxa with poor dispersal capacity and/or long generation times;
- species that are susceptible to extreme conditions such as flood or drought;
- plants with extreme habitat/niche specialisation such as narrow tolerance to climate-sensitive variables;
- taxa with co-evolved or synchronous relationships with other species; and
- species with inflexible physiological responses to climate variables.

The IUCN is currently investigating vulnerability traits that can be built into the Red List assessment and documentation process. In the meantime, at broad level, the above criteria are a useful set of factors to take into account when considering species that might be most at threat from climate change.

5.4 Extinctions

Looking at predictions of extinction rates, on the basis of mid-range climate-warming scenarios for 2050, one study, though controversial, shows that 15-37% of species in sample regions and taxa would be 'committed to extinction' by this point (Thomas *et al*., 2004). Recent models based on a temperature rise of 2-3° C over the next 100 years suggest that up to 50% of the 400,000 or so higher plant species will be threatened with extinction (Bramwell, 2007). As discussed in Chapter 3, half the European plant species are predicted to be extinct by 2080 based on modeling distributions of 1,350 species (Thuiller *et al*., 2005).

Endemic species are especially vulnerable to extinction, since they are native to a particular region and occur naturally nowhere else. By definition they have relatively restricted distribution, and this makes them particularly vulnerable to changes in their habitats. More than half the planet's species are endemic to only 6% of its land area (Conservation International, 2007).

5.5 Species at risk

While species in most plant families will be at risk from changing climate to a greater or lesser extent, here we provide examples of different groups of species using recent information on threat status.

5.5.1 Magnolias

Magnoliaceae is an ancient family of around 245 tree and shrub species occurring in the Americas and Asia. A recent Red List evaluation of the Magnoliaceae (Cicuzza *et al*., 2007) indicated that around 131 species and subspecies are

Case study 5.2 Alpine species

The world's alpine plants are amongst those most threatened by climate change, since it is most likely that the area with suitable conditions available for them to inhabit can only decrease. On Greece's Mount Olympus and Spain's Sierra Nevada range for example, only 200-400m separate timberlines from summits. This is the true alpine zone.

Many of the world's countries have very limited areas of alpine environment. For example, of the 11,500sq km of mountain terrain in Australia, only a very small percentage is true treeless alpine, all of which is at a relatively low altitudes. In such areas there is only a very limited opportunity for altitudinal shift, since species are already at the limit. With a small change in the global average temperature, the alpine environment of Mount Bogong in Victoria, will move up the mountain from 1,750-1,900m. But this mountain is only 1,940m high (Busby, 1988). The snowbeds of Australia comprise a number of endemic plants already at risk of extinction. *Caltha introloba* and *Celmisia sericophylla* for example have total world populations of a few thousand individuals at maximum (Molau, 2007).

In addition to the adverse changes in climatic conditions, alpine plants already face strong competition from other plants. Research done in the Alps compared plant surveys done 80-100 years ago and showed that on more than two thirds of the sites resurveyed, grassland species from lower slopes had crept up as much as 4m per decade (Pauli *et al*., 2003). The risks of this climate-induced upward migration include;

"*Drastic area losses or even the extinction of cryophilous plants, a disintegration of current vegetation patterns and impacts on the stability of high mountain ecosystems*."

Such research is suggesting a very grim future for both alpine plants and associated ecosystems. As warming encourages species from the lower slopes to invade, they out compete the plants at the top. In the Italian Alps for example, trees are advancing into alpine meadows (Natura, 2007).

A more subtle effect on alpine plant communities will be the creation of changes within the communities themselves. Experiments conducted with plant species from the southern alpine region of Norway show that the effects of climate change (including more extreme conditions due to less protective snow cover) may start to significantly modify the interaction and competition between individual plant species (Klanderud, 2005).

threatened with extinction at a global scale, over half the known taxa within the family. Current threats to the species are mainly forest clearance and exploitation of particular species for timber or medicinal products.

The present disjunct distribution of magnolias can be related to climatic changes in the past. The family dates back to the later Cretaceous (around 100 million years ago). During the late Cretaceous and Tertiary periods the family occurred throughout the northern hemisphere in continuously distributed mixed mesophytic forest, enjoying warm, wet conditions. This forest was fragmented by the climatic and geological changes that occurred towards the end of the Tertiary and subsequent Quaternary (Wen, 1999; Xiang *et al*., 2000; Azuma *et al*., 2001).

Diversification into the current species appears to have occurred during the middle Eocene (around 42 million years ago) a time of climatic cooling which was associated with the widespread extinction of many ancient forms of magnolia in North America and Europe. This was also responsible for the disjunction between North America and eastern Asia. The climate continued to fluctuate between the early Oligocene and middle Miocene (around 34 million to 15 million years ago), providing opportunities for inter-continental migration of temperate lineages of the ancient magnolias (Azuma *et al*., 2001).

The greatest magnolia species diversity is in China with over 40% of the species occurring there and 46 taxa recorded as threatened. Throughout their range, members of the family have been (and are presently) used extensively in indigenous herbal medicine. The species are associated with warm wet temperate forests and, particularly in the Americas, with tropical montane forests; an ecosystem type particularly vulnerable to climate change. The direct impact of climate change has not been assessed but predictive modeling is now possible using distribution maps produced for the Red List evaluation.

5.5.2 Oaks

The genus *Quercus* has over 500 species mainly in the northern hemisphere, with the greatest species diversity in Mexico, followed by China. Oaks are of great symbolic value and of global ecological and economic importance. In the USA for example 50 oak species are represented in two thirds of the eastern North American forest cover types and dominate 68% of hardwood forests. A recent assessment of the genus using the IUCN Red List Categories and Criteria recorded 78 species of global conservation concern (Oldfield & Eastwood, 2007). For many other species insufficient information was available to undertake the assessments.

Case study 5.3 Tree species with nowhere to go

Because trees contain more carbon, live longer and decompose more slowly than smaller herbaceous plants (MA, 2005) they play a crucial role in the carbon cycle, and thus in climate change mitigation and adaptation.

Ten years ago a global evaluation of tree species indicated that around 10% of all tree species are threatened with extinction. At the time, 976 tree species were considered Critically Endangered according the IUCN Red List Categories and Criteria (Oldfield *et al*., 1998). This figure has now risen to 1,002 species. Some of these species are already reduced to less than 50 individuals in the wild. In the absence of immediate conservation action they are likely to go extinct regardless of the changing climate. In the longer term, there is more hope of saving Endangered and Vulnerable tree species if action is planned now that takes into account the impacts of climate change.

According to the 1998 global evaluation of tree species, 56% of globally threatened trees were considered to be threatened because of a limited geographical range and declining habitat. These species with restricted range may be particularly vulnerable to changing climate.

Island endemic trees accounted for approximately one third of globally threatened trees. Jamaica alone has over 300 endemic trees that are of global conservation concern. High rates of forest destruction and degradation through soil erosion and the rampant spread of invasive species have been the main threats to the flora of Jamaica. The trees that occur only in Jamaica provide one example of plant species that have nowhere to go in response to climate change. There are very many other examples.

Globally threatened tree species associated with montane habitats for example also fall into the nowhere to go category. The 1998 global tree evaluation recorded 73 Critically Endangered tree species as being confined to montane habitats. The number of Endangered and Vulnerable montane tree species amounts to over 700. Recently a list of 502 cloud forest trees for the State of Chiapas was compiled as part of Red Listing exercise for trees of Mexican cloud forests. IUCN Red List Categories and Criteria were applied to over 100 of these species (Newton, 2007). In a parallel exercise, defining and mapping groups of tree species associated with climatic variables in the Chiapas cloud forests has been undertaken, to investigate potential changes in the distribution of tree species resulting from forest disturbance and climate change. Results of the study show that a change in climate consistent with low-emission scenarios would be sufficient to cause major changes in forest composition within 50 years. Disturbance and deforestation, combined with climate change threaten the regional distribution of five Endangered tree species, including the endemics *Magnolia sharpii* and *Wimmeria montana*. 11 Vulnerable species and 34 species requiring late successional conditions for their regeneration could also be threatened (Golicher *et al*., 2008).

The trees and shrubs of the Caucasus region have recently been assessed using the IUCN Red List Categories and Criteria (Eastwood, 2005). 150 taxa were evaluated; seven are Critically Endangered, 10 Endangered and 15 Vulnerable. The main threats to these globally threatened species are exploitation and habitat degradation through logging and to some extent over-grazing. In addition, some of the species are narrow endemics whose distributions are restricted to specific forest habitats such as the Colkhic or Hyrcanian forests. With climate change, the threat of extinction will undoubtedly increase for these trees with nowhere to go.

Oaks are usually considered to be favoured by relatively warm and dry climates, and paleoclimatologists use abundant fossil oak pollen as an indicator of this type of climate (Lorimer, 1992). Various studies have been published or are underway on the impact of climate change on the distribution of oak species. In the USA, narrow endemics in California, *Quercus douglasii* and *Q.lobata* are predicted to become increasingly threatened with extinction (Kueppers *et al*., 2005).

In Mexico, projects are underway to understand the relationships of oaks to aspects of phytogeography and conservation planning taking into account the impact of climate change. Based on initial bioclimatic modeling some of the species expand their ranges with increase in temperature, but, in more drastic scenarios, most of the species contract their ranges. The vulnerability of 34 species of oaks to the effects of global climate change in Mexico was modeled by Gómez-Mendoza & Arriaga (2007). Their results show that the species expected to have most significant decreases in range as a result of climate change are *Quercus crispipilis, Q. peduncularis, Q. acutifolia*, and *Q. sideroxyla*.

5.5.3 Cacti

Cactaceae is a family of mainly spiny succulents with over 1,438 species and 378 subspecies largely confined to the Americas. Although generally associated with arid lands, cacti are represented in many habitat types ranging from Canada to Patagonia and from dry, cold montane conditions to the wet lowland Atlantic rainforests of Brazil.

A recent preliminary assessment of the conservation status of cacti based on the IUCN Red List Categories and Criteria suggest that 620 (around one third of all taxa, species and subspecies) are threatened with extinction (Taylor, 2006).

Mexico is the centre of diversity of cacti. Within the country one of the most important areas for cactus conservation is the Tehuacan-Cuicatlán Biosphere Reserve. This reserve represents the southernmost semi-arid region of North America and is a very diverse area, with almost 3,000 vascular plant species in an area of 10,000 sq km.

An assessment of the conservation status of the cacti of the area has been undertaken with distribution patterns and reproductive capacity of the species evaluated and their habitat and the effects of land use studied. The effects of climate change on their survival and future distribution patterns, especially those species that are more sensitive to climate conditions, are also being assessed. The possible future distribution of the Cactaceae species in response to global climate change in this region has been modeled. In general terms, only a few species extend their distribution area under climate change. In fact, almost 95% of species drastically reduce their areas and 50% seem to have no distribution, possibly because they will be extinct by 2100. It is also clear that most of the habitats associated with the latter species will be lost (Téllez *et al*., 2007).

5.5.4 Aloes

There are approximately 360 species and subspecies in the succulent plant genus aloe, distributed in Africa, the Arabian Peninsula and islands of the Indian Ocean. Many aloes are naturally rare and confined to specific habitats. Few evaluations have been made using the IUCN Red List Categories and Criteria, but many aloes have limited distributions and are likely to qualify for Red Listing based on geographic range. Such restricted range species include, for example, *Aloe amicorum, A. kulalensis* and *A. multicolor* which are known only from Mount Kulal Biosphere Reserve, in one province of Kenya. The sap of certain aloes has medicinal or cosmetic applications. *Aloe vera*, the wild origin of which is uncertain, is cultivated as a commercial crop in many countries for extensive use in the pharmaceutical and cosmetic industries. Other species are of great importance to rural communities who do not have access to western medicine.

One species, *Aloe dichotoma* (the Quiver tree) which occurs in Namibia and South Africa, has become a flagship for plants and climate change, being one of the few species for which the impact of climate change has been intensively studied. The soft branches of this small succulent tree are used as quivers for hunting arrows of the San bushmen. Research in Namibia has shown that populations in the northern part of the range are dying as the area experiences increasing drought. More southerly tree populations are doing well with good regeneration. Overall however, the changing climatic conditions are proceeding so quickly that the long-lived slow growing tree is unable to keep up.

The same is likely to be true for the much rarer *Aloe pillansi*, a species largely confined to an intensely hot and arid area in the Richtersveld in the Cape Province of South Africa. A serious decline in the population has reduced the numbers to less than 200 individuals. There is no recruitment and the older plants are dying. Both *A. dichotoma* and *A. pillansii*, are keystone species in their respective ecosystems, being two of the few perennial plants able to tolerate the climatic conditions.

5.5.5 Bamboos

There are estimated to be around 2,000 species of bamboos, around half of which occur in the Asia-Pacific region. They are very important as a source of material for housing, food and handicraft production. Ecologically, bamboos are important in stabilising soils and in providing food and habitat for a range of animal species. They are also considered to be of considerable importance in carbon sequestration, although less so than tree species. A study of bamboo diversity in the Asia-Pacific region (Bystriakova *et al*., 2003) pointed out that bamboos are an ancient group of forest plants intrinsically vulnerable to deforestation. The vulnerability of certain species is increased by the fact that populations flower simultaneously and then die in cycles of 20-120 years. The study mapped nearly 1,000 individual bamboo species in relation to forest cover and indicated that more than 400 species are potentially threatened by destruction of their forest habitats. These species all qualify for inclusion on the IUCN Red List. The maps provide a useful basis for predicting the impact of climate change on this group of economically and ecologically important species.

5.5.6 Palms

As mentioned in Chapter 3, palms are considered to be good bio-indicators for climate change. In total there are around 2,200 species in the palm family distributed in tropical and subtropical regions. Over 264 palms are included as threatened or data deficient in the IUCN Red List representing a partial evaluation of the conservation status of the family. An action plan for the conservation of palms (Johnson, 1996) pointed out the urgency for palm conservation on oceanic islands, particularly those of the Indian Ocean and Southwest Pacific Islands. Likewise, in the Caribbean many of the palm species are under threat. On the island of Haiti, all but three of around 24 native palm taxa are threatened, mainly because of land clearance for agriculture and fuelwood cutting.

6 Ecosystems at risk

Summary

An ecosystem is an array of living things (plants, animals and microbes) and the physical and chemical environment in which they interact. Healthy ecosystems provide the conditions that sustain human life through the provision of a diverse range of ecosystem services. Plant diversity underpins terrestrial ecosystems and they are often described according to the major vegetation type they consist of. Many ecosystems will be highly vulnerable to projected rates and magnitudes of climate change and the services lost through the disappearance or fragmentation of ecosystems will be costly or impossible to replace. Forest ecosystems are particularly important, containing as much as two thirds of all know terrestrial species and storing about 80% of above-ground and 40% of below-ground carbon. Deforestation is a major source of greenhouse gas emissions and contributes to loss of species as well as changes in regional and global climate. Reducing deforestation is therefore one of the most effective ways of reducing greenhouse gas emissions. Ecosystem responses to climate change will be complex and varied. Climatic changes will essentially affect all ecosystem processes but at different rates, magnitudes and directions. Responses will vary from the very short term response of leaf-level photosynthesis to the long-term changes in storage and turnover of soil carbon and nitrogen stocks.

Key points

- Healthy ecosystems provide services essential for human life, including clean air, water and food.
- In the past 50 years humans have altered the earth's ecosystems more than at any other time in our history.
- Devastation caused by extreme weather events is often exacerbated by degraded ecosystems, with untold consequences for human livelihoods.
- Greater diversity is likely to provide ecosystems with greater resilience and ability to respond to climate change.
- Ecosystems are increasingly fragmented and this provides a major constraint to the movement of species under climate change scenarios.
- Conserving ecosystems is an important strategy for conserving plant species diversity.

6.1 What is an ecosystem?

An ecosystem is a natural unit consisting of all plants, animals and micro-organisms in an area functioning together with all of the non-living physical and chemical factors of the environment. Central to the ecosystem concept is the idea that living organisms are continually engaged in a set of relationships with every other element constituting the environment in which they exist. Ecosystems are underpinned by plant life and are commonly described according to the major vegetation type they consist of, such as forests or grasslands.

Healthy ecosystems provide the fundamental life-support services upon which human and animal life depends. As well as providing direct products, such as food and medicine, ecosystems also provide us with services, such as purifying air and water, removing toxins from the environment, mitigating floods, moderating storm surges and stabilising landscapes. The Millennium Ecosystem Assessment (MA), the largest ever assessment of the earth's ecosystems conducted by a research team of over 1,000 scientists, grouped ecosystem services into four broad categories:

- Supporting services, such as nutrient cycling, oxygen production and soil formation. These underpin the provision of the other 'service' categories.
- Provisioning services, such as food, fibre, fuel and water.
- Regulating services, such as climate regulation, water purification and flood protection.
- Cultural services, such as education, recreation, and aesthetic value (MA, 2005).

The findings of the MA concluded that in the past 50 years humans have altered the earth's ecosystems more than at any other time in our history. Land use and habitat change have often resulted in a simplification of ecosystems to increase the economic value of specific services such as food production. Such extensive modifications reduce the capacity of ecosystems to provide a broad range of services, including those related to nutrient cycling and climate moderation. For example, before land is cleared for agricultural use it often contains high volumes of organic matter stored up within its soils. When the natural vegetation is removed, this bank of organic matter slowly starts to deplete, releasing carbon mainly in the form of CO_2, into the atmosphere, thus contributing to GHG emissions.

Box 6.1 Defining the ecosystem

An ecosystem is; "*A functional unit consisting of all the living organisms (plants, animals, and microbes) in a given area, and all the non-living physical and chemical factors of their environment, linked together through nutrient cycling and energy flow. An ecosystem can be of any size—a log, pond, field, forest, or the earth's biosphere—but it always functions as a whole unit*." British Columbia Ministry of Forests and Range, 2008.

The clearing of forest land for agriculture is of particular concern, and it is estimated that tropical deforestation is responsible for as much as 30% of GHG emissions worldwide and is the main source of GHG emissions from many developing countries. Furthermore, as organic matter levels decline, so does soil fertility. As a consequence synthetic fertilisers increasingly have to be applied in order to maintain crop yields. However, nitrogen-fertilised soils emit nitrous oxide (N_2O), a greenhouse gas with more that 200 times the warming potential of CO_2 In addition to its role in climate regulation, the loss of organic matter in the soil also reduces the ability of the land to regulate drought and flood.

Ecosystem responses to climate change will be complex and varied. Climatic changes will essentially affect all ecosystem processes but at different rates, magnitudes and in different directions. Responses will vary from the very short term response of leaf-level photosynthesis to the long-term changes in storage and turnover of soil carbon and nitrogen stocks. Overall however, many ecosystems are likely to be highly vulnerable – and some, such as alpine meadows and mangrove forests may disappear altogether in some places. The services lost through the disappearance or fragmentation of ecosystems will be costly or impossible to replace (Chivian, 2002).

Intact, ecosystems are unique, full species assemblages, self-regulating and balanced. It is believed that a greater degree of species diversity in an ecosystem may contribute to its greater resilience. This is because there are more species present at a location to respond to a factor of change and thus 'absorb' or reduce its effects, thus reducing the impact and delaying a fundamental change to a different state. A disturbance, or change in the system, as may be caused by climate change, is likely to have a disruptive effect on the ecosystem. In some cases, this can lead to ecological collapse or 'trophic cascading' and the death of many species.

We do not yet fully understand the roles and functions played by the many species that make up ecosystems. Further information is needed to understand the consequences of the accelerating loss of species and the actions required to maintain or restore ecosystem services. However, it is clear that the preservation of habitat is an important strategy to save plant diversity and individual plant species.

6.2 Defining priority areas

In the same way that species are assessed according to Red List criteria, ecosystems can be identified as being of particular conservation concern and designated as such. Identifying ecosystems in this way provides easily accessible information on the locations of, and threats to, the best sites for wild plants and their habitats. This information can then be used to ensure that specialists, conservation stakeholders and decision makers have accurate, sound data on which to prioritise national and international conservation projects.

Case study 6.1
Maximum plant biodiversity is best

There is a positive relationship between species richness of vascular plants and terrestrial vertebrates. A study in China looked at 186 nature reserves in China and found that plant richness was a significant predictor of richness patterns for terrestrial vertebrates. This suggests a causal relationship, dependent on trophic links (i.e though food supply) and non-trophic links, such as the effects of plants on the resources that an invertebrate may require (Zhao & Fang, 2006).

Box 6.2 The ecosystem approach and industrial ecology

The 'ecosystem approach' is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use.
It recognizes that humans, with all our cultural diversity, are an integral component of ecosystems, and that ultimately, one relies completely upon the other.
Ecosystem approaches to conservation apply appropriate scientific methodologies focused on levels of biological organisation which encompass the essential processes, functions and interactions among organisms and their environment. This approach blends social and economic needs with physical and biological needs to provide healthy ecosystems where all life can thrive.

Similar to this, 'industrial ecology' is an interdisciplinary field that focuses on the sustainable combination of environment, economy and technology. It is the idea that as natural systems do not have waste in them, we should model our production systems in this way if we want them to be sustainable.

The word 'industrial' does not only refer to industrial complexes but more generally to how humans use natural resources in the production of goods and services. Ecology refers to the concept that our industrial systems should incorporate principles exhibited within natural ecosystems.

Industrial ecology proposes not to see industrial systems (for example a factory or a national or global economy) as being separate from the biosphere, but to consider it as an ecosystem based on infrastructural capital rather than on natural capital. In natural ecosystems, the waste of one species is a resource for another. Therefore in industry, the outputs of one industrial process would be the inputs of another, thus reducing use of raw materials and pollution.

A notable example resides in a Danish industrial park in the city of Kalundborg. Here several linkages of byproducts and waste heat can be found between numerous entities such as a large power plant, an oil refinery, a pharmaceutical plant, a plasterboard factory, an enzyme manufacturer, a waste company and the city itself.

6.2.1 Biodiversity Hotspots

'Hotspots' is a concept developed by Conservation International (CI). To qualify as a Biodiversity Hotspot, a region must contain at least 1,200 vascular plants as endemics and must have lost at least 70% of its original habitat. The diversity of endemic vertebrates in these areas is also extraordinarily high. To date there are 34 biodiversity hotspots globally, holding at least 150,000 plant species as endemics, 50% of the world's total (Conservation International, 2007). In all, 85% of the hotspots' habitat has already been destroyed. Many hotspots are forests and mountains, and these are areas most impacted by, and influential to, climate change. Some models have estimated global-warming induced rates of plant extinctions in global hotspots would exceed those due to deforestation, supporting suggestions that climate change will become one of the most serious threats to biodiversity (Malcolm *et al*., 2006).

6.2.2 Ecoregions

An 'ecoregion' is defined as a large area of land or water that contains a geographically distinct assemblage of natural communities that share a large majority of their species and ecological dynamics, share similar environmental conditions and interact ecologically in ways that are critical for their long-term persistence.

WWF has identified 825 terrestrial ecoregions across the globe, and a set of approximately 450 freshwater ecoregions is under development. Of these, 200 (the Global 200) have been designated the most biologically distinct terrestrial, freshwater, and marine ecoregions of the planet.
The conservation of these areas is a broad-scale approach to develop and implement a comprehensive strategy that conserves the species, habitats, and ecological processes of the ecoregion.

6.2.3 Important Plant Areas (IPAs)

IPAs, defined by Plantlife International, are sites of international significance for the conservation of global plant diversity that are recognised at a national level. They are natural or semi-natural sites exhibiting exceptional botanical richness and/or supporting an outstanding assemblage of rare, threatened and/or endemic plant species and/or vegetation of high botanical value. IPAs are not legal site designations but are a framework for identifying and highlighting the very best sites for plants (and fungi) which can be used to support conservation actions and initiatives. IPAs also provide a unique opportunity to consider the best sites for plants in a broader context, and facilitate the development of landscape scale approaches to conservation that buffer the 'core' of the IPA and address habitat fragmentation issues, of particular significance in a changing climate.

6.2.4 Centres of plant diversity

In the 1990s the IUCN and WWF identified almost 250 priority sites for the conservation of higher plants, first order sights that are of global botanical importance. These areas are also likely to be important genepools of plants of known value to humans or that are potentially useful; sites with a diverse range of habitat types; sites with a significant proportion of species adapted to special soil conditions; and/or threatened or under imminent threat of large-scale devastation.

6.3 Ecosystem types under threat

There are areas where climate change is a massive threat, for example the tropical montane forests of Australia, Mexico and elsewhere in the world (See Case study 6.2), where catastrophic extinctions are predicted and those where it will have less obvious immediate impacts. Further, there are areas where the outcomes of climate change will feed into warming feedbacks more so than others. Below are summaries of how key habitats are being, and will be, impacted by climate change.

6.3.1 Mountains

Because of their altitude, slope and orientation to the sun, mountain regions are highly sensitive to climatic changes and are therefore important indicators of climate change (Mountain Partnership, 2008). As intact ecosystems they are also of critical importance globally, particularly in the provision of water. Montane endemics are particularly vulnerable to climate change because of exceeded temperature tolerances, the upward migration of pioneer species and regionally specific changes, such as reduced cloud water in the tropics.

Thuiller *et al*. (2005) point out that based on their predictive modeling for European plants, an excess of plant species loss is expected for mountain regions (mid-altitude Alps, mid-altitude Pyrenees, central Spain, French Cevennes, Balkans, Carpathians). They note that;

"*Severe climatic conditions have occurred in mountains over evolutionary times, promoting highly specialised species with strong adaptation to the limited opportunities for growth and survival. The narrow habitat tolerances of the mountain flora, in conjunction with marginal habitats for many species, are likely to promote higher rates of species loss for a similar climate anomaly than in any other part of Europe*."

6.3.2 Tundra

The tundra is a treeless polar ecosystem supporting mostly scattered communities of sedges, heaths and dwarf shrubs including some rare, endemic plant species. It is enormously sensitive to changes in climatic variables, in addition to being threatened already by mining, heavy industry and tourism.

Climate change models predict a great reduction in Arctic tundra as forests move (Huntington *et al*., 2000; Moore, 2004). Shifts of the treeline generate strong positive feedbacks to climate systems, via the effects of tree cover on albedo. It is thought that the change in feedback mechanisms will lead to a rapid shift to a new stable state in which the extent of the tundra is reduced (Huntley, 2003). Rising timberlines could trigger much change, and this is apparently already underway in some places.

Alaska for example is seeing changing vegetation patterns. Comparisons of photographs taken from 1948 to 1950 to those taken in 1999 to 2000 of the area between the Brooks Range and the Arctic coast show an increase in shrub abundance in tundra areas, and an increase in the extent and density of spruce forest along the treeline (Sturm *et al*., 2001). The increased vegetation growth is attributed to increasing air temperatures in Alaska, on average 1ºC per decade over the last three decades (Alaska Regional Assessment Group, 1999).

In Russia, researchers have reported that in the Ural Mountains, temperatures have gone up as much as 4ºC during the 20th century and trees have moved 20-80m upslope, reducing alpine zones by 10-30% (Moiseev & Shiyatov, 2003). Similar trends have been widely observed globally, for example in Sweden (Moen *et al*., 2004) and in Canada, where spruces have shifted upward by 50-60m since 1990 (Krajik, 2004).

Whilst treelines are expected to generally move northward this is also effected by other factors, such as topography, so advancement will vary in extent and intensity (Holtmeir & Broll, 2005) and may be hampered because of habitat fragmentation (Honnay *et al*., 2002). Further, some modeling, such as that done with North American tree species, assumes species are in equilibrium when in fact, this may not be the case (Iverson & Prasad, 2001).

6.3.3 Forests

Forests cover a third of the Earth's surface and are estimated to contain as much as two thirds of all known terrestrial species. In the last 8,000 years, about 45% of the Earth's original forest cover has been cleared, mostly during the last century (CBD, 2007a). Living forests 'soak up' CO_2 and store it as biomass and in soils. They are estimated to contain about 80% of above-ground and 40% of below-ground carbon (See Fig. 2.1). Forests thus sequester more carbon than is stored in the atmosphere (Michalak, 2007). Forests are particularly vulnerable to climate change as they are composed of slow-growing, woody species with a limited ability to move in response to changing conditions. In general terms, climate change is likely to reduce the ability of trees to survive where they are and to increase the occurrence of forest dieback. Dead forests cannot soak up CO_2. Moreover, disturbed forests are more vulnerable to pests, invasive species and fire, and burning wood releases once-stored CO_2. In non-fire-adapted ecosystems, burning can have a significant impact on the soil substrata, destroying soil seed banks and impeding subsequent recovery. Once burnt the forest becomes more vulnerable still, as a reduction in forest cover leads to an exponential decline in precipitation, increasing the likelihood of further fire (Mahli & Phillips, 2006), droughts and ultimately desertification. Unstable, disturbed soils release yet more CO_2, equating to the release of billions of tonnes into the atmosphere.

The direct impacts of climate change on forests however are currently dwarfed by the human impacts of rampant deforestation and forest degradation. Today deforestation continues at a rate of around 13 million ha/yr (FAO, 2006) and accounts for up to 30% of total GHG emissions according to some calculations (Woodland Trust, 2005). The conservation of forests is therefore particularly important, offering opportunities to conserve species diversity as well as slowing climate change. In terms of climate mitigation impacts, studies have shown that conservation efforts should particularly be focused on ancient old growth forests, as these store significantly more carbon than young forests (Broadmeadow & Matthews, 2003; Zhou *et al*., 2006). Though young, fast growing forests soak up carbon quickly, old growth forests store substantially more carbon in soils and continue to 'inhale' carbon even when growth has slowed. Converting old growth forests to faster growing young plantations is not therefore an effective method of increasing NPP and CO_2 storage. In fact, carbon storage of young forests does not even approach old growth capacity for at least 200 years (Harmon *et al*., 1990). With respect to their environmental responses, mature forests also have well established root systems and are less sensitive to moisture changes in the short term (Agrawal & Agrawal, 2000).

6.3.4 Peatlands

Peatlands are a particular form of wetland characterised by the underlying accumulation of peat. Peat is undecomposed plant matter that has accumulated over thousands of years. The absence of oxygen in these water-saturated environments mean that decomposition is halted. Intact peatlands thus form vast carbon stores. In their natural state, peatlands are 85-95% water so they are also important because of their ability to store, filter and provide water. The biodiversity found in peatlands is unique and highly adapted.

Peatlands are found in various parts of the world. Examples are the permafrost areas of Russia and Canada and the highlands of the Andes and Himalaya. Other examples of areas endowed with extensive peatlands are the lowlands of humid tropical forests in China and southeast Asia. In these areas peat stores 30 times more carbon than that stored above ground in normal rainforests.

Peat has commonly been used as fuel. Currently for example, peat fuelled powers stations provide 10% of the total energy consumption in Northern Ireland. During the 1960s they accounted for 40% (Environment and Heritage

Case study 6.2 The impacts of climate change on tropical forests

Tropical forests, found near the equator, are massively species rich; containing as much as 50% of all recorded terrestrial biodiversity and as many as 1,000 tree species in one sq km. The Amazon is the world's largest tropical forest, located in nine countries: Brazil, Columbia, Peru, Venezuela, Ecuador, Bolivia, Guyana, Suriname and French Guyana. At least 12% of all flowering plants (around 40,000 species) are found within the Amazon (Hansen & Hiller, 2007) and there are probably thousands of plant species as yet undiscovered. At the country level, based on current knowledge, Brazil has the highest number of forest trees in the world, with 7,800 known species. As a comparison, Canada has approximately 180.

Though there are many different types of tropical forest they are all invariably epicentres of biodiversity and important modulators of climate change. These ecosystems are hugely threatened by logging, cattle ranching for the beef trade, clearance for agriculture and plantations of biodiesel crops. In Brazil and Indonesia alone, 4.9 million hectares of primary forests were lost between 2000 and 2005 (FAO, 2005a).

Cloud forests are montane forests in the humid tropics that are frequently covered in clouds or mist. They are widely recognised as being of exceptional conservation importance, being a centre of high diversity and endemicity for many different groups of organisms (Bubb *et al*., 2004). In Mexico, cloud forests cover less than 1% of the land surface of the country, but are thought to contain about 12% of the country's 30,000 plant species. Some 30% of these species are endemic to the country (Newton, 2007). It is anticipated that cloud forests may be amongst the first ecological casualties of climate change.

In general, the predicted increase in drought stress in the southern hemisphere is likely to have an important impact on tropical forests (Schröter *et al*., 2003). The Amazon basin is predicted to experience an increase of temperature of around 3°C and a decrease in precipitation by around 30% by the end of the century, thus increasing drought stress for Amazon plant species (Mayle *et al*., 2004). In 2005, the government of Brazil declared a state of emergency due to extreme drought conditions, possibly caused by the warming of the Atlantic sea near Africa altering the circulation patterns of air currents (WWF, 2005).

Under certain climate change scenarios, modeling has shown that Amazon rainforests could become a source of CO_2 as warming accelerates plant respiration, forest dieback and loss of soil carbon (Cox *et al*., 2004). Other models of climate change in the Amazon predict that, as well as large-scale forest loss, evergreen forests will be succeeded by mixed forests. Increases in temperature and associated decreases in soil moisture are projected to lead to the expansion of savannah and grasslands, all accelerated by positive feedbacks. Western Amazonia is especially sensitive, with some 43% of plant species predicted to become non-viable by 2095 (Miles *et al*., 2004). Though this is qualitatively understood, it is difficult to estimate the probability of this happening in a real Earth system. However, the science behind the predictions that global warming is increased by carbon cycle feedbacks is solid (Huntingford *et al*., 2008).

Further, many models do not take into account land use changes, such as deforestation, which make it unlikely that tropical forests would be able to migrate to climatically suitable habitats, even if they were able to move over hundreds of kilometres in a relatively short space of time (Hansen & Hiller, 2007).

Service, 2004). Other uses include bedding for livestock, filtration systems and as a growing medium and soil improver for the horticultural industry. In 2001, the UK used 5.4 million cubic metres of (mostly imported) growing media and soil improver; 63% of this was peat.

Peatlands are highly sensitive ecosystems, especially vulnerable to climate changes such as an increase or decrease in rainfall. Human pressures of peat cutting, burning, land use change and overgrazing are very real threats to these ecosystems. On all continents, peatlands are exploited in an unsustainable manner.

The marshy areas of southeast Asia for example used to be covered with millions of hectares of dense lowland rainforest where plant material decomposed very slowly in the soaking wet soil. Over thousands of years, a thick layer of peat was formed, storing the carbon equivalent to 100 years of current global fossil fuel use. Of these forests, only small patches now remain intact and virtually none are unaffected. The global demand for hardwood, paper pulp and palm oil are the driving forces behind the destruction. Areas are drained to enable logging of the swampy rainforest. After clearance, the drainage is intensified to enable commercial production such as for palm oil. Normally, peat is wet and will not burn. Through drainage, the peat dries and starts decomposing and emitting CO_2. In the tropics this process takes place very rapidly and is often accelerated by fires. In Indonesia these fires cover millions of hectares and can last for weeks, sometimes months, burning thick layers of peat over large areas and contributing large amounts of CO_2 to the atmosphere (Wetlands International, 2007).

Case study 6.3 Climate change impacts on boreal forests

Boreal forests, or taiga, are found in northern latitudes throughout Alaska, Canada, Scandinavia and Russia, where temperatures are low.

Predictions of ecological change in boreal Alaska, Canada and Russia have suggested that warming will induce the northern and upslope migration of the treeline and an alteration in the current mosaic structure of boreal forests.

A recent study presents observations of the migration of keystone ecosystems in the upland and lowland treeline of mountainous regions across southern Siberia. Ecological models have also predicted a moisture-stress-related dieback in white spruce trees in Alaska, and current investigations show that as temperatures increase, white spruce tree growth is declining. Additionally, it was suggested that increases in infestation and wildfire disturbance would be catalysts that precipitate the alteration of the current mosaic forest composition. In Siberia, seven of the last nine years have resulted in extreme fire seasons (Hayasaka, 2003) and extreme fire years have also been more frequent in both Alaska and Canada.

Alaska has also experienced extreme and geographically expansive multi-year outbreaks of the spruce beetle, which had been previously limited by the cold, moist environment (Wohlforth, 2002). There is thus substantial evidence throughout the circumboreal region to conclude that the biosphere within the boreal terrestrial environment has already responded to the transient effects of climate change.

Additionally, temperature increases and warming-induced change in these regions are progressing faster than had been predicted in some regions, suggesting a potential non-linear rapid response to changes in climate, as opposed to the predicted slow linear response (Soja *et al*., 2007).

6.3.5 Coasts and seas

Our seas cover 70% of the planet. Thirteen of the world's 20 largest cities are on a coast. In fact, the majority of the world's population lives within 60km of a coastline, a figure that is steadily increasing since coastlines are among the most productive ecosystems on Earth.

Coastal ecosystems include coral reefs, beaches, mangroves, islands and estuaries. They are home to diverse plant and animal communities and provide critical ecosystem services, such as coastal protection, water purification, CO_2 absorption and food security.

However, intact coastal habitats are disappearing rapidly, with rates of loss reportedly four to ten times that of tropical rainforests (Duarte, 2007). Coastal development brings pollution, agricultural runoff and the over exploitation of fisheries. Climate change brings sea-level rise and the submergence of low-level areas, as well as an increase in the frequency and intensity of storms, storm surges and coastal erosion. Decreases in sea ice cover and changes in salinity, wave conditions, ocean circulation and nutrient upswelling can rapidly alter habitats to which species have long been expertly adapted.

In mangroves, plants have developed diverse physiological adaptations to high salinity and tidal inundation. Mangrove ecosystems and thus the species they contain are currently particularly threatened by clearance for logging and by intensive shrimp farming. In terms of climate change, they are increasingly trapped between rising sea levels and a proliferation of human-made barriers, such as dykes and sea defences, designed to stop coastal erosion. Perversely, where mangroves have been destroyed, coastlines are fatally vulnerable to storms and tsunamis, as was the case with the Indian Ocean tsunami in 2004, where sea was able to penetrate far inland. Areas with intact mangroves and dense vegetation were markedly less damaged than areas without (Dahduh-Guebas *et al*., 2005; Danielson *et al*., 2006; Environmental Justice Foundation, 2006).

Similarly, seagrass ecosystems have suffered severe shrinkages in the past 40 years. Seagrasses are underwater flowering plants that often occur in vast meadows and provide nurseries, shelter, and food for a variety of commercially and ecologically important species. Additionally, seagrasses filter estuary and coastal waters of nutrients, contaminants, and sediments and are closely linked to other community types; in the tropics to coral reef systems and mangrove forests, and in temperate waters to salt marshes, kelp forests, and oyster reefs. Seagrasses are threatened by numerous anthropogenic impacts, such as nutrient loading, as well as global climate change (Short *et al*., 2004). Conservative reports of losses since 1980 are of an area equivalent to two football fields every hour. Importantly, these figures are based on only 9% of seagrass meadows that have been studied.

6.3.6 Drylands

Drylands constitute over 40% of the world's surface and are home to one third of the world's population. They constitute ecosystem types such as true desert, savannah and tropical dry forest.

Drylands harbour extremely specialised communities of plants with diverse survival strategies; from trees that can store water in vast, bottle-shaped trunks (*Adansonia* spp., *Commiphora* spp.) to shrubs with small, resin covered leaves (*Laurea* spp.) to CAM plants that accumulate water in the central bud of their fleshy leaves (*Agave* spp.). Since water is a vital and limiting factor, many life forms also exist in ephemeral life stages, dormant for years until suddenly bursting into fruit and reproducing in vast numbers in response to pulses of rain.

Changes in rainfall patterns thus have the potential to impact drylands significantly. The Dashti Kbir desert in Iran has seen a 16% decrease in rainfall per decade from 1976 to 2000; the Atacama desert in Chile an 8% reduction. Conversely, the Gobi desert in China is expected to receive more rain. Drylands fed by melting snow or ice, such as those in the Andean foothills, are also particularly vulnerable to climate change impacts.

As well as climate change impacts, many of these dryland areas face additional severe land degradation, in which marginal areas are turned into wastelands and natural ecosystems are altered through the destruction of surface vegetation, poor management of water resources, inappropriate land use practices, overuse of fertilisers and the disposal of industrial and military waste. For example, about 97% of the remaining area of tropical dry forest is at risk from the above threats (Miles *et al*., 2004). But deserts are not barren wastelands, and because of their slow rates of biological activity they take many decades to recover from even slight damage.

As a result of the vulnerability of these ecosystems, populations of humans in drylands on average lag far behind the rest of the world on well-being and development indicators (MA, 2005). The maintenance of the services delivered by dryland ecosystems (firewood, food, medicine) is therefore critical to halve the number of people living in poverty globally and to help to achieve the Millennium Development Goals (MDGs).

There is a wealth of traditional knowledge in dryland, particularly desert ecosystems, associated with soil and water conservation in exteme conditions. This information has proved useful in modern water conservation techniques in Morocco and Tunisia. Drylands are also important centres of diversity for agricultural crops, both now and for an increasingly arid future.

Finally, dryland ecosystems, particularly deserts, are linked to other ecosystems in suprising ways. For example, about 40 million tons of dust are transported annually from the Sahara to the Amazon basin, making Saharan dust one of the main mineral sources that fertilise the Amazon basin. Research has shown that about half of the annual dust supply to the Amazon basin is emitted from a single source: the Bodélé depression located northeast of Lake Chad in Africa, approximately 0.5% of the size of the Amazon or 0.2% of the Sahara. Located in a narrow path between two mountain chains that direct and accelerate the surface winds over the depression, the Bodélé emits on average more than 0.7 million tons of dust per day (Koren *et al*., 2006).

6.3.7. Grasslands and prairies

Grassland ecosystems exist on every continent and provide a wide range of goods and services for human kind. They are home to many food grains, such as wheat, maize, rice, millet and sorghum and remain the primary source of genetic resources for improving these and other important crops. They also supply forage for domestic livestock, rangelands for wild herbivores and provide habitat for breeding, migrating, and wintering birds. Grasslands also help to build and stabilise soil and serve as large storehouses for carbon. However today many grasslands are better characterized as ‘fragments’ rather than as ‘vast expanses’. Increasingly, roads interrupt grasslands, breaking large tracts into pieces, and invasive species and human-induced fires change grassland composition and extent (White *et al*., 2000).

Conversion to agricultural land has caused the greatest loss of the world’s grasslands. The effects of this conversion can be dramatic as native vegetation is removed and replaced with farm crops, soil is exposed and becomes vulnerable to wind and water erosion and the use of fertilisers and pesticides changes soil composition and water-holding capacity, reducing the moisture available for plants and animals.

The major impact of climate change on grasslands is likely to be the loss of species diversity, diminishing the ability of the grasslands to support grazing animals and other wildlife. This effect has been proven in experimental trials carried out in the USA where a multi-year experiment was carried out to demonstrate how grassland ecosystems would respond to predicted increases in temperature and precipitation caused by global warming. Researchers found that exposing open grasslands to increased levels of CO_2 for three years caused a nearly 20% reduction in wildflower species and an 8% decline in plant diversity overall. The addition of excess nitrogen and other predicted climate changes caused diversity to plunge even further. The study also revealed that wildflowers were much more sensitive to the treatments than grasses, regardless of the combination of treatments applied (Zavaleta *et al*., 2003).

7 Linkages between climate change, plants and livelihoods

Summary

Agroecosystems face many of the same threats from climate change as species in natural ecosystems, including the spread of diseases, pests and invasive species and problems adapting to new extremes in temperature and rainfall. Ecosystems managed for agriculture are dependant on the goods and services provided by natural ecosystems. As with natural ecosystems, the key to adaptation is maintaining genetic diversity and it is crucial to conserve crop diversity and crop wild relatives to meet the needs of agricultural breeding programmes. Biofuels have been touted as one way to reduce greenhouse gas emissions but they are far from a panacea. Increased biofuel production may drive up food costs for many staple foods, including maize, decreasing food security. Even if non-food crops are used for biofuels, the carbon footprint of fuel production can be significant if intact plant communities are cleared for plant production. Many of the world's poor depend directly on harvesting non-timber forest products, edible, medicinal and aromatic plants for livelihoods and sustenance. With increasing human pressure and loss of natural vegetation, many of these species are under threat. Climate change will further threaten these species and, as a consequence, the people who depend on them.

Key points

- Plants are the basis of global food production. While a mere 30 crops are often stated to 'feed the world', in fact over 7,000 plant species are actually utilised in food and agriculture. Plants also underpin the world's grazing systems and support all livestock production.
- The negative impacts of climate change on agriculture (reductions in yield, shifting crop growing zones, increased pests and diseases) are likely to be most severe in tropical Africa and south Asia, where an additional 75 million people or more could become at risk of hunger. The most food-insecure people will be those most affected by climate change.
- Loss of plant diversity in farming systems means loss of capacity for adaptive responses, making farmers more vulnerable to change, including climate irregularity and extreme events.
- Crop Wild Relatives hold the key for developing new varieties with enhanced climate tolerance. However, models have shown that many CWR are in danger of extinction due to climate change.
- 80% of the world's population rely on traditional medicine – largely based on plants – for their primary healthcare. The international trade in medicinal plants is estimated to be worth US$60 billion per year. Understanding the impacts of climate change on medicinal plants is therefore clearly necessary in the context of sustainable development and health planning, as well as biodiversity conservation.
- A destructive cycle already exists between poverty and environmental degradation in many developing countries. Plant species losses due to climate change will exacerbate this, depriving millions of people of important livelihood resources.
- Well-managed carbon forestry projects provide opportunities for local communities to benefit, while at the same time restoring degraded land and storing carbon.

7.1 Ecosystems and livelihoods

As discussed in Chapter 6, plant diversity is a major pre-requisite for healthy ecosystems which provide the conditions and processes that sustain all life. Ecosystems purify air and water, mitigate floods, moderate storm surges and stabilise landscapes. As the frequency of extreme weather events increases with climate change, these latter services will become of growing importance to humankind. Salt marshes and mangrove forests buffer the coastline against ocean storms, while forests and grasslands provide natural protection for soils against erosion.

As well as providing essential ecosystem services, plants also underpin the livelihoods of billions of people, be it directly or indirectly, through the provision of food, medicine, fibres and many other materials essential for their daily lives. In developing countries, 2.5 billion people depend on agriculture for their livelihoods and activities *directly* based on plants contribute approximately 75% to the GDP of many of these countries (Nkem *et al*., 2007). Furthermore, the livelihoods of some 1.6 billion people depend heavily on forest resources, while 80% of the world's population rely on traditional medicine – largely based on plants – for their primary healthcare. Human welfare is thus intimately linked with plant diversity.

Case study 7.1
Deforestation and mudslides

Hurricane Mitch, one of the most powerful hurricanes on record in the Atlantic basin, stalled off the coast of Honduras in October 1998, in some places dropping up to 60cm of rain in one six-hour period. The resulting flooding and mudslides killed over 10,000 people. Many of the deadly mudslides occurred in areas where forests had been cleared for agriculture (Chivian, 2002).

Case study 7.2 Mangroves and tsunamis

On 26 December 2004 a devastating tsunami hit the coasts of south and southeast Asia, causing the deaths of over 200,000 people and enormous environmental damage. Assessments later indicated that areas with a relatively intact, natural shoreline were in some cases less affected by the tsunami. Reefs and mangroves can absorb at least 70-90% of the energy of wind generated waves. The tsunami devastation emphasized the strong link between natural coastal ecosystems and human livelihoods (UNEP-WCMC, 2006).

7.2 Impacts of climate change on agriculture

Plants of course form the basis of agricultural food production, with global dependence on a relatively few major crops. However, while it is often stated that only 30 crops 'feed the world', it is estimated that about 30,000 species are edible and about 7,000 have been cultivated or collected by humans for food at one time or another (Wilson, 1992) Thus several thousand species may be considered to contribute to food security. Furthermore, plants form the basis of all grazing systems and thus also underpin the world's livestock industry.

Wild plant species are also important both nutritionally and culturally to many people, especially the rural poor. Wild plants provide an important source of vitamins, minerals and other nutrients that complement the staple foods eaten by many of the world's vulnerable people, including children and the elderly. They are particularly important during periods of famine, and during the hunger season that precedes crop harvests. Wild plants may also represent a ready source of income for cash-poor households and may provide a significant portion of total household income, particularly where farming is marginal.

Although the number of plant species that supply most of the world's energy and protein is relatively small (30 crops provide 90% of the world's calorie intake), the diversity within such species is often large. Estimates of the number of distinct varieties of the rice species *Oryza sativa*, range from tens of thousands to more than 100,000. At least eight different vegetables derive from the single wild cabbage species *Brassica oleracea* (broccoli, Brussels sprouts, cabbage, calabrese, cauliflower, kale, kohlrabi and savoy cabbage). Genetic variation also exists within these vegetables and numerous different varieties of each can be found (FAO, 1998). Human food security is thus dependant on both a wide range of different plant species and a wide diversity within these species. However, much of this diversity is under threat due to the intensification of agriculture, with a focus on a limited number of crops and varieties, as well as increasing pressures (including those of climate change) on wild plant populations. Recognition that it is this range of diversity that will provide the basis for adaptation in farming systems as climates change may provide the necessary incentive to ensure its conservation for the future.

One of the landmark achievements of the 20th century was the successful expansion of food production to keep pace with growing demand caused by population increase and rising incomes, the so-called 'Green Revolution'. As these two factors continue to push demand upwards, the Food and Agriculture Organization (FAO) estimates that the world will require about 50% more food by 2030, as compared to 1998 (FAO, 2005b). Climate change will be an important factor in determining whether this can be achieved, and at what cost.

Generally, climate change will influence crop production by:

- shifting optimal crop growing zones;
- shifting the habitats of crop pests and diseases;
- affecting crop yields through the effects of carbon dioxide and temperature;
- reducing cropland through sea-level rise and vulnerability to flooding.

"*In the long list of potential damages from global warming, the risk to world agriculture stands out as among the most important*" Cline, 2007.

- Climate change will affect crop yields, as well as the types of crops that can be grown in certain areas, by impacting agricultural inputs such as water for irrigation, amounts of solar radiation and the prevalence of pests.
- Unpredictable and changing weather patterns are likely to affect agricultural productivity in different ways in different areas. The overall impact of climate change effects will vary according to elevation, soil type, crop and other local factors. This variability, along with the uncertainties of very long-term climate forecasting (especially at the regional level) makes discussion of the effects of climate change on crop production tentative. Generalisations can usually only indicate ranges of possible scenarios.
- For many tropical zones, there may be increased rainfall variability, increased incidence of extreme weather events, and reduced crop yields. Improvements in crops, techniques of cultivation, and soil and water management may be able to compensate, but increasing food production in these zones will be made that much harder (FAO, 2002).
- An increasing number of studies show that it is in tropical developing regions of Africa and south Asia where the negative impacts of climate change on crop production will be most severe. Some of the higher vulnerability of these areas can be attributed to the environmental conditions, where crops are grown close to their limits of heat tolerance or moisture availability. Some however, reflects the lower adaptive capacity in socio-economic systems of countries in these regions.
- Models developed in 1999 (Parry *et al*.), and more recently in 2008 (Lobell *et al*., 2008) indicate that sub-Saharan Africa is particularly likely to experience marked reductions in yield of the dominant crops, sorghum and maize, as well as a marked reduction in the area suitable for the production of staple cereal crops (Fischer *et al*., 2002; Lane & Jarvis, 2007). By 2030, it is projected that production of maize in southern Africa is likely to be reduced by 30%. This crop is the most important source of calories for the poor in this region.
- In south Asia, where roughly one third of the world's malnourished live, several key crops, including wheat, rice, rapeseed, millet and maize, have more than a 75% chance of incurring losses from climate change.
- As a result of the above, an estimated 75 million or more additional people could be at risk of hunger (UNEP, 2006). It is particularly worrying that the most food-insecure areas will be those most affected by climate change.

- There may be benefits for agriculture in many temperate zones, where the length of the growing period will increase, costs of over-wintering livestock will fall, crop yields may improve and forests may grow faster (UNEP, 2006).

7.2.1 Changing areas suitable for crop production

The distributions of temperature and rainfall during the year are key factors in making decisions regarding what crops are grown where. As these factors change, changes in patterns of crop distribution will be required.

There is little doubt that, as the world heats up, some areas will experience an increase in the area of land suitable for agriculture, for example in sparsely populated areas of Canada and Russia (Epstein & Mills, 2006).

Although soil types in the new climactic zones may not always be suitable for intensive agriculture as currently practiced in the main producer countries (STOA, 1998) there may also be related gains. In Iceland for example, improved grassland may be able to carry 2.5 times as many sheep as at present (Chaudary *et al*., 2007). However, it is availability of water, rather than temperature, that is often the most important factor for agriculture, and decreasing rain, or unpredictability of the timing of rainfall, is likely to be a major limiting factor, especially in the arid and semi-arid regions of the world.

Recent studies have looked at the predicted suitability of areas for the production of some of the world's major crops. The results of one show that crops likely to suffer significant decreases in suitable areas for their cultivation are typically cold weather crops, including wheat (18% decrease) rye (16%) apple (12%) and oats (12%). Some 20 of the crops studied gain in suitable area. The biggest gains are in areas suitable for pearl millet (31% gain) sunflower (18%) common millet (16%) chick pea (15%) and soya bean (14%) (Lane & Jarvis, 2007).

However, many of these gains will occur in regions where these crops are not presently an integral component of the farming systems. For example, the land area suitable for pearl millet is projected to increase by over 10% in Europe and the Caribbean, where it is not widely consumed, but not in Africa where it is widely cultivated.

7.2.2 Effect on crop yield and quality

Earlier views that elevated CO_2 would boost the productivity of agricultural crops and make up for potential losses due to lack of water now appear to be unfounded. Theoretically, for C3 plants such as wheat, rice and soyabean, doubled CO_2 levels result in an increase in productivity. However, studies have shown that the benefit of increased CO_2 concentration on crop growth and yield does not always overcome the negative effects of excessive heat and drought and that the increase in productivity levels out as plants acclimatise. Further, increasing CO_2 concentration has a limited effect on C4 plants, which include maize, sorghum, sugar-cane, millet and many pasture species.

Case study 7.3 Rice yield decline with higher night time temperatures

Looking at weather data from 1979 to 2003 at the International Rice Research Institute in the Philippines, the annual mean maximum and minimum temperatures have increased by 0.35°C and 1.13°C respectively. There is a close link between rice grain yield and mean minimum (i.e. night) temperature during the dry cropping season, so much so that grain yield declined by 10% for each 1°C increase in growing season minimum temperature (Peng *et al*., 2004).

Rice is one of the world's most important food crops. It provides 27% of the energy intake and 20% of dietary protein for people in the developing world. Three of the world's four most populous nations use rice as their staple food - China, India and Indonesia. Together, these countries have 2.5 billion people.

Case study 7.4 Impact of climate change on coffee production

Coffee is the first, second or third largest export crop for 26 mostly poor countries in Africa and Central America. Yet coffee is sensitive to changes in average temperatures. In Uganda, the total area suitable for growing Robusta coffee would be dramatically reduced with a temperature increase of 2°C. Only higher areas would remain productive, the rest would become too hot to grow coffee.

Over 500,000 farm households in Uganda depend on coffee for their livelihoods and in 2006/7 Uganda earned US$170 million through sales of coffee (UNEP, 2007c).

As discussed in Chapter 2, plants that do grow larger in response to increasing CO_2 will require more nutrients and this is likely to have a negative impact on long-term soil quality. Further, increased growth is not accompanied by a relative increase in nutritional value, therefore those dependant on such plants as a primary food source, be they humans, animals or insect pests, will need to consume more for the same benefit.

For cereal crops in mid-latitudes, potential yields are projected to increase for small increases in temperature (2-3°C) but decrease for temperature rises larger than this (IPCC, 2001b). For crops such as cereals, oilseeds and protein crops that rely on temperature and day length to reach maturity, temperature increase may actually result in a shortening of the length of the growing period. In the absence of compensatory management responses, this can result in reduced yield.

In most tropical and subtropical regions potential yields are projected to decrease for most increases in temperature as crops in these areas are already near their maximum temperature tolerance. Where increases in temperature are also associated with reduction in rainfall, losses are likely to be even higher, as water stress during flowering, pollination and grain-filling stages is known to depress yields in maize, soybean, wheat and sorghum (Epstein & Mills, 2006). There have been predictions that by 2020 all of Africa will have a crop reduction ranging from 10-20%.

Projected increases in extreme weather events, such as droughts, floods and storms could result in widespread crop damage and significant land degradation. In fact, droughts and floods already rank as the single most common cause of severe food shortages in developing countries (FAO, 2005b). The Sahel region of Africa, for example, has suffered several prolonged, severe droughts since the late 1960s. This has led to decline in forest species richness, tree density and human carrying capacity (Rosenzweig & Hillel, 2004). Extreme events, so called 'natural disasters', have the potential to do enormous, lasting damage in a short period of time.

Climate-induced drought may have other effects beside increased food insecurity. For example, drought in the Horn of Africa is driving a large part of the population into areas that are more at risk of flooding (Yahia, 2008).

7.2.3 Invasive alien species

As discussed in Chapter 4, invasive alien species are increasingly seen as a threat not only to biodiversity and ecosystem services, but also to economic development and human well-being. As well as affecting wider biodiversity, they also reduce the effectiveness of development investments by choking irrigation canals, fouling industrial pipelines and impeding hydroelectric facilities. Invasive species therefore contribute to social instability and economic hardship, placing constraints on sustainable development, economic growth, poverty alleviation and food security (CABI, 2007). Moreover, the spread of invasive species has increased alongside global trade and is likely to be further exacerbated by climate change.

Globally, the cost of damage caused by invasive species has been estimated to be US$1 trillion per year, close to 5% of global GDP (CABI, 2007). In developing countries, where agriculture accounts for a higher proportion of GDP, the negative impact of invasive species on food security as well as on economic performance can be even greater. Invasive species may affect the productive capacity of the land. Weeding increases agricultural labour time. Combined, these impacts affect human well-being by threatening the availability of food as well as reducing the time people have for recreation and other non-work activities.

7.2.4 Interactions with pollinators, pests and diseases

Also discussed in Chapter 4, climate-induced phenological changes are particularly important where there are closely coupled relationships between species, as in the case of

Case study 7.5 Agriculture and climate change in India

The agriculture sector represents 35% of India's Gross National Product (GNP) and as such plays a crucial role in the country's economy. Negative impacts on agriculture could result in problems with food security and threaten the livelihood activities upon which much of the population depends. The Indian Agricultural Research Institute examined the vulnerability of agricultural production to climate change using a variety of crop growth models. The predicted changes vary greatly by region and crop. Findings for wheat and rice were:

Wheat:
- Increases in temperature (by around 2°C) would reduce potential grain yields in most places. The reduction in yield is likely to be less in northern areas.
- There will be boundary changes in areas suitable for the crop.
- Reductions in yield are likely to be more pronounced for rain-fed crops and under limited water supply situations because there are no coping mechanisms for rainfall variability.
- The difference in yield is influenced by baseline climate. In sub-tropical environments, the decrease in potential wheat yields ranged from 1.5-5.8%, while in tropical areas the decrease was relatively higher, suggesting that warmer regions can expect greater crop losses.

Rice:
- Overall, temperature increases are predicted to reduce rice yields. An increase of 2-4°C is predicted to result in a reduction in yields.
- Eastern regions are predicted to be most impacted by increased temperatures resulting in relatively fewer grains and shorter grain-filling durations.
- In northern India, potential reductions in yield are predicted to be offset by higher radiation, lessening the impact of climate change (Defra, 2005).

Case study 7.6 Invasive species' impacts on agriculture

Some invasive species transform grasslands that support grazing. For example, *Lantana camara* poisons cattle and destroys understorey species. The tree, which is seedy and thornless, can form dense thickets. It is difficult to eradicate once established, making extensive areas unusable and inaccessible, and threatening native plants.

A detailed modeling study of climate change impacts on Namibian biodiversity and ecosystems was conducted by the South African National Botanical Institute (SANBI) for Namibia in 2003. The SANBI study projected significant additional bush encroachment of the savannah under climate change, and an expansion of Nama Karoo-type (dwarf shrubland) habitat. This would severely compromise livestock production, one of Namibia's main livelihood sectors, and put pressure on the ecology of marginal farming areas.

Similiarly, the Triffid weed (*Chromolaena odorata*), a plant native to the Americas has severely impacted natural areas in Africa and reduces crop productivity in agriculture and grazing. In Ghana the weed occupies 59% of all arable lands, and in Ubombo, South Africa it reduces the grazing capacity of grasslands significantly (UNEP, 2007b).

many plant-pollinator relationships. Pollinators such as bees, birds and bats affect 35% of the world's crop production, increasing the output of 87 of the leading food crops worldwide (Klein *et al*., 2007). Food security, food diversity, human nutrition and food prices all rely strongly on animal pollinators, which in turn depend on healthy natural ecosystems.

Pollinators will largely respond to changing climatic conditions by contracting or expanding their ranges. Thus the possibility of crops losing key pollinating species, or mismatches in the ranges of crops and their pollinators, is a real threat.

This is particularly true in the case of horticultural crops. Diversification into horticultural crops is becoming an avenue to poverty alleviation amongst many farmers around the world. The trade in horticultural crops accounts for over 20% of developing countries' agricultural exports, more than double that of cereal crops (Lumpkin *et al*., 2006). Unlike the historical increase in cereal production, the expansion of production in fruits and vegetables has come primarily from increases in the area cropped, not from yield increases. The consequences of pollinator declines are likely to impact the

Case study 7.7 Seed production in India

Climate change effects have already been felt in the seed industry of India. Since seed production requires a certain degree of chilling to induce seed formation in temperate crops, many vegetable seed farms are located in mountainous regions, such as the Hindu-Kush Himalayas. While mountainous regions can provide such a climate, they also make farmers increasingly vulnerable to the effects of climate change. Farmers in the Kullu valley of Himachal Pradesh are finding that overall temperature rise combined with increasingly unpredictable rains have led to several crop failures. Whilst vegetable seed yields decrease, the challenge of ensuring sufficient natural pollination under changing climatic conditions has not yet been adequately addressed by researchers, much less farming communities (Sharma, 2006).

production and costs of vitamin-rich crops like fruits and vegetables, leading to increasingly unbalanced diets and health problems.

Climate change is also likely to have a major impact on pest and disease incidence, with milder winters resulting in greater winter survival and warmer weather stimulating longer active periods. Further, as climates shift and pathogens change their range, diseases and pests may enter novel areas with unpredictable consequences.

7.3 So what does this mean?

Climate change is likely to affect crop production in countries very differently. Production in developed countries, with relatively stable populations, may increase, whereas in many developing countries, which have rapidly growing populations, food production is likely to decline, resulting in increasing hunger and malnutrition for millions of people.

Agriculture is also the main source of employment in many developing countries. With changing climate, agricultural regions may shift, but people will tend to migrate to places where they can continue to find employment in agriculture. With pressures of rising populations, such movement is likely to be increasingly difficult and may result in large numbers of environmental refugees. In much of sub-Saharan Africa, Central and South America, and Southeast Asia, where unused land reserves still exist under forest cover, many farming families displaced by climate change or flooding may try to find new land. In such cases, deforestation rates could increase and encroachment and poaching in national parks would grow.

Case study 7.8 Impact of climate change on pests in agriculture

In Scotland, the mild winter of 2006/2007 led to very early flights of peach-potato aphid (*Myzus persicae*) and potato aphid (*Macrosiphum euphorbiae*), with many crops of potatoes infested with aphids as soon as they emerged. This increased the threat of virus transmission by aphids into seed potato crops and consequently required aphicide treatments from crop emergence onwards.

The threat from pests not yet in the UK is increased as the Scottish climate becomes more suitable for these pests to survive and breed. For example, the climate in some areas of Scotland could be suitable for survival of Colorado potato beetles as early as 2020, should it be introduced into Scotland. New pest problems already arising in Scottish crops are cabbage stem flea beetle and rape winter stem weevil in winter oilseed rape, and orange wheat blossom midge in cereals.

Other pests have already been introduced into the UK and have established themselves. Turnip sawfly for example was eradicated from the UK but has re-established and caused serious damage to winter oilseed rape in the autumn of 2006. By 2050 it is likely to have spread from central, southern and eastern counties of England to the eastern and central areas of Scotland.

Some pests such as wheat bulb fly will decrease in severity, as the wetter winters will lead to a higher level of winter kill, making areas where the pest is currently endemic unsuitable for its survival. This increase in winter rainfall will make the north and west of Scotland the most favourable for the survival of grey field slugs, as summer rainfall will not change much. However, the reduction in summer rainfall in the east of Scotland will not favour slugs (Scottish Agricutural College, 2008).

7.4 Adapting agriculture to climate change

It has been predicted that if global temperatures do not increase more than 4ºC over the next century, arable agricultural production can probably adapt using breeding, selection and management (Porter *et al*., 2007). However, it is clear that there is an urgent need for plant breeders to focus on breeding for drought and heat tolerance, rather than producing varieties with increased pest and disease resistance, as has been the trend in the past.

7.4.1 Traditional faming systems

In traditional farming systems, as a result of centuries of observation and selective breeding, farmers have identified and maintained traditional varieties that are well adapted to local environmental conditions. Agricultural diversity at variety, species and farming system level can be manipulated to combat the abiotic and biotic stresses associated with environmental uncertainty. For example, farmers often exploit inter-varietal diversity to reduce susceptibility to disease. This maintenance of diversity in production systems means that traditional farming systems often prove more flexible in the face of unpredictable conditions, and are thus likely to be better able to adapt to climate change.
At a farm level, diversity in species, varieties and practices has aided agriculture to withstand moderate change in climate over the 10,000 years that it has been practiced by humans. Traditional knowledge combined with new knowledge from agricultural research has increased the capacity to deal with recurrent disturbances such as pests and climate change (Tengo & Belfrage, 2004). In the East African Highlands, for example, farmers choose banana cultivars predominantly for their resistance to pests and diseases (Karamura *et al*., 2003). In the same region, disease resistance is also a major criterion in selection of varieties of *Phaseolus* beans (Trutmann *et al*., 1993).
It is therefore important that traditional crop varieties are maintained in farming systems and that indigenous and local knowledge is conserved, documented and allowed to continue developing.

7.4.2 Crop Wild Relatives (CWR)

The wild plants related to modern crops harbour an extensive array of genes resistant to a wide variety of biotic and abiotic stresses. CWR have been used for crop improvement for over 100 years (Plucknett *et al*., 1987). They have saved the agricultural industry millions of dollars by increasing crop tolerance to pests and diseases and developing abiotic stress tolerances, such as to water stress and soil salinity and acidity.

Using CWR in breeding should allow development of new varieties with enhanced climate tolerance. However, it is also important that improved varieties are adapted to low-input cultivation so that they can be used by resource-poor farmers without the need for inputs that are scarce (such as water) or costly and environmentally damaging (such as herbicides and pesticides) (Jarvis *et al*., 2007).

It is worrying that the very CWR that may provide the key to improving climate tolerance of cultivated species, are themselves are in danger of extinction due to climate change. Jarvis *et al*., (2008) found that up to 61% of wild peanut species (*Arachis*), 12% of potato species (*Solanum*) and 8% of cowpea species (*Vigna*) could become extinct within 50 years.

The significance of loss of the CWR lies not only in the loss of potentially important genes for breeding programmes, but also in the loss of species that may themselves also be

Case study 7.9 Crop Wild Relative breeding for climatic tolerances

Use of CWR for breeding for tolerance to abiotic stresses is less common than for biotic stresses (Hajaar & Hodgkin, 2007) but some notable examples include wild tomatoes (*Lycopersicon chilense* and *L. pennellii*), which have been used to increase drought and salinity tolerance (Rick & Chetelat, 1995). *Oryza rufipogon* genes have been exploited for tolerance to soils with high acidic-sulfate content in Vietnam (Nguyen *et al*., 2003), and *O. longistaminata* genes for drought tolerance (Brar, 2005).

important for agricultural production. This is the case for some wild potato and peanut species that are likely to be severely affected by climate change. Similarly a number of wild *Vigna* species (Cowpea) that contribute to food security are under threat. The tubers of *V. adenantha*, and *V. stenophylla* and the fruit and seeds of *V. junceum* are consumed by people (Padulosi & Ng, 1990).

Potatoes, peanuts and cowpeas are all important crops for small-holder farmers throughout the developing countries of the tropics. The loss of wild species and associated genetic diversity of these and other crops could have profound and disproportionate economic and social consequences for these farmers.

Conservation of CWR and traditional varieties is therefore critical to ensure that genetic diversity is available to meet the demands of agricultural production under unpredictable climatic conditions, and to continue to provide food and income to local people, especially between harvests and during times of climate uncertainty.

7.5 Biofuel production and livelihood implications

Biofuels, including bioethanol, biodiesel and biogas, are renewable fuels generally produced from agricultural crops or organic matter such as livestock waste.

7.5.1 The rise of biofuels

Rising oil prices, climate change and development concerns are causing countries around the world to increase their demand for biofuels. Some countries have even started setting targets for future use, with the European Union (EU) for example, ordering its member states to ensure that by 2020, 10% of the petroleum used by cars is replaced with biofuels. In response to this demand, global ethanol fuel production (over 90% of total biofuel production) more than doubled between 2000 and 2005 and global biodiesel production nearly quadrupled in the same period (Msangi, 2007).

The high demand for biofuel provides a market opportunity for developing countries in the South, with its available natural resources. It is clear that the opportunity to diversify and participate in new markets can result in social and rural development, increased employment, income generation, infrastructure and training, and the development of human resources and skills capacity. Because of these economic benefits, many countries are rapidly developing their biofuel production capacity. In Africa for example, in 2007, ministers responsible for energy development announced a commitment to increase research into the development of renewable energy, most notably biofuels. Nigeria aims to produce cassava ethanol worth over US$150 million every year, once it establishes a suitable infrastructure. This includes construction of 15 ethanol plants with assistance from Brazil, who produced 33% of the world's biofuel ethanol by the end of 2007 (SciDev., 2007).

7.5.2 The risks of biofuels

Biofuel production also poses new food security risks and challenges, as well as having the potential for untold environmental degradation.

There is the worry that an increase in the use of food crops such as maize, cassava and sorghum for biofuels will increase the food price of most staple foods in Africa, notably maize. Price rises are also likely to be determined by whether or not

Case study 7.10 Palm oil

High in vitamin A and magnesium, palm oil from the species *Elaeis guineensis* has recently replaced soy as the world's leading edible oil. 90% of the world's palm oil exports are produced in Malaysia and Indonesia. The development of the oil palm industry has brought economic benefits to both of these countries. However, palm oil is now starting to be used as an ingredient in biodiesel and as a fuel to be burnt in power stations to produce electricity. This is a new market for palm oil and is a trend that has the potential to dramatically increase global demand for this commodity.

In Indonesia over 100 million people depend upon access to rainforest resources for their survival, but the development of oil palm plantations is causing massive rainforest clearance. A recent report suggests that palm oil plantations are responsible for 87% of deforestation in Malaysia, and forest fires - the quickest and cheapest method of clearing trees - are often started by palm growers. Moreover, forest land that is allocated for clearing, in order to make way for oil palm plantations, is frequently left abandoned and undeveloped once the valuable trees have been removed (New Agriculturalist, 2006).

oil crops are planted on arable land that could otherwise be used for growing food crops, and whether water is diverted from food crops to irrigate the biofuel plantations. Increasing crop prices go hand-in-hand with decreasing availability of (and access to) food. Poor people spend a much bigger share of their budgets on food than they do on energy (about 50-70% on food and 1-10% on energy). With high prices, they will likely spend less on food, exacerbating poor diets and malnutrition. Further, since the biofuel industry requires economies of scale, it usually bypasses smallholder farmers who cannot grow enough of the main biofuel crops. While the use of crop residues for energy purposes, rather than the crop itself, may reduce objections to growing crops for fuel instead of for food, removing crop residues can increase the rate of soil erosion many-fold (Palmer *et al*., 2007).

Not least of the objections to the widespread replacement of oil with biofuels are issues surrounding environmental degradation where land is cleared for conversion to biofuel plantations. Putting millions of hectares of land under intensive agriculture to produce biofuels causes habitat and biodiversity loss, upsets water supplies and disrupts the soil balance. Further, if biofuel crops are grown with the use of fertiliser, they have the potential to add significantly to the nutrient overload in the biosphere that already contributes to increased GHGs (N_2O) and pollutants (NO_x). A recent study suggests that microbes convert much more of the nitrogen in fertiliser to N_2O than previously thought - 3-5% or twice the widely accepted figure of 2% used by the IPCC. For rapeseed biodiesel, which accounts for about 80% of the biofuel production in Europe, the relative warming due to N_2O emissions is estimated at 1-1.7 times larger than the quasi-cooling effect due to saved fossil CO_2 emissions (Crutzen *et al*., 2007).

In its draft directive, the EU has ruled that biofuels should not be produced by destroying primary forest, ancient grasslands or wetlands, as this could cause a net increase in GHG emissions. Nor should any biodiverse ecosystem be damaged to grow biofuels. However, if biofuels can't be produced in virgin habitats, they must be confined to existing agricultural land, which in turn, will increase the price of food, and put further pressure on the use of protected and fragile landscapes for food production.

Allowing natural vegetation to regrow instead of planting biofuel crops could reduce GHG emissions from the soil and stress on water resources, while also creating wildlife habitats and corridors, allowing species to migrate in response to climate change. It may be that a greater contribution to climate change mitigation could be made by restoring land to original vegetation than by growing energy crops (Biofuel Watch, 2007).

7.5.3 Second generation biofuels

To address these issues, research is ongoing on the development of second generation biofuel crops, focusing on high biomass, non-food species that can be grown in degraded and saline environments that are unsuitable for crop production. Such plants provide the opportunity to use previously abandoned areas for economically productive purposes, while at the same time helping to restore degraded soils. Further, once cellulose conversion technology has been further developed (production of ethanol from cellulose rather than plant sugars) production of liquid fuels from a wide variety of agricultural biomass, including wood chips, grasses, crop residues and seaweed should be possible.

Case Study 7.11 Biodiesel and the Amazon

The Brazilian Amazon has been decimated by a combination of loggers, farmers and ranchers over the last 40 years. Environmentalists say as much as 20% of the rainforest has already been destroyed, mostly since the 1970s. After three years of reduced deforestation, levels have recently risen sharply again. Subsidies for biofuel crops in the USA have encouraged farmers to switch from soya to maize to produce ethanol. This has increased the world soya price and encouraged Brazilian farmers to clear forests for soya farms and buy-up large expanses of cattle pasture. This has pushed ranchers further into the Amazon and made cattle food more costly, creating another incentive for forest conversion to pasture. Scientists have warned that 40% of the Amazon could be lost by 2050 if these trends continue (Soares-Filho *et al*., 2006).

Case Study 7.12 Bioenergy and floodplain restoration in Hungary

Contrary to the negative press about the potential environmental and social impacts of bionergy, this new sector can provide surprising solutions for nature conservation, as illustrated by a pilot restoration project in Hungary's Tisa floodplain.

Invasive species are a particular problem for these restoration efforts – the most aggressive one being false indigo (*Amorpha fructicosa*), a fast-growing shrub from North America. Removal of this invasive has been quite costly as it requires the use of heavy machinery to harvest the false indigo several times a year for more than a year. However, its suitability for bioenergy production (once dried, it burns well) has meant that the local power plant is willing to buy the biomass as fuel and the funds generated have been used to help finance the eradication work. Ideally, once the land is cleared of the invasive, the traditional extensive land-uses, including floodplain forests with native species, can be reintroduced as sustainable, diverse sources of local livelihoods (Vaszkó, 2007).

7.5.4 Issues to be addressed

In weighing up the pros and cons of planting biofuel crops, the following points should be taken into account:

- A comparison of the CO_2 and N_2O emissions saved if the same land were left under natural cover or restored to natural vegetation;
- Negative impacts on ancient forests or other biodiverse ecosystems;
- Impacts on soils and water supplies;
- Impact on local and global food supply;
- Social and economic importance for local populations.

7.6 Forestry

Over 350 million people live in forested areas and about 1.6 billion people rely heavily on forest resources for their livelihoods. Forests, both natural and planted, make an important contribution to national and local economies with about 60 million people being employed in the forestry and wood industries. In Africa alone, firewood and charcoal provide approximately 70% of energy requirements and the export of timber, nuts, fruit, gum, and other forest products generates 6% of the economic product of African countries (FAO, 1999).

Furthermore, over 2 billion people rely on traditional medicines harvested from the forests and a wide range of other non-timber forest products (NTFPs) that are harvested from forests, both for direct use and for sale. The value of NTFPs in global trade is currently estimated at US$4.7billion annually (Marshall *et al*., 2006).

For millions of people living in poverty, forests and trees outside forests not only provide food, cooking and heating fuel, shelter and clothing, but they also function as safety nets in sudden crises or emergencies – for example, when crops fail owing to prolonged drought or when heads of households can no longer engage in productive activities because of HIV/AIDS or other devastating diseases. In these instances, forest resources generate income through employment and through the sale of surplus goods and services.

The impacts of climate change on forests are described in Chapter 6 and will vary from region to region. Typical impacts however are likely to include forest dieback, shifting boundaries and loss of species diversity. These pressures on forest diversity are likely to exacerbate the already existing vicious circle that exists between poverty and environmental degradation in many developing countries. Communities that lack sources of income are forced to cut down forests to sell timber and other products. Yet continued deforestation depletes their natural resources and income streams, resulting in greater poverty (Green Belt Movement, 2008). Any additional factor, such as climate change, that has the effect of further reducing the supply of plants used for food, medicines and income generation by rural populations, will result in an increase of hunger and disease amongst millions of people. Links have also been established between reduction in forests and increases in certain infectious diseases such as malaria, leishmaniasis, chagas, and yellow fever (Chivian, 2002).

Reforestation offers a means of mitigating the process of degradation of land while sustaining human communities. However in the past, the focus has been on plantation forestry, concentrated on a few, often exotic, species. For example, *Tectona grandis, Acacia* sp. and *Eucalyptus* sp. represent more that 51% of all plantations established in the Neotropics and *T grandis* comprised 76% of plantations established in the Republic of Panama between 1992 and 2000 (FAO, 2000). Well-managed monoculture plantations of exotic species may be productive under favourable conditions, but these species have often been selected to produce a very limited set of goods and services, such as timber, and may do a poor job of achieving other objectives, such as protecting soils from erosion. It is obviously unrealistic to expect a small number of species to provide the full range of goods and services communities might seek from planted forests.

A lack of information regarding tree species performance has been identified as an important limitation on the success and adoption of diversified reforestation strategies (Wishnie *et al*., 2007). However, for reforestation strategies to be effective at national and regional scales, and for reforestation to become a viable, widespread activity, landholders must be able to select tree species based on their specific restoration objectives and on the climatic and other relevant physical characteristics of their landholdings.

Recognition of the critical role forests play as carbon reservoirs has resulted in the development of a number of projects in Africa, Asia and Latin America which support forest livelihoods while at the same time increasing carbon sequestration. Carbon forestry projects provide a new source of income through carbon revenues and help strengthen local capacities in forest management. Nevertheless, these projects can also exacerbate inequalities at the local level and undermine the access of the poor to forest assets; careful attention to their design and monitoring is therefore extremely important.

The Clean Development Mechanism (CDM) of the Kyoto Protocol provides a mechanism to support reforestation and afforestation projects and such projects are required to contribute to sustainable development as well as carbon sequestration. Studies have shown that projects for reforesting degraded and deforested areas can be fashioned to provide significant benefits to communities. However, it is clear that most developing countries still require policy action to establish the enabling conditions for forest carbon projects to contribute on a large scale to local livelihoods. Due to the high transaction costs and complicated procedures, at the present time, only one plantation-based reforestation project in China is operational through the CDM (Boyd *et al*., 2007).

7.7 Medicinal plants

Medicinal plants have been used by humankind for millennia. The range of species used and their scope for healing is vast. It is estimated that more than 50,000 plant species have medicinal qualities and numerous important modern medicines are derived from plant extracts. According to the World Health Organisation (WHO), 80% of the world's population rely on traditional medicine for their primary healthcare. The trade in medicinal plants is also an important economic activity, especially for landless rural poor. For example, more that half of the 6,000 plant species in Yunnan province in China are used for medicinal purposes, with an estimated worldwide market of 4 billion people (Arnold, 2006). Internationally, the trade in medicinal plants is estimated to be worth US$60 billion per year, increasing at a rate of 7% a year. Medicinal plants are therefore fundamental to the well-being of billions of people (Hawkins, 2008).

Despite this, many thousands of medicinal plant species are under threat because of growing global demand, unsustainable harvesting and habitat loss. It is generally the collection for commercial trade rather than home use that is the overwhelmingly the problem (Hamilton, 2003). This situation is exacerbated by the effects of climate change (Mahat, 2007).

Species such as *Prunus africana*, a tree commonly used to treat symptoms of malaria and some forms of cancer is under threat in several areas of Africa, and the so-called sex tree, *Citropsis articulata*, is quickly disappearing from Uganda's Mabira Forest Reserve, one of the country's last remaining rain forests, because its roots are believed to cure impotence

Case study 7.13 Medicinal plants and species extinction

The story of the potential anti-HIV drug Calanolide provides a tragic reminder of what we risk losing with species loss. Chemists from the U.S. National Cancer Institute identified a novel agent (named Calanolide A) from the leaves and twigs of a tree *Calophyllum langierum* found in Sarawak. It was discovered on a return visit to Sarawak that the original tree was gone and that other *C. langierum* trees could not be found. It was not clear whether the species was extinct. A close relative *C. teymannii* was identified and was found to contain a weaker drug, named Calanolide B, which, while having anti-HIV activity and the same mechanism of action (it is a non-nucleoside reverse transcriptase inhibitor), nevertheless was not as potent as Calanolide A. Calanolide B is currently in clinical trials, the result of a successful venture between MediChem Research and the government of Sarawak (UNDP, no date).

(National Geographic, 2007). Members of the family *Magnoliaceae* are used extensively in indigenous herbal medicine throughout their range and it is known that up to half of all *Magnolia* species are under threat of extinction (Cicuzza *et al*., 2007). In a recent report, BGCI has identified over 400 medicinal plant species and genera that are considered to be at threat, either globally or locally, and for which urgent conservation action is required (Hawkins, 2008).

Case study 7.14 Saving the snow lotus *(Saussurea laniceps)*

The snow lotus (*Saussurea laniceps*) is popularly used in Tibetan medicine. However, increased world demand for the blossom is pushing the species towards extinction. Medicinal uses for the flower range from rheumatism to 'women's diseases'. It is also highly sought after by tourists as a symbol of the region. The plant favours steep, unstable scree slopes well above 12,000ft. In heavily harvested areas, the plant is all but gone.

Botanists have been comparing the size of specimens preserved in herbariums to plants found in the wild, and they believe that humans have played a role in actually shrinking the species by as much as four inches in the past century. In an accelerated version of natural selection, harvesters take the biggest blossoms they can find and leave only the smaller ones to sow their seeds.

For the snow lotus, the underpinnings of conservation already exist in Tibetan culture and holy sites, such as the eight sacred mountains of Tibetan Buddhism, have become pockets of biodiversity in a rapidly changing landscape (Arnold, 2006).

The consequences of increasing rarity and even extinction of medicinal plants are far-reaching and not simply confined to a loss of healthcare or biodiversity. Many of the world's poorest people rely on the collecting and selling of wild medicinal plants for income generation. Though prices paid to gatherers tend to be low, medicinal plant collection provides a significant income for the often marginal, rural poor (World Bank, 2004). At the very least, climate change will add to the pressures many medicinal plants are currently facing, and at worst, it may push already threatened species over the brink into extinction. Medicinal plant conservation is particularly challenging since the taxa occur in a wide range of habitats and geographic regions. However, activities that, for example promote diversity in ecosystems as an adaptation response to climate change, in combination with more sustainable levels of harvesting, can promote the conservation of medicinal plants in the wild.

Case Study 7.15 Conservation of medicinal plants in the Himalaya

The situation in the Himalayas is particularly critical. Medicinal plants collected from these peaks play a significant role in the region's culture and economy. They are a major source of income for communities in the region and provide basic healthcare for millions of people. This resource base, in terms of both the plants themselves and the knowledge of their use, is being eroded at an alarming rate. In some areas plants are becoming increasingly scarce, while others have disappeared completely from their traditional harvesting areas.

Ensuring a sustainable future for medicinal plants in the Himalayan region is therefore of great importance. A collaborative project between Plantlife International and national partners in five Himalayan countries – Bhutan, China, India, Nepal and Pakistan – is focusing on the identification and conservation of IPAs for medicinal plants in the Himalaya.

53 IPAs for medicinal plants have been provisionally recognised, with a significant number of smaller sites at a more local level. The identification of these sites will be useful for landscape-level planning, including the siting of protected areas. Based on the gross geography of the IPAs (as currently recognised) protected area networks in the Himalaya should be reviewed. A good distribution of protected areas will help ensure survival of species in the face of climate change. It will also help to ensure that the genetic diversity of medicinal species is conserved (Hamilton & Radford, 2007).

8 Managing the impacts of climate change on plant diversity

Summary

It is clear that many species of wild plants are likely to become extinct within the next century, and, at least for some communities and ecosystems, climate change is already imposing huge costs. Uncertainty about how climate change will unfold or what the response of species and habitats will be, must not prevent us from taking urgent action now. Conserving plant diversity will help in the maintenance of carbon sinks and will ensure options for future plant use under different climatic conditions. The Global Strategy for Plant Conservation (CBD, 2002), and achieving its 16 plant conservation targets for 2010, becomes even more important in the light of climate change. It also provides a useful framework for amending or developing additional plant conservation targets post-2010, many of which are outlined below. The richness of future biodiversity depends on how we act and what we conserve today.

Key points

- Doing nothing is not an option.
- There is a lack of consolidated information on the current threat status of plants. We do however know that many species are already under threat, and that climate change will exacerbate existing threats as well as introduce new stresses to plant diversity.
- Diverse ecosystems (both natural and managed) are most resilient against changing conditions. Management of natural and productive landscapes should therefore focus on maintaining high levels of diversity.
- Management of plant diversity will have implications both for mitigating climate change (through carbon sequestration) as well as adaptation to climate change.
- In the face of an uncertain future, an urgent priority must be conservation through seed-banking and conservation in living collections for as many plant species as possible as an insurance policy.
- Education has a key role to play in ensuring plant conservation action in the future.
- Lack of capacity in botanical conservation is an important issue that needs to be continually addressed at all levels.

8.1 Need for action

The level of species loss due to climate change will be directly related to the extent to which global warming can be limited. At 2ºC warming, it is likely that many species will be lost, but a range of management actions may be able to conserve a broad array of global plant diversity. However, at 4ºC warming and above, a multitude of species will likely be lost, with few viable management options and enormous financial costs. Clearly, mitigation measures are required to reduce global greenhouse emissions, ultimately stabilising atmospheric concentrations at a level that can sustain an acceptable dynamic equilibrium between climate, ecosystems and human society. It is noteworthy that management actions undertaken to conserve plant diversity in a changing climate also contribute to the mitigation of climate change itself.

Box 8.1 The Precautionary Principle

Extract from the United Nations Framework Convention on Climate Change (UNFCCC), signed by over 160 countries in Rio de Janeiro in June 1992:

Article 3 includes agreement that Parties:

"*…take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing such measures….*"

In some situations, enough information is known about a plant species to be able to say that immediate conservation action is urgently required – but this information is not necessarily acted upon. More broadly, a lack of comprehensive conservation information on current and future threats to species survival should not impede targeted, efficient conservation actions to ensure the survival of the world's plants in today's rapidly changing climate. A multifaceted approach to plant conservation is required.

8.2 The Global Strategy for Plant Conservation (GSPC)

In response to a need for greater focus on plants within the broad biodiversity agenda, the GSPC was unanimously agreed by all Parties to the Convention on Biological Diversity (CBD) in 2002. The Strategy has 16 ambitious targets to be achieved by 2010 (Annex 1) and, since its adoption, it has motivated action to save plant diversity from extinction at national, regional and international levels (CBD 2007b). A number of countries have used the GSPC as a basis for developing national plant conservation strategies. Particularly notable amongst these has been the development of the China Plant Conservation Strategy (CPCS Editorial Committee, 2008). As China has some 10% of the world's flora, the implementation of its strategy is of global significance. The GSPC has also served as a unifying mechanism for organisations involved in plant conservation around the world and despite under-resourcing it has achieved considerable gains. Many of the implementation activities of the GSPC have been undertaken by NGOs, and botanic gardens have played a particularly significant role (CBD, 2007b).

The Strategy includes actions that are necessary to maintain ecosystems as carbon sinks and promotes action towards a better understanding of which species are most at risk. It includes international targets for the conservation of threatened species and promotes education and awareness about plant diversity. At a meeting in 2006, a group of leading plant conservationists considered that, despite the enormous challenge of climate change, the prevention of mass extinction of plant diversity could be achievable if the GSPC targets were implemented in full (Gran Canaria Group, 2006). There is however a need to look beyond 2010, build on the partial achievements of the GSPC and re-visit the GSPC targets, taking into account the profound shift in environmental parameters brought about by climate change. Biodiversity conservation plans and targets need to integrate both mitigation and adaptation strategies against climate change, adopting an approach that allows for adaptive conservation management of plant diversity.

In this chapter we examine the targets of the GSPC in the light of climate change and make recommendations for how these might be adapted and further developed post-2010.

8.3 Understanding and documenting plant diversity

8.3.1 How many plant species are there?

A working list of known plant species is essential for plant diversity management and underpins all conservation actions. It helps to prevent duplication of effort and accidental oversight when planning conservation strategies. The name of a plant is the key to information about its use, conservation status, relationships and place within ecosystems. Target 1 of the GSPC calls for "*A widely accessible working list of all known plant species as a step towards a complete world flora*". It is estimated that there are around 350,000 known species of flowering plants, but a complete inventory of the plants of the world has not yet been assembled. The world's herbaria hold a wealth of knowledge that is available to help in naming and understanding the distribution of plant species. We need to use this data, and increased fieldwork, to catalogue the world's flora before they are lost. In the framework of the GSPC work is progressing well and the world's leading herbaria are collaborating on this target. At the current rates of progress, it is anticipated that the target will be at least 85% complete by 2010, with a high possibility of complete coverage by the end of 2010.

***Action:** Mobilise resources to support those organisations working towards compiling a working list of all known plant species, to ensure that this is completed as soon as possible.*

8.3.2 How many species are under threat?

Target 2 of the GSPC is: "*A preliminary assessment of the conservation status of all known plant species at national, regional and international levels".* Progress on this target at the international level has been disappointing, and is constraining conservation actions at a global level by limiting the ability to prioritise species and habitats for targeted plant conservation action.

To date, less than 5% of the world's known plant species have been assessed in a globally comparable way using IUCN Red Listing Categories and Criteria (as compared to over 40% of the world's known vertebrate species). This lack of complete information means that plants remain relatively invisible in global biodiversity assessments such as the Millennium Ecosystem Assessment, and presents a false impression of the relative threatened status of the world's biodiversity. There is clearly a need to speed-up the IUCN Red Listing process for plants, and to supplement this with information already available in national lists of threatened species. This will provide a baseline to monitor the impacts of climate change.

Of the small fraction of plant species that have so far been assessed using IUCN Red Listing criteria, 70% have been identified as threatened. Despite the fact that we do not yet have comprehensive data for many species, there is additional compelling evidence that climate change will be catastrophic for many more species (Baillie *et al*., 2004). Recent models suggest that up to half of the world's higher plant species will be threatened with extinction over the next 100 years (Bramwell, 2007). A significant number of species that have been assessed with IUCN Red Listing criteria are trees, which has great importance given their key roles in strategies to mitigate and adapt to climate change. However, much of these data are now 10 years old and require re-validation. It is therefore essential that an up-to-date assessment of the status of the world's trees is carried out as a matter of priority. The process of re-validating threat assessments of numerous species will additionally shed critical light on how climate change and current conservation actions have impacted some of the world's most threatened tree species over the last decade.

Even where data concerning the threatened status of plant species is available, such datasets are often not easily accessible or available for use. Efforts have been made at the international level to provide a mechanism for sharing biodiversity information through the Global Biodiversity Information Facility (GBIF) but only limited data is presently made available this way. Reluctance to share information often relates to the economic value attached to such data and incentives are required to ensure the free sharing of plant distribution data.

New tools are currently being developed to accelerate the Red Listing process, but criteria still lack an explicit assessment of vulnerability to climate change. The IUCN is, however, working to identify 'vulnerability traits' that are specific to climate change (See Section 5.3). Such traits may include:

- Specialised habitat and/or microhabitat requirements;
- Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage of the life cycle;

- Dependence on climate-related triggers that are likely to be disrupted by climate change (e.g. flowering, seed germination etc.);
- Dependence on interspecific interactions for successful reproduction (pollination etc.);
- Poor dispersal ability/ability to colonise new areas.

Incorporating such trait-based vulnerability assessments into the IUCN Red Listing process would allow the creation of climate change 'watch lists', comprised of species, or groups of species that, while currently secure in the wild, may be threatened by climate change in the future as they possess traits associated with high vulnerability.

Action: *Collate all available information on the status of threatened plants to supplement the IUCN Red Listing process and achieve Target 2 of the GSPC.*

Action: *Agree upon and implement climate change vulnerability criteria for plants as a matter of urgency and ensure that these are applied by as wide a range of botanical experts as possible worldwide to identify the species most at risk from climate change.*

Action: *Carry out a global tree assessment using the IUCN Red List categories and criteria, updating existing information as a basis for monitoring climate change and increasing conservation action for the world's most threatened trees.*

8.3.3 How will climate change affect individual species and entire plant communities?

Target 3 of the GSPC calls for the "*Development of models with protocols for plant conservation and sustainable use, based on research and practical experience*". In the face of rapidly changing climates, there is great demand for realistic modeling approaches that can project the future distribution of species given different climate change scenarios. This information is critical in guiding management actions for threatened species, as it can be used to help identify biological corridors for dispersal, potential sites for reintroduction (or introduction), as well as areas where habitat protection will be most effective.

Climate change modeling is increasingly undertaken for both basic and applied science uses. While increasingly useful for generalised climate change scenarios and broadly distributed species, constraints on the applicability of current models exist for many reasons. Different models rarely provide similar species distribution predictions given similar climate change scenarios because they rely upon different and untested assumptions. Species with narrow or infrequent distributions constrained by a few key climatic conditions are currently difficult to model (Mclachlan *et al*., 2007), and few, if any, of the most popular models explicitly deal with species interactions, the interaction between the effects of climate and land use, and the direct effects of changes in atmospheric CO_2 and nitrogen deposition (Thuiller, 2007). Finally, models of future plant distributions are also constrained by a lack of information on the environmental tolerances of plant species. Much more research is needed to determine the plasticity of different species to changes in the environment, and therefore species-level adaptability to climate change.

Models of the impacts of climate change on plant diversity thus need to be backed up by more detailed field-based monitoring programmes focusing on long-term monitoring. These efforts can be labour-intensive, but many regions have successfully used volunteer citizen scientists to conduct long-term plant monitoring or to collect phenological observations such as the time of appearance of flowers or other natural events. Such data sets can be compared against recorded variations in temperature or precipitation. Another approach is the re-surveying of sites sampled 50 or 100 years previously. Species' identities and abundances can then be compared with changes in climatic factors. A global network of monitoring sites, such as could be provided by the world's botanic gardens, could also provide a starting point for gathering data on the performance, or plasticity, of key species over a wide range of environmental conditions.

Action: *Develop more realistic plant diversity – climate change modeling approaches to detect potentially threatened species and potentially invasive species in a changing climate scenario. Make protocols available through the plants2010.org website.*

Action: *Develop field-based monitoring programmes, focused on vulnerable areas, to enable long term assessment of the impact of climate change on plant diversity.*

Action: *Develop a global plant adaptation network to gather data on the plasticity of key species under a wide range of environmental conditions.*

8.4 Conserving plant diversity

8.4.1 Are plants being effectively conserved when and where it matters most?

Effective conservation of plant diversity requires the protection and appropriate management of significant portions of the world's key ecological regions. Target 4 of the GSPC recognises this in calling for "*At least 10% of each of the world's ecological regions effectively conserved*". The current estimate for coverage of the global network of protected areas is 11.6% of the earth's land surface (19 million sq km within 106,926 areas) (UNEP-WCMC, 2007). However, the degree to which key ecological regions with important plant diversity are protected is currently unclear and likely in need of modification as plants move and adapt to changing climates and effective conservation is increasingly requiring management actions that take into consideration climate change effects.

8.4.2 Conserving important areas for plant diversity

Although over 10% of the earth's surface is officially classed as protected area, as noted above, there remains uncertainty as to how well areas of high plant endemism and diversity are covered within the protected area system. Target 5 of the GSPC, "*Protection of 50% of the most important areas for plant diversity assured*", specifically addresses this issue.

Ensuring the conservation of key plant diversity sites allows plant populations to build resilience by promoting exchange of genetic material and the development of diverse gene pools for the future. Despite the uncertainties introduced by climate change, it is clear that areas of high plant diversity will remain important as refuges and resources.

The development of national networks of important areas for plants provides the basis for *in situ* conservation matrices. For example, to date, 69 countries, covering all the continents, have participated in IPA initiatives. More than half of these countries have taken steps to identify IPAs and 17 countries have on-going conservation and documentation activities at these sites.

However, it will be self-defeating if effort is put into protecting areas that are home to plants that can no longer grow there. There is a need to focus on places that will be buffered from climate change, protect places where plants will move to and create corridors to help plants move to safety. In Africa for example, it is predicted that the wetter parts of central Africa, such as the coastal regions of Cameroon and Gabon, will retain more plant diversity than elsewhere, as will the mountains of eastern coastal Africa (Lovett, 2007). Conservation matrices that incorporate IPAs and corridors in the wider landscape will provide a mechanism to protect plant diversity in the face of changing climates.

Action: *Step-up activities to conserve maximum habitats for plant conservation, notably tropical forests.*

Action: *Carry out further modeling to identify ecological regions and plant diversity hotspots most at risk because of climate change.*

Action: *Identify geographical areas that will provide refugia for the maximum diversity of species (e.g. montane areas with heterogenous relief) and prioritise these as IPAs for* in situ *conservation.*

8.4.3 Managing threatened plant species – *in situ* approaches

Target 7 of the GSPC calls for "*60% of the world's threatened plant species to be conserved* in situ". Management options for the conservation and recovery of threatened plant species *in situ* can range from habitat protection, through to habitat restoration and the removal of the source of threat, to active management of the site or species. Habitat protection can be achieved through formal protection in a conservation area, through community-based management approaches or, in some instances, through threatened species legislation – which may be more effective if the species exists on private land. For some threatened species, further action, such as the removal of invasive species, restriction of disturbances or the exclusion of grazing animals may be required. However, where the population of a species is very low and only a few individuals remain in the wild, more extreme measures may be required.

Active management focuses on increasing the number and size of populations and, if care is not taken, can affect the species' genetic structure and its evolutionary development. Different populations across a species range will differ to varying degrees in their genetic composition. Thus populations supply genetic diversity and as populations are eliminated locally, genes may become extinct globally.
Low risk techniques aim to manipulate or restore natural processes in order to increase recruitment in the target population. Such techniques may include hand pollination, or clearing competitor plants. However, for species characterised by extremely low numbers, high risk techniques, such as translocation and *ex situ* propagation of planting materials may be required. Translocation, with its associated high cost and maintenance requirements, may best be viewed as a last resort when all other options are deemed inappropriate or have failed (Vallee *et al*., 2004).

Action: *Ensure that* in situ *conservation strategies, supported as necessary by* ex situ *action, are in place for all plant species presently known to be threatened at the global level.*

8.4.4. Conserving plant diversity *ex situ*

Ex situ conservation of plants is defined as the conservation of plant species outside their natural habitats. The increasing awareness of the effects of climate change on plant distributions *in situ* has made the appropriate application of *ex situ* techniques more crucial. We cannot save all plants *in situ*, and seed banking offers a cost-effective, supplementary conservation activity to *in situ* efforts. While prioritisation of *ex situ* activities continues to be important, wide-scale seed banking efforts are a logical first step in a changing climate where virtually all species are at risk.

Ex situ collections play a key role in securing the conservation of plant diversity, not only as an insurance policy for the future, but also as a basis for restoration and reintroduction programmes. Work towards ensuring the *ex situ* conservation of plants falls under GSPC Target 8: "*60% of threatened plant species in accessible* ex situ *collections, preferably in the country of origin, and 10% of them included in recovery and restoration programmes".*

In recent years major progress has been made towards Target 8, and it is estimated that some 30-40% of globally threatened species are now included in *ex situ* conservation programmes. BGCI maintains a database of living plant collections held by over 600 botanic gardens worldwide. To date, over 12,000 globally threatened plant species have been identified amongst the over 80,000 species held in botanic garden collections. Many other locally threatened species are also amongst the holdings of botanic gardens. The database is being further developed to record medicinal plants and crop wild relatives, as well as propagation techniques and species used in restoration programmes. Institutions holding living *ex situ* collections are beginning to assess the conservation value of their collections, and are taking steps to ensure that they can act as a true safety net for rare species (BGCI, 2007). BGCI is also undertaking gap analyses for selected groups of plant in *ex situ* collections as a basis for strengthening these and planning for restoration of key species. At present the focus of these analyses is on oaks, magnolias, maples, rhododendrons and threatened plants of Europe.

Complementing the *ex situ* living plant collections are a large number of seed banks, operating at both national and international levels. For example, the Millennium Seed Bank project, created by the Royal Botanic Gardens Kew and its partners worldwide now includes 37,000 accessions from 20,000 plant species (both common and threatened), mainly from drylands.

In relation to crop diversity, the need for *ex situ* conservation of diverse crop material has been recognised as increasingly urgent – with a particular need to focus on crop wild relatives and local varieties of crops as a rich source of diversity and adaptive traits for extreme abiotic conditions. A Global Crop Diversity Trust has been set up to ensure the conservation and availability of crop diversity for food security.

The extent of genetic diversity of crop species presently in *ex situ* collections varies considerably from crop to crop. GSPC Target 9 calls for "*70% of the genetic diversity of crops and other major socio-economically valuable plant species conserved*". It is likely that together the world's crop genebanks contain as much as 95% of the genetic diversity of the major cereal crops – wheat, rice and maize. However, only around 35% of cassava diversity is thought to be conserved in genebanks and many locally important crops, such as African leafy vegetables, have no significant genetic collections at all.

Tree species and species with recalcitrant seeds (seeds that cannot be dried and stored in conventional seed banks) are also under-represented in *ex situ* collections and greater efforts are needed to ensure the conservation of these species. Furthermore, there are questions about the genetic 'representativeness' of many *ex situ* collections, and thus their suitability for use in restoration and reintroduction programmes. These questions must be addressed and steps taken to ensure that *ex situ* collections are increasingly representative of *in situ* genetic diversity.

While the focus up to now has been on conserving threatened species, climate change is rapidly redefining what is a threatened species. Species with particular climate change vulnerability traits (See Section 8.3.2), Crop Wild Relatives and local crop varieties with abiotic stress tolerance traits now also need urgent attention under *ex situ* programmes.

The process of collecting seeds for *ex situ* conservation also provides an ideal opportunity for collecting baseline information on plant species distribution. Data such as locality, population sizes and existing threats can be used over time to measure changes, for example in population ranges and sizes, and thus form the basis of a global early warning system for the effects of climate change on wild plant diversity.

Restoration of threatened plant species in the wild to reach Target 8 of the GSPC has so far been relatively restricted. However, recovery of wild populations of depleted species may be increasingly important in repairing 'damaged' ecosystems and restoring connectivity at a landscape scale. Genetically diverse populations of species therefore need to be maintained in *ex situ* collections and capacity to propagate and cultivate endangered species needs to be enhanced, in support of such habitat restoration work. In this respect, the use of locally appropriate species in restoration work such as tree planting schemes, should be encouraged, with the aim of creating diverse, resilient native communities.

Case study 8.1 The Green Belt Movement and tree planting in Kenya

The Green Belt Movement (GBM) was founded in Kenya over 30 years ago by Wangari Maathai. The organisation aims to address serious problems of poverty and environmental degradation through tree planting. As a result of their programmes, 40 million trees have been planted, hundreds of thousands of women in rural Kenya have lifted themselves out of poverty, soil erosion has been reduced in critical watersheds and thousands of hectares of biologically rich forests have been restored or protected.
The GBM takes a holistic approach to sustainable development, with projects based on community involvement and self-sustainability. With the acquired knowledge of tree planting and the incentives associated with livelihood improvement, communities continue to protect their forests to meet their own needs. The end-point is therefore a self-sustaining forest system which does not depend on continued outside support for survival (Green Belt Movement, 2008).

Action: *Continue efforts to identify gaps in existing* ex situ *collections as an urgent priority and ensure that genetically representative populations of threatened species as well as species vulnerable to climate change are conserved* ex situ. *Prioritise montane, coastal and island species as well as those of livelihood value in marginal areas.*

Action: *Develop methodologies to enable the capture of maximum genetic diversity at population level of target species for* ex situ *conservation and ecosystem restoration.*

Action: *Encourage the use of locally appropriate threatened tree species in tree-planting schemes designed to offset carbon emissions.*

Action: *Collect baseline data on species distribution and threat assessment when collecting seed and make information freely available via the internet – using existing biodiversity information resources, such as GBIF.*

8.4.5 Managing ecosystems for climate change

Although the plant and animal species that comprise the world's ecosystems have shifted and adapted to historical climate changes, the current rate of change is unprecedented and species face new and unique barriers to movement and adaptation that now hinders their ability to respond similarly. In order to enhance the resilience of ecosystems and reduce the risk of irreversible damage, there is an urgent need to develop and implement climate change management strategies. The main principle behind these measures is to maintain or enhance ecosystem health to allow natural processes, such as migration, selection and community composition changes to occur.

All else being equal, ecosystems with greater plant diversity have a greater capacity to adapt to changing conditions (Tilman *et al*., 2006). Thus, any management strategy that maintains or restores the diversity of an ecosystem will have the effect of enhancing its resilience. Other key climate change management strategies may include: removing barriers to plant migration; afforestation to condition soils, improve water infiltration and provide shade; managing forests in order to reduce the potential for forest fires; managing water to address unpredictable rainfall; restoring degraded areas; and removing stresses due to non-climatic effects, such as invasive species.

Action: *Establish research programmes and feedback loops linking scientific knowledge with site management and conservation policy process to foster better understanding of climate change management.*

Action: *Implement climate change management strategies in ecosystems that are most vulnerable to climate change, with a particular focus on forest, island and alpine ecosystems.*

Box 8.2 Managing for climate change: Guiding Principles

Six guiding principles have been developed by the UK's Department for Environment, Food and Rural Affairs (Defra) to inform implementation of the UK Biodiversity Action Plan in the light of climate change.

The principles are;

1 Conserve existing biodiversity; conserve protected areas and other high quality habitats and conserve range and ecological variability of habitats and species.
2 Reduce sources of harm not linked to climate change (e.g. over-grazing of grasslands; nutrient enrichment; introduction and spread of non-native species; intensive farming systems; excess extraction of water).
3 Develop ecologically resilient and varied landscapes; conserve and enhance local variation within sites and habitats; make space for the natural development of rivers and coasts.
4 Establish ecological networks through habitat protection, restoration and creation.
5 Make sound decisions based on analysis; thoroughly analyse causes of change; respond to changing conservation practices.
6 Integrate adaptation and mitigation measures into conservation management, planning and practice.

(Defra, 2007).

8.4.6 Climate change and plant migration

Fossil and pollen evidence indicates that in the past, species have responded to climate change by dispersing out of areas with an unfavourable climate into areas with a favourable climate. For example, at the end of the last glacial retreat 10,000 to 17,000 years ago, trees migrated north at an average of 200m per year (Williamson, 1996). Both protection and management efforts must therefore be focused on enabling nature to migrate on its own and the protected areas of the future need to be designed to accommodate natural movement of species as they respond to climate change. Intact landscapes should continue to be an important focus for conservation activity, as they provide the most favourable conditions for species survival by dispersal. However, in fragmented landscapes, creating ecological networks that improve connectivity between habitat patches by, for example, establishing new protected areas, restoring degraded habitat or reducing the intensity of management of some areas between existing habitats will encourage this. Landscapes in which habitat patches are concentrated together and where the intensity of land use is reduced in intervening areas are likely to provide the most favourable conditions for species to spread in response to climate change.

Table 8.1 – Some climate change management responses for a range of terrestrial ecosystems (adapted from CBD 2007a)

Ecosystem	Management response
Dry and sub-humid lands • Home to 2 billion people • Great biological value (agricultural resources) • Vulnerable to temperature and rainfall changes	• Encourage agro-forestry • Manage water resources • Restore degraded lands • Manage fire • Integrate traditional knowledge about plant species management • Protect climatic refugia and provide buffer zones to protect genetic diversity
Forest ecosystems • Contain 80% of carbon stored in terrestrial vegetation • Trees less able to move with changing climates • Deforestation activities emit 1.7 billion tonnes of carbon per year into atmosphere	• Conserve old-growth forest • Afforest and reforest to create carbon sinks • Avoid habitat fragmentation and provide connectivity • Prevent conversion to plantations • Practise low-intensity forestry and encourage sustainable use • Maintain natural disturbance regimes, including fires
Wetlands • Peatlands are the world's primary carbon sequestration mechanism	• Reduce fragmentation • Reduce pollution • Restore habitat • Manage invasive species • Avoid draining and drying • Maintain genetic diversity and promote ecosystem health via restoration
Mountains • Species have limited capacity to move and nowhere to go	• Link upland and lowland management • Manage watersheds • Provide migration corridors

Case study 8.2
Facilitating plant migration

In China's Yunnan province, the Nature Conservancy and partners are working not only to protect temperate mountain forests, but also to secure grassland areas immediately upslope of those forests, where at least some of the forest species will migrate as temperatures rise. Similarly, in the Cape Floristic Province of South Africa, several migration corridors are being established to connect mountains with coastlines (Fox, 2007).

While enlarging protected areas and creating corridors to connect them may help plant communities to move, in today's fragmented habitats this may not always be possible. In certain situations, if circumventing climate-driven extinction is a conservation priority, assisted migration might also be considered a management option.

Assisted migration is a contentious issue that places different conservation objectives at odds with one another. This element of debate, together with the growing risk of biodiversity loss under climate change, means that now is the time for the conservation community to seriously consider assisted migration and address the constraining issues.

Issues that will need to be taken into account include:

- The need for basic current distribution data;
- The accuracy of predicted future distribution based on modeling;
- The importance of community interactions, including trophic associations and mutualisms. Paired or multi-species assisted migration might be necessary in some species;
- Extent and type of intraspecific diversity to be included in source population;
- Potential for invasiveness in the new habitat;
- National sovereignty of plant resources if new suitable habitats only exist across country borders (McLachlan, 2007).

Action: *Review the effectiveness of biodiversity corridors in facilitating plant movement and conduct further research on the issues related to assisted migration.*

Case study 8.3 The Torreya Guardians

Torreya taxifolia is a species of Florida yew tree which is under severe decline in its native habitat. Only a few hundred individuals remain. Nevertheless, a group of enthusiasts known as the Torreya Guardians are working to save the species by spreading its seeds up to 1,000km north of its present geographical range. Their intent is to avert extinction by deliberately expanding the range of this endangered plant.

Because planting endangered plants in new environments is relatively simple, as long as the seeds are legally acquired and planted with the landowner's permission, they believe their efforts are justified.

However, in this, as in any such case of assisted migration, care must always be taken to not place under threat any other species in the transplanted location. (The Economist, 2007).

8.5 Managing invasive species

The removal of invasive alien species is a key management activity for effective conservation in any climate. Invasive species of animals, plants and micro-organisms threaten and degrade plants and their habitats in almost every region, ecosystem, latitude and longitude. Invasives have been shown by the Millennium Ecosystem Assessment (MA) to be a major agent of ecosystem degradation. To address this, GSPC Target 10 calls for "*Management plans to be in place for at least 100 major alien species that threaten plants, plant communities and associated habitats and ecosystems*". This target has effectively been met, as over 100 management plans are currently in place for important invasive species that threaten and affect plants, but the effective management of invasive species is increasingly pressing in the context of climate change.

Climate change is predicted to enhance the spread and impact of many existing invasive species, as well as potentially providing suitable conditions for presently non-invasive species to become invasive. Both native and alien species are routinely planted in gardens and parks around the world, often far from their native ranges. Global climate change could spark a new round of 'escapes' if conditions changed in such a way that species long occurring as agricultural weeds or maintained by cultivation outside their natural range were able to grow in the wild (Pitelka, 1997). Experience has shown that preventing invasions of harmful species is more cost-effective than waiting until they have become a threat. Applying preventative measures requires action at both international and national level including the coordination of agencies working in the areas of transport, trade, tourism, protected areas, wildlife management, water supply, and plant health.

Action: *Apply preventative and precautionary principles in addressing issues related to invasive species and develop early warning systems and rapid response capacities at the national level.*

Action: *Increase the range of management plans for dealing with invasive plants, building on the success of the GSPC.*

8.6 Managing production lands

One third of the world's land area is used for food production and agricultural landscapes can be found in almost every part of the world. Furthermore over a billion people are dependent upon forest products for their livelihoods. A balance between natural ecosystems and agroecosystems needs to be maintained.

While forest landscapes provide ecosystem services, such as carbon sequestration and water storage, agriculture is a contributor to climate change. Flooding areas for rice production, burning crop residues, raising ruminant animals and using nitrogen fertilizers are all activities that release greenhouse gases into the atmosphere. Global agriculture is now estimated to account for up to 20% of total anthropogenic emissions of greenhouse gases (UNEP, 2006) and actions, such as zero tillage and improved fertilizer use efficiency, are required to reduce such emissions.

Agricultural production is also likely to be negatively affected by climate change, and there is an urgent need for plant breeders to focus on breeding crops tolerant to drought and heat. In order to do this, they will require ready access to the wild plants which are related to modern crops, as well as a wide diversity of landraces and farmers' varieties of crops, as such plants harbour an extensive array of genes conferring tolerance to biotic and abiotic stresses.

Traditional agricultural and forestry practices that maintain a high level of plant diversity in production systems are likely to be more effective in adapting to changing conditions than large scale monocultures. The deployment of plant genetic diversity in agricultural and forestry systems should therefore be encouraged as an important management response to climate change.

GSPC Targets 6 and 9 relating to the management of production lands are:

Target 6: "*At least 30% of production lands managed consistent with the conservation of plant diversity*".
Target 9: "*70% of the genetic diversity of crops and other major socio-economically valuable plant species conserved and associated indigenous and local knowledge maintained*".

Achievement of these targets will help to ensure that the necessary diversity is available to meet the demands of production under future changing and unpredictable climatic conditions. Progress on these targets is however mixed and greater efforts are required to ensure a good understanding of plant conservation needs within the agricultural and forestry sectors.

The MA highlighted agroforestry as a system of alternative land use that has great potential for generating 'win-win' opportunities for sustaining ecosystem services. In addition to providing a harvest of fruits, firewood, medicine, animal forage and resins, agroforests offer great potential for adaptation to climate change by smallholder farm households. The diversity of plants used in agroforestry systems provides multiple harvests at different times of the year, which in turn reduces risk. Increases in soil carbon, when combined with the greater drought resilience of adapted agroforestry tree species, make such systems more resilient in the face of climate change and helps farm families to more readily adapt (World Agroforestry Centre, 2007). The IPCC 'Land Use, Land-Use Change and Forestry Report' of 2001 concluded that transformation of degraded agricultural lands to agroforestry has far greater potential to sequester carbon than any other managed land use change. Furthermore, components of production ecosystems that provide goods and services for agriculture, such as natural pest control, pollination and seed dispersal, will be favoured by agroforestry systems.

Action: *Reform policies that encourage inefficient, non-sustainable farming, grazing and forestry practices and increase incentives for agri-environment and forest certification schemes which promote the conservation of plant diversity.*

Action: *Develop more effective and cheaper methods for smallholder agroforestry carbon projects to allow such farmers to participate in carbon markets and improve their livelihoods by incorporating useful trees in their farms.*

Case study 8.4 The biodiversity benefits of agroforestry

In Indonesia, the regeneration of woody species in rubber agroforests is recognised as a practical opportunity to support biodiversity in a landscape where the natural forests are disappearing. In the Americas, traditional coffee-based agroforestry systems play an important role in protecting the migration corridors for birds. As a result of such synergies, complex agroforests represent a win-win opportunity for leveraging biodiversity conservation and carbon sequestration through innovative agricultural practices (World Agroforestry Centre, 2007).

Case study 8.5 The Plan Vivo model

The Plan Vivo model stems from the Scolel Té project in Chiapas, Mexico, developed since 1994 and supported by the Edinburgh Centre for Carbon Management (ECCM). Scolel Té involves over 700 farmers from 40 communities working with a range of agroforestry systems and small timber plantations. A trust fund provides farmers with financial and technical assistance based on the expected carbon revenues. Recent research on social impacts in this project indicates some trade-off between poverty and environmental objectives.

ECCM has now developed the Plan Vivo model as a management system and certification standard which incorporates sustainable livelihoods. The Plan Vivo model is being tested in the buffer zone of a protected area in Mozambique, and one in Southwest Uganda. These projects involve agroforestry activities and small-scale plantations, diversification of income generation activities and re-investment of profits in community infrastructure. In Mozambique, it is estimated that farmers will receive an average of US$35 per hectare per year for seven years for carbon sequestered by various land use activities. Although forest carbon is not profitable *per se*, positive net incomes are expected when it is combined with tree/crop product sales. Other reported benefits in Mozambique include increased availability of fruit, fodder, fuelwood, better soil structure and improved organisational capacity (Plan Vivo, no date).

8.7 Land use changes and carbon mitigation strategies

Land use changes in the tropics are a net source of carbon to the atmosphere, primarily due to deforestation – reported to be at least 20% (and perhaps as much as 30%) of total annual carbon emissions. Deforestation is the single most significant source of emissions in countries such as Brazil and Indonesia. Furthermore, research has shown that the highest level of carbon benefits result from conserving or extending primary rain forest (Smith & Scherr, 2002).

"*Curbing deforestation is a highly cost effective way of reducing ….emissions and has the potential to offer significant reductions fairly quickly*." Stern, 2006.

It has been argued that the conservation of tropical forests will be difficult unless the people who use the forests are compensated for the environmental services their forests provide to the world community. The Clean Development Mechanism (CDM) developed under the Kyoto Protocol may provide such a mechanism, but so far, only schemes for afforestation and reforestation are included within the CDM. This means that while there is an incentive to restore degraded forests and carry out new plantings, tropical deforestation is not covered and there is thus no incentive for developing countries to protect old-growth forests, which are some of the planet's major carbon storehouses.

At the December 2007 meeting of the Parties to the UNFCCC there was widespread support for the 'Reducing Emissions from Deforestation and Degradation' (REDD) plan, which aims to provide carbon credits to countries that achieve verifiable emissions reductions from forest protection measures. Although REDD projects are not recognised under the CDM during the first commitment period of the Kyoto Protocol (2008-2012), there is growing international consensus that REDD should be included post-2012. Such inclusion would have the potential to increase financial and political weight for programmes of sustainable forest management and conservation. However, some countries and groups have voiced skepticism that carbon trading can prove an effective mechanism to tackle deforestation, while others are concerned that REDD schemes may yield little benefits for local people (IUCN/WWF, 2007).

Case study 8.6
Costa Rica's expanding forests

Costa Rica has achieved dramatic results in addressing deforestation with a mix of conventional measures – such as creating national parks, banning deforestation and planting trees – and cash incentives, similar to those proposed through REDD. Its expanding forests are now absorbing so much carbon that Costa Rica expects to be carbon-neutral by 2021 - the first country to achieve this (Pearce, 2008).

Any intervention that prevents the conversion of a higher to a lower carbon storing land use, or that encourages conversion from a lower to a higher carbon storing status will contribute to net carbon storage. Although the per-hectare carbon benefits of agroforestry are low relative to averted deforestation, the area under low-productivity annual crop land and pastures is extensive in the tropics. There is thus significant potential to increase the carbon density of existing crop and pasture-based land use systems in ways that not only increase farm productivity and income but also support plant conservation through the use of greater plant diversity (Smith & Scherr, 2002).

Action: *Put incentives in place to encourage land to be used to its maximum carbon-storing potential, while ensuring that new plantings are ecologically suitable and are not detrimental to other ecosystem functions.*

Action: *Develop models and guidelines to ensure that REDD projects contribute to global biodiversity conservation, provide goods and services to forest-dependent people and contribute to sustainable development.*

8.8 Sustainable use of plant resources

Sustainable use of plant resources is crucial in a time of rapid global change. Unfortunately the track record on the sustainable use of plants has not been impressive to date and a significant proportion of globally threatened plants are threatened at least in part by unsustainable levels of harvesting from the wild. If action is not taken, climate change could prove to be the final straw for already threatened species, pushing them over the brink into extinction. There is however an increasing interest in sustainably produced plant products and certification schemes are in place in some areas to support this.

Targets of the GSPC relating to sustainable use are:

Target 11: "*No species of wild flora endangered by international trade".*
Target 12: *"30% of plant-based products derived from sustainably managed sources".*

8.8.1 The role of CITES

Species of wild flora endangered by international trade are covered by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Approximately 300 plant species are included in CITES Appendix I, over 28,000 in Appendix II (including the entire orchid family) and 10 in Appendix III. International trade in wild specimens of Appendix I species is effectively banned and this may encourage artificial propagation of wild species, thus reducing pressure on wild populations. For Appendix II species, the requirement that a non-detriment finding be made before trade is allowed is important, as this links trade to sustainable management. By no means all plant species that are threatened by international trade are included in the CITES appendices. Listing of high-value species such as trees traded for timber has been particularly slow. Nevertheless there is now a recognition that CITES can support the sustainable management of timber species and good collaboration has been developed between CITES and the International Tropical Timber Organisation (ITTO).

Action: *Carry out further research into the impact of international trade on wild plant species and develop a broader range of management responses that take into account the impacts of climate change on vulnerable species.*

Box 8.3 CITES Appendices

Appendix I – includes plant species threatened with extinction, for which international trade must be subject to particularly strict regulation, and only authorized in exceptional circumstances.

Appendix II – includes species which are not threatened with extinction at present, but may become so if unregulated trade continues.

Appendix III – includes species which are threatened locally through trade and are the subject of trade controls within certain nations (Oldfield & McGough, 2007).

8.8.2 Forest certification

The conservation of forest ecosystems, particularly old-growth tropical rainforest, is of particular importance as a climate change mitigation strategy. However, the high value and demand for tropical timber is an important driving force in the destruction of many old-growth forests. Sustainable forest management is therefore a key issue in the climate change debate.

The Forest Stewardship Council (FSC), which is widely regarded as the 'gold standard' in forest certification, has certified more than 90 million hectares of forest in 70 countries and other national forest certification schemes have been developed in over 35 countries. FSC has met with an enthusiastic response in many countries, and demand for FSC-certified products outstrips supply. Major retail outlets in the UK and USA for example are committed to stocking as many FSC products as they can and several governments have developed timber procurement policies that require them to seek certified products.

Although a comprehensive analysis of the overall impact of certification is lacking, within individual certified forest management units positive effects on biodiversity and the increased use of reduced impact practices can be seen. However, the main benefits of certification continue to be seen in the management of northern forests and certification has been a less effective tool in tackling the crisis of forest destruction and degradation in tropical forests (Magin, 2008). An ITTO report in 2006 estimated that only 5% of the total permanent forest estate in tropical countries is managed sustainably (ITTO, 2006).

Action: *Put incentives in place to encourage sustainable management of old growth natural vegetation to maintain carbon stocks.*

8.8.3 Sustainable harvesting of wild plants

Many wild plant species are already in decline as increasing demand from a growing population results in ever more unsustainable levels of harvesting. Such species include those that are used for medicinal purposes by large sectors of the world's population, and others that provide sources of nutrients that are particularly important for the rural poor. The loss of these species, as changing environmental conditions push already threatened populations towards extinction, is likely to have major livelihood implications for large numbers of the world's most vulnerable people.

This issue is addressed through GSPC Target 13: "*The decline of plant resources and associated indigenous and local knowledge, innovations and practices that support sustainable livelihoods, local food security and health care, halted*".

However, overall progress towards this target has been slow compared to the magnitude of the task and there is a great need for good case studies and analysis and dissemination of best practice.

An International Standard for the Sustainable Wild Collection of Medicinal and Aromatic Plants (ISSC-MAP) was launched in 2007. The standard is based on six principles: maintaining medicinal and aromatic plant resources in the wild; preventing negative environmental impacts; legal compliance; respecting customary rights; applying responsible management practices; and applying responsible business practices. However, protocols for sustainable production and trade in wild plants remain scarce at a species level and greater efforts are needed to develop and disseminate models and protocols.

Action: *Prioritise research on the development of protocols and models of sustainable harvesting for plant resources in marginal areas and for species and habitats vulnerable to climate change.*

8.9 Education and public awareness

In recent years climate change has become widely recognised as an important environmental issue. Regrettably however, the pivotal role of plant life in relation to climate change is frequently overlooked. This grave oversight occurs both in public discussion and in education strategies, and is reflected in policy development and strategic planning.

The fact that plants are neglected in the climate change debate can be attributed to both 'plant blindness' (failing to see, take notice of, or focus attention on plants in everyday life) (Wandersee & Clary, 2006) and to a lack of readily available statistics and data on the impact of climate change on plants.

During 2006, BGCI organised six national stakeholder consultations on the implementation of GSPC Target 14, which calls for "*The importance of plant diversity and the need for its conservation incorporated into communication, education and public awareness programmes*".
The meetings were held in Brazil, China, Indonesia, Russia, UK and the USA and over 375 representatives from all levels of the formal and informal education sectors participated in the consultation. The meetings emerged with an overwhelming consensus that communication, education and public awareness about plants was at a low ebb.

Everywhere, the emphasis on plant-based teaching was found to be weaker than animal-focused teaching in school curricula. This also mirrored a perceived media bias towards animals. Although it is well established that people develop an interest in biodiversity and conservation through first hand experiences with nature, the consultations reported that children were not being given sufficient opportunity to learn first-hand in this way.

Given the potential scale of the crisis and the small window of opportunity available for tackling climate change, immediate and intensive public awareness and education initiatives are needed at all levels. Such programmes should focus on encouraging and empowering people to:

- take a systemic approach to understanding their environment;
- reduce their individual and collective carbon emissions to mitigate climate change impacts;
- learn how to adapt to the climate change effects that are already being felt.

Public awareness and education strategies envisage a bilateral approach to consciousness-raising. In this framework public awareness aims to raise the baseline level of understanding of the importance of plants in the climate change debate and also to raise the profile of the subject among opinion formers and policy makers. As well as using the conventional machinery of public relations, press and media, new opportunities are also emerging to exploit the enormous potential of the internet. According to Inspire Foundation, an Australian not-for-profit organisation set up to create opportunities for young people to change the world using the internet, over 83% of youth have accessed the internet in the last 12 months and social networking is the most popular way for young people to be entertained and engage in society. We need to understand that technology has changed the way in which tomorrow's adults will interact with society and use this to engage young people in debate about climate change and plants.

Education is a long-term and systemic process that needs to start at the most basic level of human interaction with nature. Reintroducing people to all types of direct experiences, in and with nature, and providing a context in which they are encouraged to use these experiences to make meaning will enable people to address climate change, both as individuals and as members of social and societal organisations.

Formal education strategies would thus aim to embed plant-based education in school and other academic or training curricula, whereas informal strategies would aim to incorporate plants into workshops, art and media events, short courses, in-service education programmes, training and ecotourism. Informal strategies would encourage and facilitate interaction with and conservation of existing natural resources such as parks, nature preserves, and water features. Here botanic gardens, located as many of them are in the world's major cities and visited by at least 200 million people annually, have a particularly important role to play.

Case study 8.7 Education and public awareness programmes in botanic gardens

There are already many excellent examples of public awareness and education programmes run by botanic gardens around the world, for example:

The South African National Biodiversity Institute (SANBI) manages a network of nine botanic gardens throughout South Africa. It runs a very effective outreach programme assisting local schools and communities to 'green-up' their areas through developing water-wise gardens and planting indigenous trees and plants that can be used as well as enjoyed.

Fairchild Tropical Garden, USA, runs a competitive multidisciplinary education programme called the Fairchild Challenge. Teenagers select environmental challenges that will give them an opportunity to research, debate, create, perform, interview and design. Over 40,000 youngsters have been involved in the programme so far and this number is growing as increasing numbers of botanic gardens set up their own Fairchild Challenge.

In 2007, the Zoological-Botanical Foundation in Rio do Sul (FZB), Brazil, initiated a public awareness campaign on climate change to show the importance of individual and collective contributions by citizens, as well as to explain causes and consequences of climate changes. FZB ran lectures and discussion meetings and produced educational materials for students and teachers of state public schools.

The staff of the University of Oxford Botanic Garden and the Harcourt Arboretum, UK, have scrutinised every aspect of their working practices to reduce their carbon footprint and communicate this to their visitors. Special education programmes and activities, including public lectures, leaflets and exhibitions, focusing on climate change have been offered to schools and families. The garden's zero-waste challenge for visiting school groups also reinforces the message about our need to reduce carbon usage.

Action: *Ensure that plant-based education is included within national education curricula and that out-of-classroom learning is an integral part of every child's education. A particular aim would be to ensure that all children understand the fundamental role of plants in the carbon cycle and the relevance of this to climate change.*

Action: *Identify and scale up effective public awareness and education programmes for climate change, including coordinated national campaigns with highly visible spokespeople to raise public awareness of the need for plant conservation.*

Action: *Increase overall awareness and use of public natural areas for providing direct experiences of nature.*

Action: *Provide an internet based information service on plants and climate change, building on the findings of this report.*

8.10 Capacity building for plant conservation

In the development of the GSPC in 2002, it was recognised that achievement of the targets included in the Strategy would require very considerable capacity building, particularly to address the need for conservation practitioners trained in a range of disciplines, with access to adequate facilities. In light of this, Target 15 calls for "*The number of trained people working with the appropriate facilities in plant conservation increased, according to national needs, to achieve the targets of the Strategy*".

At the time it was suggested that the number of trained people working in plant conservation worldwide would need to double by 2010, with comparatively more capacity needed in developing countries, small island developing states and countries with economies in transition.

Some progress has been made towards this target with the development of various collaborative projects and training programmes aimed to help countries meet their obligations under the CBD, including the GSPC. However it is clear that considerable gaps still exist. Furthermore, the challenges provided by climate change will require new skills and capacity building across most countries of the world.

Action: *Encourage sharing of skills through plant conservation training courses at all levels as provided by BGCI and its associated botanic garden networks in order to boost capacity to propagate, conserve, cultivate and restore threatened plant species and to carry out relevant education programmes.*

8. 11 Partnerships and networking

Networks can enhance communication and provide a mechanism to exchange information, knowledge and technology. Target 16 of the GSPC calls for "*Networks for plant conservation activities established or strengthened at national, regional and international levels*".

Effective networks provide a means to develop common approaches to plant conservation problems, to share policies and priorities and to help disseminate the implementation of all such policies at different levels. They can also help to strengthen the links between different sectors relevant to conservation, e.g. the botanical, environmental, agricultural, forest and educational sectors.

Within the botanic garden community, BGCI provides an effective network for botanic gardens around the world and has facilitated the exchange of information and expertise for over 20 years. A programme specifically relating to climate change is planned based on recommendations of the Gran Canaria II Declaration and findings of this current report. As part of this, the International Agenda for Botanic Gardens in Conservation (Wyse Jackson & Sutherland, 2000) which has

Box 8.4 - Some relevant networks and partnerships

Ecoagriculture Partners - Ecoagriculture Partners comprise dozens of institutions and thousands of individual experts whose work is geared toward ensuring that agricultural landscapes are increasingly managed to achieve enhanced rural livelihoods, conservation of biodiversity and sustainable production.

Collaborative Partnership on Forests - The Collaborative Partnership on Forests (CPF) is an informal, voluntary arrangement between 14 international organizations and secretariats with substantial programmes on forests. The mission of CPF is to promote the sustainable management of all types of forests and to strengthen long-term political commitment to this end.

Global Partnership on Forest Landscape Restoration - The Global Partnership on Forest Landscape Restoration brings together more than 25 government agencies and organizations to foster innovative and practical approaches for restoring degraded forest ecosystems.

ASB Partnership for Tropical Forest Margins - The goal of ASB is to raise productivity and income of rural households in the humid tropics without increasing deforestation or undermining essential environmental services.

been adopted by 485 botanic gardens will be strengthened to recognise more comprehensively the impact of climate change and develop urgent responses. A specific objective of BGCI's current five year plan is to strengthen the links between botanic gardens and other conservation agencies to promote integrated biodiversity conservation solutions.

The GSPC itself has sparked the formation of the Global Partnership for Plant Conservation (GPPC), which is a network of international, regional and national organisations committed to supporting implementation of the GSPC. The GPPC provides a framework to facilitate harmony between existing initiatives aimed at plant conservation, identify gaps where new initiatives are required, and promote mobilisation of the necessary resources. The GPPC now includes 34 member institutions and organisations worldwide.

A large number of relevant networks and partnerships exist at various levels, from local to global and these include national and regional networks of botanic gardens that focus on the conservation of wild plant species, to international partnerships between governments and organisations focused on a broad range of plant conservation work.

It is notable however that most of the existing networks tend to be sector-specific, with a focus on for example, wild plant conservation, agriculture or forestry. Few genuinely cross-sectoral networks exist and this is a constraint for effective plant conservation. As has been made clear in this report, plant conservation requires action by a broad range of actors, including botanists, agriculturalists, land managers, foresters and educators. There is therefore a need to further develop cross-sectoral networks at both national and international levels in order to develop holistic responses to plant conservation needs in a changing climate.

Action: *Establish a coordinating mechanism and task force enabling botanical information and expertise to be fully available and utilised in responding to the challenge of climate change based on the membership of the GPPC.*

Conclusions and recommendations

It is clear that climate change is happening now. The direct effects of anthropogenic climate change have been documented on every continent and complexities surrounding methods of detection and attribution have been explored in depth (Parmesan, 2006). Although catastrophic predictions exists, these do not have to come true. Future climate change will depend on the actions we take now.

"*There is high agreement and much evidence that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers*". IPCC, 2007.

We know that many plant species are already threatened by habitat loss and unsustainable levels of exploitation. The additional threats posed by climate change are therefore likely to result in plant extinctions occurring at a rate unmatched in geological history. Action is needed now to ensure our options for the future.

We also know that the most diverse ecosystems will be the most resilient and adaptable in the face of changing climates. Every species has a role to play in a functioning ecosystem, and conserving ecosystems is therefore an important way of conserving species. However, in order to ensure effective conservation, climate change management strategies will require reliable scientific data both on the nature of climate change and on its potential impact on plants and plant communities.

Further, priority must be placed on assessing how future climate conditions will impact the most vulnerable species so that current and future management actions can be most effectively targeted. At a time when we should be conserving more, we are in fact losing more.

In this report we have identified a number of areas where we believe actions are needed now to ensure a future for the world's flora. These can be grouped together under three major recommendations:

Recommendation 1: Ensure that strenuous efforts are made to meet the targets of the GSPC by 2010.

Actions required:

- Mobilise resources to support those organisations working towards compiling a working list of all known plant species, to ensure that this is completed as soon as possible.
- Collate all available information on the status of threatened plants to supplement the IUCN Red Listing process and achieve Target 2 of the GSPC.
- Ensure that *in situ* conservation strategies, supported as necessary by *ex situ* action, are in place for all plant species presently known to be threatened at the global level.
- Reform policies that encourage inefficient, non-sustainable farming, grazing and forestry practices and increase incentives for agri-environment and forest certification schemes which promote the conservation of plant diversity.
- Ensure that plant-based education is included within national education curricula and that out-of-classroom learning is an integral part of every child's education. A particular aim would be to ensure that all children understand the fundamental role of plants in the carbon cycle and the relevance of this to climate change.
- Encourage sharing of skills through plant conservation training courses at all levels as provided by BGCI and its associated botanic garden networks in order to boost capacity to propagate, conserve, cultivate and restore threatened plant species and to carry out relevant education programmes.

Recommendation 2: As a matter of urgency, reform existing plant diversity management activities so as to maximize climate change mitigation and adaptation opportunities.

Actions required:

- Encourage the use of locally appropriate threatened tree species in tree-planting schemes designed to offset carbon emissions.
- Collect baseline data on species distribution and threat assessment when collecting seed and make information freely available via the internet – using existing biodiversity information resources, such as GBIF.
- Step up activities to conserve habitats with maximum plant diversity, notably tropical forests.
- Implement climate change management strategies in ecosystems that are most vulnerable to climate change, with a particular focus on forest, island and alpine ecosystems.

- Put incentives in place to encourage land to be used to its maximum carbon-storing potential, while ensuring that new plantings are ecologically suitable and are not detrimental to other ecosystem functions.

- Put incentives in place to encourage sustainable management of old growth natural vegetation to maintain carbon stocks.

- Increase the range of management plans for dealing with invasive plants, building on the success of the GSPC.

- Develop more effective and cheaper methods for small-scale agroforestry carbon projects to allow such farmers to participate in carbon markets and improve their livelihoods by incorporating useful trees in their farms.

- Identify and scale up effective public awareness and education programmes for climate change, including coordinated national campaigns with highly visible spokespeople to raise public awareness of the need for plant conservation as a component of climate change strategies.

- Increase overall awareness and use of public natural areas for providing direct experiences of nature.

- Establish a coordinating mechanism and task force enabling botanical information and expertise to be fully available and utilised in responding to the challenge of climate change based on the membership of the GPPC.

Recommendation 3: Collect information to prepare comprehensive strategies and plan effectively to deal with plant conservation in the face of climate change.

Actions required:

- Provide an internet based information service on plants and climate change, building on the findings of this report.

- Agree upon and implement climate change vulnerability criteria for plants as a matter of urgency and ensure that these are applied by as wide a range of botanical experts as possible worldwide to identify the species most at risk from climate change.

- Carry out a global tree assessment using the IUCN Red List categories and criteria, updating existing information as a basis for monitoring climate change and increasing conservation action for the world's most threatened trees.

- Develop more realistic plant diversity – climate change modeling approaches to detect potentially threatened species and potentially invasive species in a changing climate scenario. Make protocols available through the plants2010.org website.

- Develop field-based monitoring programmes, focused on vulnerable areas, to enable long term assessment of the impact of climate change on plant diversity.

- Develop a global plant adaptation network to gather data on the plasticity of key species under a wide range of environmental conditions.

- Carry out further modeling to identify ecological regions and plant diversity hotspots most at risk because of climate change.

- Continue efforts to identify gaps in existing *ex situ* collections as an urgent priority and ensure that genetically representative populations of threatened species as well as species vulnerable to climate change are conserved *ex situ*. Prioritise montane, coastal and island species as well as those of livelihood value in marginal areas.

- Identify geographical areas that will provide refugia for the maximum diversity of species (e.g. montane areas with heterogenous relief) and prioritise these as IPAs for *in situ* conservation.

- Develop methodologies to enable the capture of maximum genetic diversity at population level of target species for *ex situ* conservation and ecosystem restoration.

- Establish research programmes and feedback loops linking scientific knowledge with site management and conservation policy process to foster better understanding of climate change management.

- Review the effectiveness of biodiversity corridors in facilitating plant movement and conduct further research on the issues related to assisted migration.

- Apply preventative and precautionary principles in addressing issues related to invasive species and develop early warning systems and rapid response capacities at the national level.

- Develop models and guidelines to ensure that REDD projects contribute to global biodiversity conservation, provide goods and services to forest-dependent people and contribute to sustainable development.

- Carry out further research into the impact of international trade on wild plant species and develop a broader range of management responses that take into account the impacts of climate change on vulnerable species.

- Prioritise research on the development of protocols and models of sustainable harvesting for plant resources in marginal areas and for species and habitats vulnerable to climate change.

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Annex 1. The Global Strategy for Plant Conservation: 2010 Targets

A) Understanding and Documenting Plant Diversity

Targets in this theme are:

(i) A widely accessible working list of known plant species, as a step towards a complete world flora;

(ii) A preliminary assessment of the conservation status of all known plant species, at national, regional and international levels;

(iii) Development of models with protocols for plant conservation and sustainable use, based on research and practical experience.

B) Conserving Plant Diversity

Targets in this theme are:

(iv) At least 10 per cent of each of the world's ecological regions effectively conserved;

(v) Protection of 50 per cent of the most important areas for plant diversity assured;

(vi) At least 30 per cent of production lands managed consistent with the conservation of plant diversity;

(vii) 60 per cent of the world's threatened species conserved in situ;

(viii) 60 per cent of threatened plant species in accessible ex situ collections, preferably in the country of origin, and 10 per cent of them included in recovery and restoration programmes;

(ix) 70 per cent of the genetic diversity of crops and other major socioeconomically valuable plant species conserved, and associated indigenous and local knowledge maintained;

(x) Management plans in place for at least 100 major alien species that threaten plants, plant communities and associated habitats and ecosystems.

(C) Using Plant Diversity Sustainably

Targets in this theme are:

(xi) No species of wild flora endangered by international trade;

(xii) 30 per cent of plant-based products derived from sources that are sustainably managed.

(D) Promoting Education and Awareness About Plant Diversity

The target for this theme is:

(xiv) The importance of plant diversity and the need for its conservation incorporated into communication, educational and public –awareness programmes.

(E) Building Capacity for the Conservation of Plant Diversity

Targets in this theme are:

(xv) The number of trained people working with appropriate facilities in plant conservation increased, according to national needs, to achieve the targets of this Strategy;

(xvi) Networks for plant conservation activities established or strengthened at national, regional and international levels.

Botanic Gardens Conservation International

Descanso House, 199 Kew Road,
Richmond, Surrey, TW9 3BW, U.K.

Tel: +44 (0)20 8332 5953
Fax: +44 (0)20 8332 5956
E-mail: info@bgci.org
Internet: www.bgci.org








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