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Biodiversity–climate interactions: adaptation, mitigation and human livelihoods

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Biodiversity–climate interactions: adaptation, mitigation and human livelihoods

Report of an international meeting, June 2007

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Preparation of this report

This policy report is based on material presented at an international workshop held in June 2007 at the Royal Society, London, and reflects the main messages that arose from discussions during the break-out and plenary discussions.

The report was drafted by the Royal Society Science Policy section with support from the UK Department for Environment, Food and Rural Affairs; UK Department for International Development; UK Joint Nature Conservation Committee; Royal Botanic Gardens, Kew; and the Met Office Hadley Centre, UK. Presenters at the meeting were invited to submit additional text summarising their key messages following the workshop. The responses received are appended to this document.

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This report does not necessarily represent the views of the sponsoring organisations or the meeting speakers and participants.

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Summary

1 Climate, biodiversity and human wellbeing are inextricably linked. Significant political commitments and policy objectives for each now exist at national and international levels. Our understanding of these issues, the relevant processes and their inter-relationships is far from complete. However, we know enough to identify some critically important matters for immediate attention and priority areas for research and policy development. New mechanisms are needed to galvanise work in this area, especially at the inter-governmental level.

2 Significant impacts of climate change on biodiversity have already been identified, with up to 50% of the species studied worldwide affected. The Inter-governmental Panel on Climate Change (IPCC 2007b) concludes that if global mean temperature increases exceed 2–3 °C above pre-industrial levels, 20–30% of plant and animal species assessed are likely to be at increasingly high risk of extinction.

3 The continuing, accelerating loss of biodiversity could compromise the long-term ability of ecosystems to regulate the climate, may accelerate or amplify climate warming and could lead to additional, unforeseen and potentially irreversible shifts in the Earth system. Urgent action now to halt further loss or degradation of biodiversity will help to maintain future options for tackling climate change and managing its impacts.

4 Both mitigation and adaptation are required if we are to reduce climate change and its impacts over coming decades. Many of the people most vulnerable to climate change are those who depend most on biodiversity. Climate-change policy must maximise the opportunities for implementation of mutually supportive strategies.

5 New policies are needed to integrate options for meeting biodiversity, climate and sustainable development objectives at the international, national and local levels. Difficult policy choices lie ahead, requiring scientific and technical expertise and understanding of socio-economic and ethical considerations. For example, climate-change policies must, as a priority, identify the protection of biodiversity and healthy ecosystems as highly relevant to climate-change mitigation and adaptation.

6 Our understanding of the impact of climate change on biodiversity is increasing, but our knowledge of the impact of biodiversity on climate is less advanced. A significant new research effort is required to improve understanding of the role of biodiversity in Earth and climate systems, the impacts of climate change on biodiversity and human populations, and their inter-linkages, feedback mechanisms and cross-scale effects.

1 Introduction

1.1 The interconnectedness of climate, biodiversity and human wellbeing

Biodiversity is important in ecosystems and for the provision of ecosystem services including climate regulation. It can therefore play an important role in reducing climate change and its impacts, and protecting and improving societal wellbeing. However, there is growing concern that efforts to address climate change may have the unintended consequence of exacerbating biodiversity loss, and so reduce future options for responding to climate change.

Climate, biodiversity and human wellbeing are inextricably linked (Figure 1). Over the past few hundred years, human activity has significantly changed the face of the planet, a period sometimes described as the anthropocene (Crutzen & Stoermer 2000). Consequently, we are changing the Earth's climate, species are disappearing at a faster rate than ever before, and many of the ecosystems on which humans and other species depend for their basic survival are being degraded or used unsustainably.

Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history (Millennium Ecosystem Assessment (MA) 2005a). The implications of these changes are only now beginning to be understood. Anthropogenic climate change provides a compelling example of the profound effect human activities can have on natural systems and of the consequences of these impacts for human wellbeing. Even if greenhouse gas emissions were to cease immediately, temperatures would continue to rise for at least 30 years, and sea levels for the next 100 years. Action must be taken now to prepare for the impacts that are inevitable over forthcoming decades. Efforts must be targeted at reducing the vulnerability of those human populations and ecosystems most at risk.

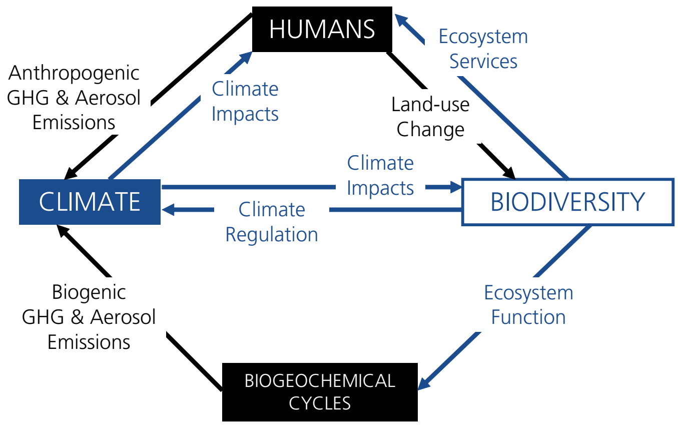
Because ecosystems collectively determine the biogeochemical and biophysical processes that regulate the Earth system, the potential ecological and climate consequences of biodiversity loss are arousing significant scientific interest. Continued biodiversity loss may compromise the long-term ability of ecosystems to regulate the climate, may accelerate or amplify climate warming, and could lead to additional, unforeseen and potentially irreversible shifts in the Earth system. Biodiversity loss and ecosystem degradation should be of major concern to decision-makers around the world. However, recognition of the critical nature of this problem, and of the potential opportunities of biodiversity management for meeting climate-change policy objectives, has been slow to appear outside of the biodiversity community.

The interdependencies of biodiversity, ecosystems, human livelihoods and the climate system make it possible to address biodiversity loss, ecosystem degradation, sustainable development, and climate change and its impacts, together. However, there is also growing awareness that win–win–wins will not always be possible, and trade-offs may be necessary. To realise the potential co-benefits, and to ensure trade-offs are as equitable and ecologically sustainable as possible, new decision-making and implementation frameworks are required.

The international community has a critical role to play in this, and in supporting the capacity building and resources required for implementation. National governments and local communities also have their part to play.

The messages are simple; climate change is unequivocal. Mitigation and adaptation will be required to address the

Figure 1 Simple schematic demonstrating linkages between human wellbeing, biodiversity and climate change.



risks posed by climate change. Biodiversity is necessary for human wellbeing and climate regulation: it must be central to the development of adaptation and mitigation programmes.

1.2 Origins of this report

In June 2007 the Royal Society hosted a meeting in collaboration with Defra[1], DFID[2], JNCC[3], Kew[4], the Met Office Hadley Centre[5] and NERC[6] to investigate the inter-linkages between biodiversity, climate change, and human livelihoods.

The meeting brought together experts from the biodiversity, climate change and sustainable development communities to encourage dialogue and cooperation and to identify opportunities for maximising policy and science synergies. The aims of the meeting were to identify the potential role for biodiversity management in climate-change mitigation and adaptation, and to identify the priority science needs for improving our understanding of the role of biodiversity in climate regulation. The main messages to emerge from the meeting are designed to inform future work and provide new impetus for active, integrated policy and research programmes on biodiversity, climate-change mitigation and adaptation, and human livelihoods.

The meeting's objectives were:

a to raise the profile of biodiversity within the climate-change debate and to encourage decision-makers to consider biodiversity, climate change and human livelihoods together when developing strategies for sustainable development, protection of biodiversity, and reduction of climate change and its impacts;

b to explore the role and function of biodiversity and ecosystems in the climate system;

c to consider the interactions between human livelihoods, the biosphere and climate in terms of functions and impacts;

d to consider the role that maintaining and managing biodiversity can, and should, play in climate change adaptation and mitigation strategies; and

e to identify key areas in which biodiversity, climate change, and sustainable development science and policy can be coordinated.

A summary of the meeting's main messages was produced for the Convention on Biological Diversity (CBD) Subsidiary Body on Scientific, Technical, and Technological Advice (SBSTTA) in Paris in July 2007. This is available on the Royal Society's website at http://www.royalsoc.ac.uk/document.asp?tip=0&id=6830.

This final report was showcased at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) meeting in Indonesia in December 2007.

This policy report is based on material presented at the June meeting, and during the breakout groups and plenary discussions. The abstracts are appended with the meeting programme to the end of this document (Appendix 1). Additional text provided by speakers is attached in Appendix 2. For detail about the science of climate change and its impacts, readers should refer to the IPCC Fourth Assessment Report (2007). For detail regarding ecosystems and human wellbeing, readers should refer to the MA (2005a–c).

[1] UK Department for Environment, Food and Rural Affairs.
[2] UK Department for International Development.
[3] UK Joint Nature Conservation Committee.
[4] Royal Botanic Gardens, Kew.
[5] Met Office Hadley Centre, UK.
[6] UK Natural Environment Research Council.

2 Biodiversity and ecosystem functioning

Biological diversity (biodiversity) is defined by the Convention of Biological Diversity (CBD) as the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems. The role and function of biodiversity in ecosystems is complex but we know that ecosystem properties, and therefore the services they provide, are influenced by the characteristics of the species present and their functional traits (Reich et al 2004, Hooper et al 2005).

Crucially, higher genetic and species diversity tends to make ecosystems more resistant and resilient to disturbance. This is because species are more likely to be present with characteristics that will enable the ecosystem to adjust to environmental change (Hooper et al 2005; Reusch et al 2005; Tilman et al 2006). This means that ecosystems can continue to function and provide critical services such as water purification. As biodiversity declines, so too does the resilience of the system. Ecosystems with low resilience, when subject to shocks or disturbance, may reach a threshold at which abrupt change occurs (Scheffer et al 2001). Biodiversity is therefore important as it provides flexibility and insurance, and spreads risk across temporal and spatial scales (Yachi and Loreau 1999; Loreau et al 2003).

2.1 Biodiversity, ecosystems and human wellbeing

The components of human wellbeing were defined by the MA (2005a–c) as security, basic material for a good life, health, good social relations, and freedom of choice and action, all of which depend either directly or indirectly on ecosystems and the services they provide (and therefore on biodiversity). Humans rely on food, clean air and water, timber and medicines for survival. Human livelihoods rely on ecological services that support global employment and economic activity (for example food and timber production, marine fisheries and aquaculture, and recreation) (MA 2005a).

The relationship between biodiversity, ecosystems, and human wellbeing was characterised by the MA (2005a), which described four categories of services provided by ecosystems to society (see Figure 2). Supporting services underpin all other ecosystem services and capture processes such as carbon cycling (eg primary production, decomposition, and soil formation), and water and nutrient (eg nitrogen and phosphorus) cycling. Regulating services provide the mechanisms that moderate the impact of stresses and shocks on ecosystems (Kinzig et al 2006) and include, for example, climate and disease regulation. Regulating services determine the distribution of provisioning services, such as food, fuel and fibre, and cultural services such as spiritual and aesthetic values (Kinzig et al 2007).

The transformation of ecosystems and exploitation of natural resources have resulted in substantial gains in human wellbeing and economic development. However, the benefits have not been equitably distributed, and the costs of biodiversity changes either not recognised or quantified. This is because ecosystems tend to be valued by people in terms of the direct benefits provided by provisioning and cultural services (for example food, fibre, recreation and aesthetics respectively) which represent a relatively small component of biodiversity. However, the supply of these services is underpinned by supporting and regulating services, (for example pollination, climate regulation and primary productivity respectively), for which the value of biodiversity is less visible but no less important (Scholes & Midgley 2007, Kinzig et al 2007). Biodiversity loss, ecosystem degradation, and consequent changes in ecosystem services have also led to a decline in human wellbeing in some groups by exacerbating poverty and increasing inequities and disparities (MA 2005b).

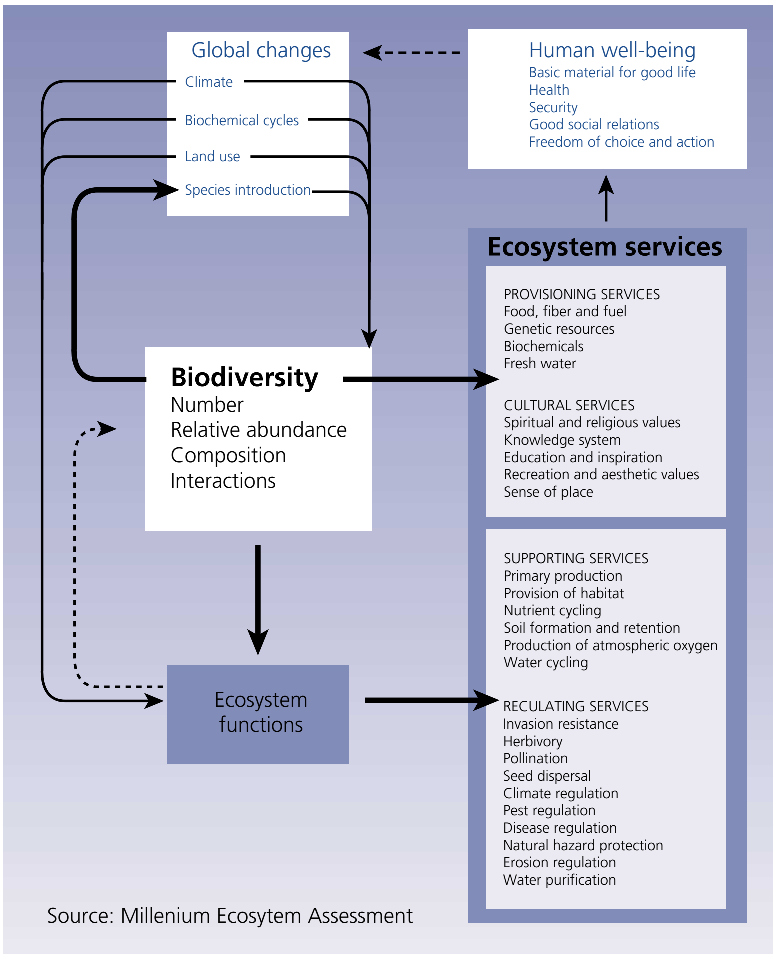
By highlighting the inter-relationships between biodiversity, ecosystems and human wellbeing, the MA demonstrated that environment and development objectives are not incompatible, and in many cases are inter-dependent. Many of the examples we have of impacts on livelihoods that have arisen due to changes in biodiversity, are the result of system changes, rather than the losses of individual species (Scholes & Midgley 2007).

2.2 Implications of biodiversity loss

Biodiversity plays a fundamental role in underpinning ecosystems and the services they provide, including climate regulation. Continued biodiversity loss may compromise our ability to tackle climate change, and to manage climate impacts now and in the future. Biodiversity also provides other services to human livelihoods either directly or indirectly, so the implications of biodiversity loss for human health and wellbeing are expected to be significant. The MA concluded that continued environmental degradation will affect the achievement of the Millennium Development Goals (MA 2005).

Coral reefs are a good example of ecosystems that provide a vital role in human livelihoods, in the climate system and in terms of biodiversity. Coral reefs cover 0.1% of the ocean floor but host an estimated 25% of marine species. An estimated 500 million people depend on coral reefs for food, coastal protection and income from fisheries or tourism (Wilkinson 2004). Coral reefs will

Figure 2 Millennium Ecosystem Assessment typology of the relationships between biodiversity, ecosystem functioning and ecosystem services. Biodiversity is both a response variable affected by global change drivers, and a factor modifying ecosystem processes and services and human wellbeing (MA 2005b).



suffer significant negative impacts as a result of the increasing acidification of the world's oceans and increases in sea temperature arising from increasing carbon dioxide (CO_2) emissions and climate change. They exist within a narrow band of temperature, light and calcium carbonate limits. Temperatures exceeding 2°C of the upper end of this range can cause corals to bleach and die. Atmospheric CO_2 concentrations of 500 ppm are sufficient to prevent coral calcification rates from keeping up with erosion rates. Together, these effects are likely to cause major changes to corals over the next few decades. Models suggest that the corals could become rare by 2050 if atmospheric CO_2 concentrations were to double (Hoegh-Guldberg 2007). Reefs are under threat from other pressures such as overexploitation, invasive species and pollution. These multiple impacts increase reef vulnerability and reduce resilience to climate change. Clearly, the collapse of these systems would have significant implications for the millions of people who rely on them.

3 The role of ecosystems in the climate system

Ecosystems play a direct role in climate regulation via physical, biological and chemical processes that control fluxes of energy, water and atmospheric constituents. Marine and terrestrial ecosystems provide sources and sinks for many atmospheric constituents including the greenhouse gases tropospheric ozone (O_3), CO_2, methane (CH_4) and nitrous oxide (N_2O), and aerosols. The biophysical properties of ecosystems also affect water and energy fluxes between the atmosphere, land and ocean, with consequent effects on rainfall, temperature and wind patterns. As these ecosystems change, for example as a result of natural variation or from human activities, there will be inevitable effects on the climate system.

The physical characteristics of ecosystems determine surface albedo, which also influences water and energy fluxes between the Earth's surface and the atmosphere. Surface climate is affected by, and interacts with, vegetation characteristics, productivity, soil and vegetation respiration, and fires, all of which are also important in the carbon cycle (IPCC 2007a). Plants play a particularly important role as plant evapotranspiration drives the water cycle in the terrestrial environment, and influences land surface albedo (for example, deserts have a much higher albedo than forests). Forests transmit a larger proportion of their energy to the atmosphere as latent heat by evapotranspiration than grasslands because they have deeper roots and greater leaf area (MA 2005c). The composition of plant communities therefore has an influence on the quantity of energy absorbed and exchanged with the atmosphere, and the partitioning of the energy flux (MA 2005c). Many plant species emit volatile organic compounds (VOCs) such as isoprene, which act as precursors for the formation of ground level ozone (a greenhouse gas), and may also be important in cloud formation (Nobre 2007).
In the marine environment, phytoplankton can modify surface ocean albedo and produce VOCs including dimethyl sulphide (DMS), which also influences cloud formation over the oceans (Charlson et al 1987).

The carbon cycle is the process by which carbon is exchanged between the terrestrial and marine environments and the atmosphere through biogeochemical processes. Terrestrial ecosystems contain more than three times as much carbon as the atmosphere, with peatlands and wetlands providing the largest below-ground stores, and tropical forests dominating above-ground biomass. The oceans are arguably even more important in the long-term carbon cycle as they account for about 95% of all the carbon in the oceans, atmosphere and terrestrial system, constituting a massive reservoir of carbon (Royal Society 2005). Species composition influences biological productivity, which in turn largely determines the sequestration of carbon in ocean and terrestrial ecosystems. In the terrestrial environment, plant photosynthesis captures carbon, which is returned to the atmosphere through soil, plant and animal respiration (IPCC 2007a). In the ocean, species richness and composition of the plankton community is important for the efficiency of the transfer of carbon from the surface to the deep ocean (through food webs).

There are multiple positive and negative feedback processes between ecosystems and climate. For example, large-scale tropical deforestation reduces regional rainfall, potentially causing further forest loss and additional impacts on regional climate (see below). These feedbacks are generally nonlinear and have the potential to produce large, undesirable results, particularly at the regional level. For a more detailed explanation of the role of ecosystems in the climate system, readers should refer to the IPCC (2007a).

Box 1 Amazonia: an example of a key ecosystem for climate regulation (based on the presentation provided by Antonio Nobre 2007)

The climate of Amazonia is strongly dependent on the presence of the forest. Amazonia has been described as a 'Green Ocean' with satellite imagery revealing very high cloud cover and rainfall over the region compared with the surrounding oceans. The forest is also a very large carbon store.

Compared with unforested land, forest cover can enhance evapotranspiration through the extraction of moisture deep in the soil by plant roots. The canopy can capture a greater fraction of rainfall which is then re-evaporated back to the atmosphere, compared with bare soil which holds less water on the surface before runoff and infiltration. Furthermore, the higher aerodynamic roughness of a forested land surface can promote the flux of moisture to the atmosphere through enhanced turbulence. Biogenic VOCs are emitted by many different plant species, and may act as cloud condensation nuclei, potentially enhancing cloud cover. VOCs can also affect concentrations of ground-level O_3, an important greenhouse gas, leading to O_3 destruction when nitrogen oxide (NO_x) levels are low, but net O_3 production when NO_x levels are higher (Sanderson et al 2003). Aerosols arising as a result of biomass burning may change rainfall regimes and maintain a dry fire-prone land surface.

Deforestation in the Amazon region accounts for 5–10% of global CO_2 emissions. Global climate change may also lead to changes in Amazonian vegetation cover, especially if there is a significant reduction in rainfall in the region. The relationship between the warming of global average temperature and changes in regional rainfall patterns is highly uncertain, but several climate models suggest that global warming could lead to particular patterns of warming in the North Atlantic, and tropical east Pacific sea surface temperatures (SSTs) which change the atmospheric circulation reducing rainfall across large parts of Amazonia. Strong drying of Amazonia or northeast South America is simulated by variants of the Hadley Centre climate model (Cox et al 2004) and feedbacks between the forest loss and regional and global climate contribute to the strength of this drying (Betts et al 2004).

Deforestation or degradation of the forest as a result of habitat fragmentation or climate change may therefore significantly alter the climate of the Amazon region and also contribute to global climate change.

4 Impacts of climate change

The recent warming of the climate system is unequivocal and is very likely to be due to human activities (IPCC 2007a). Since the Industrial Revolution, human activities have led to increased concentrations of greenhouse gases (CO_2, CH_4, N_2O) in the atmosphere, causing changes to the climate system. There may be short-term local and regional benefits from these changes as a result of low to moderate levels of increased atmospheric CO_2 and climate change (IPCC 2007b), for example increased water availability, ecological and crop productivity, and human health. However, as climate change continues, greater impacts are projected (IPCC 2007b). The effects on terrestrial ecosystems may lead to a weakening or even reversal of terrestrial carbon sinks by 2100, potentially amplifying climate change (IPCC 2007b).

Adverse impacts arising from changes in climate are already being observed. For example, climate change may have led to the extinction of 74 species of highland cloud forest frogs (Parmesan 2007). In Asia, rising temperatures have contributed to declines in crop yield (IPCC 2007b), and in 2003, a heatwave across Europe caused 35,000 deaths in France, Belgium, the Czech Republic, Germany, Italy, Portugal, Switzerland, the Netherlands and the UK (IPCC 2007b). Furthermore, the oceans are becoming more acidic as a direct result of the increase in atmospheric CO_2 since 1750 (Royal Society 2005).

In addition to the direct impacts of climate change on natural systems and society, there may be indirect effects; for example on human wellbeing as a result of political and social instability prompted by climate induced resource scarcity. Equally, the efforts of society to reduce climate change, eg by growing biofuel crops, will in some cases cause further biodiversity loss and reduced ecosystem functioning. It is therefore essential that these interactions are taken into account when assessing the implications of climate change and the impacts of mitigation policies.

4.1 Impacts of climate change on biodiversity

Predicting the impacts of climate change on biodiversity is difficult because the ability of many species or ecosystems to respond to changes in climatic extremes, and shifts in intensity and frequency of extreme weather events, are unknown. The fossil record may provide insights into what can be expected (Willis et al 2007). For example, approximately 11,500 years ago, regional temperatures may have increased by as much as 15–20 °C over a period of 50 years. Although there is no evidence of species extinctions arising as a result, there is evidence for redistribution of species and communities, and local and regional extinctions (Willis 2007). Such results must be interpreted with caution as the expected magnitude of future climate change is greater than that seen in the past 500,000 years, and ecosystems are more degraded relative to the geological past (CBD 2006).
The unprecedented combination of climate change, associated disturbances and other global drivers, are expected to exceed the resilience of many ecosystems this century if allowed to continue at current rates (Sala et al 2000; IPCC 2007b). The key questions are how much climatic change ecosystems are able to tolerate before being forced into a new state, and what the consequences of such changes may be.

Recent reviews (IPCC 2007b; Parmesan 2007) have concluded that climate change is already disrupting species interactions and ecological relationships.
With relatively small changes in recent temperatures (a rise of 0.76 °C from 1905 to 2005), half of all wild species for which there are long-term data have shown a response to local, regional or continental warming (Parmesan & Yohe 2003). Every major biological group that has been studied (eg from herbs to trees, from plankton to fish, and from insects to mammals) has shown a response, and responses have been seen on all continents and in all major oceans (Parmesan and Galbraith 2004; Parmesan 2006). Rare species that live in fragile or extreme habitats are already being affected, for example species that depend on the extent of sea ice such as the polar bear, ringed seal and the Adelie Penguin are showing drastic declines (Parmesan 2007). Globally, over the past 40 years there has been a strong, consistent pattern of poleward movements of 50–1000 km in species ranges. Several mountain-top species such as the American Pika and the European Apollo Butterfly are suffering range contractions as lower elevations have become climatically unsuitable (Parmesan 2007).
Throughout the Northern Hemisphere spring is earlier by about two weeks and autumn is later by about one week (Parmesan 2007). With these seasonal shifts there is some evidence for differences in species responses across trophic levels, the implications of which are not well understood. Changes in interspecific dynamics are already being observed in predator–prey and host–pathogen relationships. For example, in Europe the pine processionary moth has moved northward and is invading new territory. Warmer winters and extended growing seasons have resulted in large population increases of insect pests like the mountain pine beetle in Colorado and the spruce bark beetle in Alaska (Parmesan 2007). As a consequence of these new dynamics, wildlife, human health and productive sectors (eg agriculture, forestry and fisheries) may be impacted with potentially significant economic consequences.

Of the plant and animal species assessed so far, 20–30% are likely to be at increased risk of extinction if increases in global average temperature exceed pre-industrial levels by 2–3 °C (IPCC 2007b). With increases in temperature of this magnitude, substantial changes in ecosystem structure and function, species' ecological interactions and geographic ranges are expected with predominantly negative consequences for biodiversity and ecosystem goods and services (IPCC 2007b). Above 4 °C, it is projected that 40–70% of the species assessed will become extinct (IPCC 2007b).

4.2 Impacts of increasing CO_2 concentrations

In addition to the direct and indirect effects of changes to climatic parameters (eg temperature and precipitation), increases in CO_2 concentrations as a result of anthropogenic activity will have a direct effect on terrestrial and marine ecosystems.

Over the short term, some plants (those with the C_3 photosynthetic pathway) including trees, most agricultural crops including wheat and rice, and most cold climate species, are expected to respond positively to rising CO_2 concentrations because higher photosynthesis rates increase biomass (IPCC 2001). However, the magnitude and duration of this effect is uncertain as it may be constrained by nutrient balance (eg nitrogen and phosphorus), forest tree dynamics and secondary effects of CO_2 on the water cycle (IPCC 2007a).

Some species are better than others at responding to increases in CO_2 concentrations. For example lianas are increasing in abundance at a rate of 50% per decade in some parts of the Amazon, and are competing with tree species with greater biomass and longer life histories. This could potentially reduce the strength of the tropical forest carbon sink (Phillips et al 2002). In peatlands, however, rising atmospheric CO_2 may increase plant exudation of reactive carbon (Freeman et al 2004) and accelerate decomposition of soil carbon stores (Fontaine et al 2007).

Increased atmospheric CO_2 also has a critical effect on the marine environment. Over the past 200 years approximately half of the CO_2 produced by fossil fuel burning and cement production has been absorbed by the oceans. As a result, oceans are becoming more acidic (Royal Society 2005). Calculations indicate a reduction in the pH of surface seawater of 0.1 units, equivalent to a 30% increase in the concentration of hydrogen ions. If global CO_2 emissions from human activities continue to rise on current trends then the average pH of the oceans could fall by 0.5 units by 2100. This pH is probably lower than for hundreds of millennia and, critically, this rate of change is probably one hundred times greater than at any time during this period (Royal Society 2005).

Ocean acidification is likely to affect some marine organisms more than others. Evidence suggests that acidification will affect the process of calcification, by which animals such as corals and molluscs make shells and plates from calcium carbonate. Tropical and subtropical corals are expected to be among the worst affected, with implications for the stability and longevity of the reefs and the organisms that depend on them. Cold-water coral reefs are also likely to be adversely affected. Components of the phytoplankton and zooplankton are also likely to be impacted with consequent effects on the fish and other animals that feed on them. From the evidence available it is not certain whether marine species, communities and ecosystems will be able to respond to changes in ocean chemistry, or whether ultimately the services that the ocean's ecosystems provide will be compromised (Royal Society 2005). It is clear, however, that the only way to avoid ocean acidification is to reduce anthropogenic CO_2 emissions.

In terms of the overall climate system, ocean acidification will reduce the amount of CO_2 absorbed by the oceans and will mean that relatively more CO_2 will stay in the atmosphere. This will make global efforts to reduce atmospheric concentrations of CO_2 and associated climate change more difficult (Royal Society 2005).

Box 2 Climate system feedbacks

The oceans and terrestrial ecosystems are currently providing an important service to humanity by absorbing about half of anthropogenic CO_2 emissions. However, the combined effects of climate change and associated disturbance, and other global change drivers such as pollution, land-use change and over-exploitation, may exceed the resilience of many marine and terrestrial ecosystems this century (Sala et al 2000). These changes will cause feedbacks that may either amplify or dampen the response of the climate system. For example, deforestation may alter albedo and latent heat flux, etc, causing changes in local climate that may lead to further forest decline and more release of carbon (or reduced carbon uptake).

There are considerable uncertainties in the direction and magnitude of many of these feedback processes, partly because the interactions between physical, chemical and biological processes that determine the response of the climate system are generally not linear and are not fully understood. For example, a positive feedback that enhances climate change will occur from soil carbon stocks if carbon stored below ground is transferred to the atmosphere by accelerated decomposition induced by warming (Cox et al. 2000). Conversely, if increases of plant-derived carbon inputs to soils exceed increases in decomposition the feedback will be negative (Davidson and Janssen 2006).

The IPCC, using first-generation coupled climate-carbon models, found that warming will reduce terrestrial and ocean uptake of atmospheric CO_2 causing more to remain in the atmosphere and causing a positive feedback to climate. The strength of this feedback varied depending on the model used (IPCC 2007a). Several potential key processes are often still not represented, such as fire. Many of these affect climate through feedbacks other than through the carbon cycle, for example by affecting other greenhouse gases such as methane or aerosol concentrations. Atmospheric chemistry is also inextricably linked to air quality, which can affect the health of humans and ecosystems.

The resilience of ecosystems will be critical in determining the strength of these feedbacks. It is widely accepted that greater species diversity increases the resilience of ecosystem services to drivers of change. However, the rate of change relative to a typical species life time is likely to be crucial, and, beyond a certain critical rate of climate change even the most diverse ecosystems will not have sufficient resilience.

4.3 Impacts of climate change on human livelihoods

Although climate change will have some benefits for human livelihoods in some areas, most impacts are expected to be negative. Effects of climate change will not be uniform globally and will vary according to underlying environmental, economic and social conditions (eg gender inequalities), which together determine levels of vulnerability. The gravest threat is to the developing world, where climate change presents a major obstacle to poverty reduction (Stern 2007) and sustainable development. It also presents a significant threat to the rest of the world. In Europe for example, water stress and climate related hazards are expected to increase, and economically important sectors such as agriculture, energy and tourism will be adversely affected (IPCC 2007b).

Climate changes will affect society directly (eg changes in temperature, precipitation and sea level rise), and indirectly as a result of changes in ecosystems and the provision of ecosystem services. People living in poorer countries are particularly vulnerable, especially those in rural areas, as the health of human communities often directly depends on locally productive ecosystems for basic nutrition and fresh water (MA 2006). For example, if climate change causes species extinctions, even at a local level, there are likely to be impacts on the people that live in these areas. Similarly, inter-species dynamics and populations of vectors and reservoirs of human pathogens in the wild (eg *Vibrio cholerae*) are likely to change. However, there is very little understanding of how these dynamics may change or of the implications for human health and wellbeing (Parmesan 2007).

Climate change is clearly relevant to development objectives. Efforts to address poverty and food security must also take into account the influence climate change will have on measures to reduce malnutrition, hunger and the disease burden. Furthermore, poorly designed adaptation and mitigation measures may themselves have an effect on human livelihoods.

5 Policy responses: adaptation, mitigation and sustainable development

The climate change post-2012 discussions provide an opportunity to ensure that the interdependencies between biodiversity and ecosystems, human livelihoods and climate change are reflected in climate policy. A failure to recognise these inter-relationships may undermine efforts to make improvements in each area.

Options for adaptation and mitigation need to be developed within a sustainable development framework. This would have the added benefit of requiring evaluation of climate-change policies against other environmental, social and economic objectives. This can contribute to the delivery of mutually supportive objectives where possible, and where they are not, can aid with identifying possible trade-offs and to the appropriate management of any negative impacts. Key to this, however, will be the demonstration and communication of the interlinkages and potential benefits of integrated approaches. For example, efforts to reduce greenhouse gas emissions (eg methane) could reduce ground-level ozone concentrations with the added benefit of increasing crop yields and reducing adverse health effects.

5.1 Adaptation

Mitigation remains an urgent priority for addressing climate change. However, given the inertia in the climate system and the greenhouse gases already in the atmosphere, impacts of climate change are inevitable over forthcoming decades. Action is required now to prepare for the impacts of current and future climate change.

Adaptation refers to the activities that are undertaken to reduce the impacts of climate change. Vulnerability to climate change is determined by a range of economic, social and environmental factors. Adaptation must consider and address the root causes of vulnerability to climate change if the impacts of climate change are to be managed.

Groups that depend on primary natural resources are particularly vulnerable to climate-change impacts if their natural resource base is already degraded or stressed. Interconnected, dynamic and resilient ecosystems can help to protect against climate impacts. For example, Reusch et al (2005) found that genetic diversity in eelgrass (*Zostera marina*) meadows increased the rate of recovery after the European 2003 heat wave. Similarly, intact coastal marshes, mangroves and reefs can provide protection against storm surges (Badola & Hussain 2005), salt water intrusion and sea level rise. Activity to restore or sustainably manage key ecosystems, or to protect specific elements of biodiversity, may therefore moderate the vulnerability of these groups to climate change and at the same time increase the resilience capacity of natural systems to other disturbances. Understanding how climate change and other drivers of environmental change (habitat change, pollution, etc) interact is critical to this aim.

A more dynamic and proactive approach to biodiversity management is required to incorporate ecosystems into climate policy. This is likely to require a fundamental review of biodiversity and ecosystem management regulatory frameworks, including the way in which protected species and area designation is determined and applied. The identification, evaluation and weighting of the relative risks posed to biodiversity, as well as threats to human wellbeing and climate, will become more important in ecosystem management. A combination of approaches, such as microhabitat management, protected areas, ecological networks, and broader landscape management, and sustainable use policies will be necessary.

New tools will be required to inform decision-making to ensure that potential solutions (eg assisted migration or species reintroductions) are fully assessed and any risks identified and managed to avoid unintended biodiversity losses.

Efforts should also be taken to reduce other ecosystem pressures. This may require preventing or reducing ecological fragmentation, maintenance of connectivity across gradients, and a range of protection strategies targeting genetic diversity, species, habitats and landscapes. Crucial to this will be action to reduce other drivers of biodiversity loss (eg deforestation, spread of invasive species, pollution, overexploitation) to improve resilience and make biodiversity more robust to future changes. This is a strategy that can be employed now, using existing tools, and one which can provide a significant contribution to reducing vulnerability to climate change impacts. Climate-change policy should therefore identify the protection of biodiversity and healthy ecosystems as a priority strategy for adaptation.

5.2 Mitigation

Mitigation is defined as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC 2001c). Efforts to date have focused on reducing greenhouse gas emissions from fossil fuel combustion by increasing the efficiency of use, developing techniques for capturing, storing or converting carbon emissions, or advancing alternative technologies (such as biofuels) that produce less greenhouse gases. However, over recent years the potential contribution of terrestrial and marine ecosystems as sinks for greenhouse gases has begun to receive more attention.

In 2004 emissions from land-use change and forestry contributed 17% of greenhouse gas emissions, third only to energy supply and emissions from industry (IPCC 2007c). To stabilise atmospheric concentrations of CO_2 at levels below which the European Union has agreed dangerous climate change may occur (2 °C below pre-industrial levels), a reduction in global CO_2 emissions of the order of 50–85% (below 2000) is required by 2050, with continuous reductions thereafter (IPCC 2007c).

Efforts to reduce emissions from land-use change and forestry could provide a substantial contribution to achieving these reductions. The sustainable management of ecosystems such as forests, peatlands and other wetlands, and the ocean should be considered alongside other mitigation strategies. Equally, the risks of carbon release as a result of damage to ecosystems from alternative mitigation options (such as habitat conversion to grow biofuels) should be considered and avoided where possible. The development and application of sustainability criteria to all mitigation options, but particularly to biofuel production (Royal Society 2008), are essential in this respect.

The potential contribution of forest ecosystems to mitigating climate change has recently been recognised – most notably under the UNFCCC[7] which provides for reforestation and afforestation under the Kyoto Protocol Clean Development Mechanism. The avoidance of carbon release from deforestation, and the importance of reducing carbon loss arising from forest ecosystems fragmentation and degradation, are also receiving increased attention, although they are currently excluded from the Kyoto Protocol.

Less accepted by the climate-change community are the value of biodiversity for maintaining ecological resilience and the broader climate regulation function provided by forest (and other) ecosystems. Similarly, the importance of other ecosystems (for example agricultural soils) in carbon storage, although acknowledged, has not yet been incorporated into climate-change policy negotiations. For example, persistent environmental change, in particular drainage (Freeman et al 2001) and forest clearing, threatens the stability of peatlands (Page et al 2002) and increases their susceptibility to fire. Hooijer et al (2006) estimated the CO_2 emissions from peatlands (drainage, and fires included) in southeast Asia to be 2000 megatonnes per year (Mt/y), equivalent to 8% of global emissions from fossil fuel burning.

Novel policy mechanisms are required that recognise the climate regulatory value of ecosystems and that look beyond the value of tropical forests to other terrestrial, and potentially also marine, ecosystems. This ecosystem-based approach to climate policy will require collaboration between the biodiversity, climate, and international development research and policy communities.

5.3 Integrated management for co-benefits

Appropriate management of ecosystem resources may result in mutual benefits by reducing emissions, climate change impacts and biodiversity loss, while also improving human livelihoods. Such win–win–win solutions should be a priority goal for political initiatives and scientific research. In Alaska, for example, Chapin et al (2006) found that by understanding the links between global-scale changes and local-scale dynamics of human and environment interactions, sustainable policy responses were possible for the management of vulnerability, enhancement of adaptability and resilience in social, environmental and economic systems.

Adaptation and mitigation policies are often considered separately because of perceived differences in temporal and spatial scales of activity, effect, and the relative distribution of costs and benefits. For example, the benefits of global greenhouse gas emissions are generally not felt for decades into the future whereas the benefits of adaptation tend to be more immediate. Reduced greenhouse gas emissions are usually considered to have global benefits, whereas the benefits arising from adaptation are local and national in scale. However, when considered in terms of impacts avoided, mitigation may also have benefits at the local and national level. Similarly, where adaptation activities include management to maintain or improve ecosystem resilience and provision of natural resources, there may also be global benefits in terms of global greenhouse gas emissions reductions. It is clear that, with careful planning and management, and appropriate financial structures, ecosystems being managed for adaptation purposes may also contribute to mitigation and vice versa.

Appropriate governance regimes (ie that ensure the equitable distribution of benefits gained and burden sharing), careful policy design and implementation in line with sustainable development criteria, setting of appropriate incentives, and regular monitoring and reporting are all essential requirements for the pursuit of mutually supportive objectives that will reduce emissions, increase adaptive resilience and deliver sustainable development. This will require the redefinition of

[7] United Nations Framework Convention on Climate Change.

mitigation and adaptation to include the broader climate regulatory functions of ecosystems and the role of land surface, and acknowledgement of the importance of socio-economic drivers in determining vulnerability to climate change.

Clearly the potential for achieving co-benefits will depend on access to the necessary resources and capacity, which may require support from appropriate institutional bodies and business at the international, national, or local level. However, one of the benefits of integrated policy is the maximisation of efficiency and improved policy coordination. Fundamental to the achievement of objectives for each is the importance of strengthening the socio-economic input to policy and setting of the research agenda.

Box 3 Reducing emissions from deforestation

According to the IPCC (2007c), emissions from land-use change and deforestation accounted for 17% of anthropogenic global greenhouse gas emissions in 2004.

Reducing deforestation avoids the release of carbon and, by reducing atmospheric carbon, has the added benefits of reducing the impacts of climate change on remaining forests (eg reduced rainfall), biodiversity loss and degraded human health from biomass burning pollution, and the unintentional loss of productive forests. Conservation by the community can also provide goods and services for local livelihoods (Murdiyarso et al 2007). Curbing deforestation can therefore make an important contribution to reduction of global CO_2 emissions, biodiversity protection and human livelihoods.

Although the potential contribution of forest ecosystems to climate change mitigation has been acknowledged by the addition of afforestation and reforestation to the Kyoto Protocol, reducing deforestation has so far been excluded from the international climate change framework. Given the essential climate regulatory role of forest ecosystems (particularly in the tropics) and the important contribution of deforestation and forest degradation to global greenhouse gas emissions, mechanisms for the reduction of emissions from this sector must be included within the international climate-change policy framework.

Discussions on the post-2012 framework include a debate on establishing a new mechanism which links reductions in deforestation and forest degradation (REDD) to an international carbon market or a voluntary fund. Proponents of REDD see it as an opportunity to reduce a substantial share of global emissions while contributing to alleviating poverty and protecting biodiversity. By putting a value on the carbon in standing trees (or rather the rate at which it is emitted as a result of their destruction), the current economic incentives for deforestation could be reversed.

However, economic incentives are only part of the picture in addressing deforestation in a situation where many countries face widespread illegality in the sector. It cannot be assumed that simply creating a market for forest carbon will change behaviour in the forest. Development of national capacity and political will to govern the resource and capture potential revenues for national and local benefit will be a vital pre-requisite to meeting any national targets or establishing a functional market for forest credits.

Analysis by Saunders et al (2007) outlines experiences from ongoing efforts to improve forest governance (particularly the EU Forest Law Enforcement Governance and Trade (FLEGT) Action Plan), which should be considered at both the design and implementation stage of REDD. Lessons learnt suggests that countries that establish legal and legitimate control over their forest resources by improving institutional governance, clarifying land tenure and enforcing forest law are significantly more likely to reduce deforestation, particularly over the medium to long term, and achieve maximum benefit from potential REDD investment.

5.4 Tools for prioritisation of policy interventions, research and management

Although biodiversity, climate change and sustainable-development policy may potentially result in win–win–win solutions, in many cases politically difficult trade-offs will be required. It is essential, however, that such trade-offs do not undermine ecosystem resilience as this may ultimately compromise the long-term ability of ecosystems to regulate the climate, may accelerate or amplify climate warming and could lead to additional, unforeseen and potentially irreversible shifts in the climate system. However, tools are not yet available for prioritising ecosystems for research or management under the integrated framework recommended here. One approach would be to strategically prioritise ecosystems according to their importance in the climate system, their biodiversity value and the other ecosystem services they provide, and the value of these to human wellbeing.

The matrix below is shown for illustrative purposes to indicate how such an approach could work. The 'relative climate value' of ecosystems could be explored in terms of their albedo, water cycling, carbon sink, aerosol contribution (for example), and compared against their biodiversity value, the other ecological services provided, the value of these in enabling climate change mitigation and adaptation, and in contributing to human wellbeing. This matrix approach could operate at a range of different scales depending on the purpose of the assessment and may need to be undertaken separately for different biomes and geographical areas. This would provide a transparent framework for assessing where management or research effort should be placed as a priority. Multiple criterion decision-analysis tools will be required for this evaluation.

Once populated with evidence supported by peer-reviewed literature (where possible), the matrix approach proposed will enable policy makers to identify available options for achieving co-benefits for climate change, biodiversity, and human livelihoods. To ensure appropriate trade-offs are made, stakeholders must be involved throughout the decision-making process to ensure symmetry of power and information. Where possible, interactions should be quantified and major externalities included. Optimisation criteria may be necessary to ensure that decisions are taken in the context of the medium- to long-term impacts of climate change.

To support decision-makers in these assessments, innovative, novel and experimental approaches are needed to support the identification and analysis of potential trade-offs and co-benefits. In particular, there is a need for the development of accurate methodologies for identifying and quantifying the value of climate regulation and biodiversity in terms of human wellbeing and mitigation and adaptation objectives.

5.5 International governance, capacity issues and science advisory mechanisms

The international biodiversity and climate policy and scientific communities have recently begun to recognise the interdependent nature of the biodiversity and climate change issues, as demonstrated by the activities of the Joint Liaison Group of the CBD[8], UNFCCC and UNCCD[9].

There are, however, only limited international management or governance structures in place for implementation of projects at trans-national levels or over the longer term. The CBD, UNFCCC, UNCCD, Ramsar[10], CMS[11] and WHC[12] have taken positive steps in collaborating and taking integrated action on biodiversity and climate change and have identified overlapping activities that relate to climate change adaptation (see CBD 2006). More progress is needed and there is scope for further collaboration on cross-cutting issues like

Figure 3 Illustration of proposed evaluation matrix.

Ecosystem type	Climate regulation role	Biodiversity and ecosystem services values	Mitigation potential	Adaptation potential	Benefits for human wellbeing	Co-benefits
Peatland/wetland	Carbon store	High	High	High	Medium	High
Tropical forest	Carbon store, water cycling, albedo	Very high	High	High	High	Very high
Arable farmland	Below ground carbon store	Low	Medium	High	High	Medium
Oceans	Carbon sink, water cycling, albedo	High	Low	Low/Medium	High	Medium
Coral reefs	Carbon cycle	Very high	Low	High	High	High

8 Convention on Biological Diversity.
9 United Nations Convention to Combat Desertification.
10 The Ramsar Convention on Wetlands.
11 Convention on Migratory Species.
12 UNESCO Convention concerning the Protection of the World Cultural and Natural Heritage.

capacity building, technology transfer, research and monitoring, information and outreach, reporting and financial resources. Integrated work programmes like this would improve understanding of the drivers of climate change and biodiversity loss, and their interactions, and are fundamental for underpinning practical and effective programmes of mitigation and adaptation activity.

Greater integration and collaboration are required between the Rio Conventions and the primary international trade (eg World Trade Organization) and development mechanisms (eg United Nations Development Programme (UNDP)). Initiatives by other institutions and processes (such as the G8, Global Environment Facility and World Bank) should also be encouraged. Greater collaboration between these communities will provide better understanding of which priority areas can best be tackled using these instruments and could, if appropriately managed, foster closer working at the country level.

Improved coordination of the science inputs to the Conventions and closer working of scientists researching biodiversity, ecosystems, climate and development issues are required. The IPCC model provides a useful guide for the way in which independent scientific advice can be used to inform and strengthen the international policy process. A flagship project could include an IPCC special report on the interactions between climate change, biodiversity and ecosystem services, and human wellbeing.

Inadequate human and societal capacity is a major impediment to the achievement of international biodiversity, climate change and sustainable development objectives, particularly in developing countries. Good governance is critical for ensuring that objectives are effectively delivered, especially where these need to be integrated across sectors. Equity, cost and benefit-sharing issues also need to be considered and resolved. Many countries lack national institutions and financial resources for implementation of work programmes. Efforts to establish and increase capacity for implementation of the international environmental Conventions would provide an opportunity for developing integrated capability at both the strategic and grass-roots levels. This will require the development of new mechanisms and methods for assessing progress against policy objectives, and best practice guides for policy development and implementation. Improving coordination of implementation of convention decisions at the national level may help to address some of these capacity issues. Similarly, ensuring the consistency of recommendations from the different Conventions is essential. The identification of measures that achieve multiple (climate, biodiversity and development) objectives could reduce the capacity burden.

The international institutions have an important role to play in providing guidance for the development and implementation of climate change strategies. However, national climate change programmes should be prepared according to national and local characteristics and should address specific drivers of vulnerability. Top-down approaches may be appropriate for the setting of national strategic objectives. However, bottom-up approaches will be most appropriate for identifying solutions, priority setting, and programme design and implementation. Community-based, de-centralised, market-focused adaptation and mitigation projects should be implemented to build best practice and to test whether win–win–win situations are feasible.

5.6 Communication

Climate change, biodiversity and human livelihoods interdependencies must be actively communicated to all levels and sectors of society. The messages are simple:

- climate change is unequivocal;
- we are already seeing the impacts of climate change on natural and human systems,
- adaptation is necessary to cope with inevitable changes;
- mitigation is essential to avoid dangerous climate change;
- biodiversity is fundamental to human wellbeing and climate regulation, and must be central to the development of adaptation, mitigation, and sustainable development programmes.

The MA provided a valuable contribution to demonstrating the important contribution of biodiversity and ecosystems to human health and wellbeing. The ongoing communication of the main messages to a broad cross-sectoral audience across the private and public sector is necessary if the results of the assessment are to be embedded into decision-making at all levels.

Communicating success stories can be a powerful tool for encouraging positive action and the adoption of new practices. However, the urgency of these issues must be translated into terms that are meaningful to different groups in society. The impacts and benefits of taking action, and the costs of inaction, will have more resonance with society if these are communicated in a way that is directly relevant. This is particularly important at the grass roots level as it is here that biodiversity and ecosystems will be actively managed, and at this scale that human livelihoods will be most directly impacted by biodiversity loss and climate change.

The climate-change community has been successful at communicating the complex science of climate change by using simple metrics to communicate the concepts. Communicating the complexity of the biodiversity issue has not had the same success, and confusion remains despite the efforts of the CBD and the MA. In the same way that the climate-change community has been successful at communicating what can be done to reduce climate change, the biodiversity community should develop equivalent messages that illustrate the value of biodiversity to everyday life and what can be done to reduce biodiversity loss.

Policy-makers rely on indicators representing different aspects of biodiversity and, unlike the concepts used by the climate-change community, no simple tools for communicating biodiversity have yet been agreed. Greater collaboration is needed between the policy and science communities to enable research to be policy relevant. Communication of science should be focused on communicating what is known rather than the unknown.

The UK Government Stern Report (Stern 2007) on the economics of climate change has had a major impact on decision-makers around the world. However, the report did not reflect the full costs of climate change impacts on biodiversity and ecosystems. A more balanced treatment of the issues of climate change and biodiversity depends on a comparable economic assessment of the costs associated with biodiversity loss as agreed by the G8+5 Environment Ministers at the March 2007 Potsdam meeting. The results of this work will be critical for demonstrating to decision-makers the costs to society of failing to halt the loss of biodiversity.

6 Research

During the course of the workshop a range of science and policy gaps, and research needs, were identified. These are summarised in the table below and fall into the following themes:

6.1 Taking a strategic approach to coordination of long-term research

Although we understand enough about the linkages between biodiversity and ecosystems, human wellbeing, and climate change to identify the critical areas for research and policy development, our understanding is far from complete. An internationally strategic approach and wider mechanisms are required to coordinate long-term research on biodiversity, climate and human livelihoods. These research communities must work more collaboratively to exchange ideas, best practice, data and other information. This is fundamental to progressing research in these areas.

6.2 Interactions between human livelihoods, biodiversity and climate change

The MA and IPCC Assessment Reports have provided a valuable contribution to the biodiversity and ecosystems, human wellbeing, and climate-change evidence base. However, these assessments were conducted independently by scientists from the biodiversity, development, and climate-change communities respectively. A stronger evidence base is required to demonstrate the linkages between each area across a range of temporal and spatial scales. Further sub-global assessments are required that look specifically at the interactions between biodiversity and ecosystems, human livelihoods, and climate change. These should consider the needs, objectives and possibly governance structure for a further global assessment.

The interactions between human livelihoods and biodiversity (at the local, national and international scale) require further investigation. In particular, improved understanding of the impact of policy on the way communities interact with biodiversity will enable the development of climate change adaptation and mitigation policies that support biodiversity and development objectives.

The vulnerability of populations to the impacts of climate change and climate-change policies depends on a variety of social, economic and environmental drivers that vary spatially and temporally. Integrated research into the factors that determine vulnerability and their interactions is required to inform the development and implementation of adaptation and mitigation programmes.

6.3 Biodiversity and ecosystem function

Research into the mechanisms of biodiversity function is essential to improve our understanding of how biodiversity underpins ecosystem structure and function, in climate regulation, and in human livelihoods. Biodiversity and climate change inter-relationships require further research and evaluation by the scientific community. In particular, the hypothesis that systems with high biological diversity are more resilient to global change than less diverse systems requires further testing.

By focusing research on ecosystems important in the climate system (eg peatlands), in areas where biodiversity is changing rapidly or at a large scale, or where there are major impacts on human livelihoods, we would increase our understanding of the mechanisms of change, feedbacks in the system, and effects of interactions of global change drivers. Palaeo-ecological information is not currently used to its full potential and may be helpful for improving understanding of how past climate change has affected biodiversity and for informing predictions of how biodiversity may change with anthropogenic climate change.

6.4 Modelling approaches

Earth system models provide an important tool for understanding and assessing future climate change and its impacts. The accuracy of these would be improved by including key ecological and physiological processes and more sophisticated representation of the links between biodiversity and human wellbeing. Improved understanding of local and regional climate processes is required for informing climate change prediction and development of adaptation options. There is a similar need for biodiversity assessments. More powerful and sophisticated climate models will be required to undertake this work.

6.5 Summary of science and research gaps identified

During the course of the workshop several research and science needs were identified. These are summarised in the table on pages 20–23.

Thematic area	Priority science gap	Description
Biodiversity and ecosystem functioning	Role and function of biodiversity in ecosystem services	Role and function of different hierarchical levels of biodiversity with particular attention to ecosystems under change. Investigations should include the contribution of community structure and composition in addition to diversity.
		Improving the evidence base for the role and function of biodiversity in supporting ecosystem services and human wellbeing.
Human livelihoods and ecosystem services	Interactions	How human livelihoods are affected by changes in species and community structure.
		The links between biodiversity and human pathogens and how these relationships will change with climate change.
	Effects of policy	The effects of climate mitigation and adaptation and biodiversity policy on human livelihoods (and health and wellbeing).
	Human wellbeing	Identification and evaluation of the relationships between the different constituents of human wellbeing (as defined by the MA 2005) and biodiversity.
Impacts of climate change, increased CO_2 concentrations, habitat loss, invasive species, pollution, etc on biodiversity	The role of extreme events	Understanding how extreme climatic events impact upon biodiversity. Improving the prediction of frequency, magnitude, and duration of extreme events to improve adaptation, and biodiversity protection.
	Interactions between drivers of biodiversity change	Understanding the impacts resulting from interactions between climate change and other global environmental changes (eg land use).
		Initiate research on the mechanisms of changes in ecological interactions resulting from climate change (eg new species assemblages, predator–prey and host–pathogen relationships).
		An evaluation of the extent to which human effects on biodiversity are related to climate change.
		How will changes in human behaviour as a result of climate change affect biodiversity, and identification of potential feedbacks to the climate system.
	Key species in ecosystem services	Improve understanding of key species and functional traits in ecosystems.
	Indicators of biodiversity change	Develop a suite of biodiversity change metrics equivalent to those used by the climate change community.
		Establish appropriate programmes of long-term ecological monitoring.
	Scenario modelling	Develop scenarios for impacts on biodiversity and ecosystem services under different levels of climate change (these are necessary for informing the development of management priorities, and would be helpful for identifying potentially dangerous levels of biodiversity loss).
	Non-CO_2 greenhouse gas effects	How biodiversity responds to the other (non-CO_2) greenhouse gases.
Biogeochemical processes	Linkages	Improve understanding of the role of biodiversity in the major biogeochemical processes, and the links between biodiversity, ecosystem function and climate regulation.
	Carbon storage and stability	Improve understanding of the stability of carbon stocks held in different ecosystems (eg such as rainforests, peatlands and tundra, which have large stocks).
Climate regulation	The role of biodiversity in the climate system	Improving our understanding of the role of biodiversity in regulation of climate. How representative are known examples? What is the role of biodiversity in positive and negative climate feedbacks?

Thematic area	Priority science gap	Description
		Biological complexity – how much is enough (eg ecosystem structure, including representation of functional groups and traits)?
		Understanding resilience: undertake comparative studies of the resilience to drivers of change in pristine versus modified systems.
	Scale issues	Improve knowledge of how biodiversity regulates climate at larger spatial scales, including the influence of landscape heterogeneity (patchiness).
		Initiate long-term ecological studies of the impacts of climate change (extending for multiple generations of species of interest).
		Focus on areas that are changing the fastest and on large scales (eg impact of land-use change due to biofuels).
		Further develop and test the matrix approach proposed in chapter 5. Use this approach to inform large-scale planning to establish which areas could most appropriately be used for which land use (integrated sustainability assessment to identify costs and benefits).
	Emerging threats	Undertake horizon scanning to identify emerging climatic threats.
Climate modelling	Integration	Identify the levels at which it is necessary to integrate biodiversity (genetic, species, ecosystem) and ecosystem services into climate change models, and how to achieve this. Physiological and ecological processes, including species population dynamics, should be included.
		Integrate the human dimension (socio-economic and human behavioural changes) into climate-biodiversity models.
	Predictive ability	Improve the ability of global climate models to predict local or regional responses of aquatic ecosystems to climate change.
		Improve the ability of models to predict the extent to which shifts in the extremes of climatic parameters such as temperature and moisture will have an impact on biodiversity.
Climate science	Physical science of climate change	Improve understanding of local and regional climate processes. Continued increase in development of computing resource will be essential to increasing our understanding at regional and local levels.
Science-policy linkages	Drivers of change	Adopt an integrated approach to policy making, recognising that climate change is only one driver of biodiversity loss; eg inclusion of socio-economic drivers.
Biodiversity-dependent livelihoods	Context	Undertake a review of the generic factors constraining livelihoods at national, regional and international levels; considering social, economic and institutional factors.
		Categorise impacts on biodiversity from different factors, and complete comparative studies of their severity.
	Goods and services	Improve knowledge of the relationships between management and delivery of ecosystem services (ie which conservation measures sustain which ecosystem services?)
	Governance and implications	Review approaches for instituting better governance to enable change at the country level (working with existing policies and institutions, and using local knowledge). Consider addressing these issues through the application of the ecosystem approach.

(Table *continues*)

Thematic area	Priority science gap	Description
		Carbon storage by ecosystems – consider the cost implications (ie who will pay) and impacts (ie who will lose).
Strategies and vulnerability	Policy integration	Review opportunities for integration of biodiversity and sustainable development into national climate change strategies – particularly those for least developed countries (LDCs).
	Trade-offs	Identify the principles for a quantitative framework to facilitate and inform decision-making.
		Adopt a case study-based approach to climate change and biodiversity at the local level to inform where trade-offs will be required and to stimulate acion to reduce the impacts.
	Synergies	Identify opportunities for 'win–win' strategies: eg consider networks of marine protected areas, ecotourism, maintenance and restoration of native forests, wetlands, coral reefs and mangroves
Enabling adaptation and mitigation	Ecosystem management	Using a transparent and scientifically robust methodology (such as the matrix approach proposed in Chapter 5), identify the co-benefits of different ecosystems, in terms of biodiversity value, carbon sequestration value, human livelihoods value, etc.
		Establish which ecosystems and associated management practices contribute the most to climate change mitigation and adaptation.
		Identify the ecosystem components that are involved, eg processes, structures, biodiversity.
		Assess the contribution that these ecosystems and their associated management contribute to sustainable development.
	Landscape management	Develop a programme of new research to consider how to apply landscape management under changing climate (eg a combination of approaches, such as protected areas, ecological networks, and broader landscape management will be necessary).
	Human livelihoods	Ensure the inclusion of human livelihoods – through market-based projects – to identify win–win situations.
		Undertake an assessment of the strategies used at the local level to use biodiversity within an ecosystem to adapt to or mitigate climate change.
	Technology and innovation	What are the technology and innovation needs for adaptation and mitigation?
	Adaptation strategies	Improve our understanding of the role of the marine environment in adaptation.
		What role can biodiversity play in contributing to adaptation of human populations to climate change?
	Mitigation strategies	Investigate the best approaches to promoting ecological and societal resilience, eg traditional agricultural practices (diverse systems v monocultures); primary v secondary forest (need scientifically robust and practical avoided deforestation plans).
		Assess how policies to promote reduced emissions from deforestation can maximise opportunities to improve human livelihoods and protect biodiversity.
		Undertake large-scale planning exercises to establish which areas will be used for which land uses (integrated sustainability assessment to identify costs and benefits).

Thematic area	Priority science gap	Description
	Reducing deforestation and forest degradation	What are the advantages and disadvantages of including deforestation in the post-2012 frame.work? What are the advantages and disadvantages of financing REDD from the carbon market, versus relying on bilateral donor commitments?
		How can policies to promote REDD maximize opportunities to improve livelihoods for the rural poor, and minimize the tendency of forest law enforcement efforts to be biased against smaller and poorer forest resource users? How can policies be implemented equitably so as to avoid adverse effects on local communities or the poorer forest resource users?
		How should baselines be established and what is the role of predictive models in setting national baselines? What sort of measuring, monitoring and accountability mechanisms are technically feasible? How large are the transaction costs of putting into place compensation mechanisms, and how can rules and procedures be simplified to avoid high transaction costs? What would be the implications of including forest degradation in the accounting system to address sustainable forest management and changes in carbon stocks rather than forest cover?

7 Conclusions and recommendations

Climate change is clearly one of the most pressing challenges of our generation and warrants urgent and concerted global action. The loss of biodiversity presents a more insidious threat, but one that is no less important in terms of the long-term wellbeing of the planet. The loss of biodiversity and degradation of ecosystems should therefore be of major concern to decision-makers around the world.

Although our understanding is far from complete, we know that climate, biodiversity and human wellbeing are inextricably linked. We also know that diverse ecological systems tend to be more dynamic and resilient to change, that ecosystems are important in climate regulation and deliver a range of other services of importance to human wellbeing. A failure to halt the loss of biodiversity caused by overexploitation, pollution, invasive species and habitat change, and to manage the impacts of climate change on biodiversity, will therefore have increasingly significant implications for human health and wellbeing, economic livelihoods, and ecosystem services including climate regulation.

The messages are clear and simple. Biodiversity and ecosystem resilience are necessary for climate regulation and human wellbeing. Climate change is unequivocal and inevitable. Adaptation is necessary and mitigation essential if dangerous climate change is to be avoided. Urgent, global action is required if the health and livelihoods of people around the world are to be protected and improved, if biodiversity loss is to be halted, and dangerous climate change avoided.

To achieve these goals unprecedented global action is needed. The negotiations for a post-2012 framework for climate change present an opportunity for the international community to take a leadership role on climate change. It is critical that any future framework has sustainable development at its core and that it recognises the fundamental role of biodiversity and ecosystem resilience in the climate system.

> ***Recommendation 1:*** *The international community must take a leadership role to ensure the principle of halting biodiversity loss is embedded into the international climate-change framework and, in particular, into the UNFCCC activities on adaptation and mitigation, including: the guidance for development of national programmes; capacity building; technology transfer; and development of financial mechanisms.*

The concept of sustainable development is not a new one and provides the umbrella under which strategies for achieving mutual objectives for biodiversity, human livelihoods, and climate change can be delivered. However, this requires a new philosophy and improved cooperation and collaboration between the environment, development and climate change communities. The development of new and innovative approaches and mechanisms is essential, and their demonstration on the ground critical, if progress on developing truly integrated solutions is to be made.

Reducing emissions from deforestation and forest degradation is one approach that could achieve win–win–wins for biodiversity, climate change and human livelihoods. There are clearly challenges to be resolved, not least the need for an equitable framework that recognises the economic, cultural and ecological diversity of the forested nations, and the need for commitments from other nations to make significant reductions in their greenhouse gas emissions. However, these challenges are not insurmountable. FLEGT may provide a useful model for understanding some of these issues. Science and technology can also play an important role.

Provision must be made to ensure that national level measures are taken to establish legal and legitimate control over the forest resources, by improving institutional governance, clarifying land tenure and enforcing forest law. Measures are also needed so that the costs and benefits are equitably distributed and local communities are involved in the decision-making processes.

The international community will need to support the participation of developing countries in such a scheme by providing resources for establishing appropriate baselines, and the scientific research required to underpin reporting, monitoring, verification and the future development of this and other similar mechanisms.

> ***Recommendation 2:*** *The post-2012 climate-change framework discussions must recognise the contribution that reducing emissions from deforestation and forest degradation (REDD) can make to global reduction of greenhouse gas emissions and take steps to design and implement a mechanism for incorporating REDD into the post-2012 framework.*

Reducing emissions from deforestation clearly must play an important role in any global framework to address climate change. However, other ecosystems also provide important climate regulatory roles. The biodiversity, climate and development research communities must collaborate to identify where opportunities exist to take advantage of the climate regulatory services already being provided by ecosystems, while at the same time contributing to improving human livelihoods and meeting biodiversity goals. Peatlands and other wetlands are obvious other contenders for integration into a post-2012 framework. Their potential should be actively investigated and assessed against sustainability criteria. The UNFCCC in collaboration with the CBD, UNCCD, **Ramsar**, UNEP[13] and the UNDP should, in the meantime, identify and report examples of cases where these win–win–wins are already being realised.

> ***Recommendation 3:*** *Under the auspices of the UNFCCC, a programme of work should be coordinated jointly by the CBD, UNCCD, Ramsar, IPCC, UNEP, UNDP, and the World Bank, to investigate the potential contribution of other ecosystems to climate change. This should explicitly consider the contribution of non-forest ecosystems, in addition to forest systems, to reducing vulnerability and increasing resilience to climate change. Current examples should be gathered and reported to the UNFCCC.*

> ***Recommendation 4:*** *The UNFCCC should develop guidance for the development of mutually supportive adaptation and mitigation programmes, and sustainability criteria against which such programmes should be assessed.*

Policy-makers at the international, regional, national and local levels should be encouraged to develop and implement new mechanisms for achieving adaptation and mitigation benefits at the same time. Where these mechanisms already exist and have been implemented, particularly at the local level, exchange of best practice should be facilitated and the results communicated to the UNFCCC and CBD.

> ***Recommendation 5:*** *The IPCC, in collaboration with the CBD, UNCCD, Ramsar and UNDP, should develop a decision-making framework, as suggested in Figure 3, to enable the assessment of appropriate land-use priorities for ecosystems (landscapes or communities), with the objective of identifying potential for delivery of co-benefits, and the transparent assessment of trade-offs.*

Despite the efforts of the CBD, UNFCCC, UNCCD, Ramsar, CMS and WHC to improve integration on biodiversity and climate change at the international level, further collaboration, particularly with the international development community, is essential for capacity building, resourcing and implementation of Convention work programmes (particularly at the national level), technology transfer, and communication, financing, and research and monitoring.

Science and research are critical to halting biodiversity loss, and to reducing climate change and its impacts, and improving human health and wellbeing. Halting biodiversity loss under the added pressure of climate change presents a significant challenge and one that will only be met by a shift in the approaches taken to biodiversity and ecosystem management. This must be underpinned by robust science.

Similarly, improved understanding of the role of biodiversity in ecosystem resilience, and of ecosystems in providing human health and wellbeing, including through climate regulation, will be fundamental to the development of adaptation and mitigation approaches that are sustainable over the long term.

Better progress towards achieving biodiversity and climate and sustainable development objectives could be achieved with the improved collaboration and implementation of existing knowledge and tools. However, significant new research is required to improve understanding of the role of biodiversity in the climate system, the impacts of climate change on biodiversity and human populations, their inter-linkages and cross-scale effects. An internationally strategic approach to integrated biodiversity, climate and sustainable development research will be essential. Increased capacity for involvement at the grass roots level in science and research, development and implementation of new technologies, exchange of best practice, and communication of success stories and failures will be critical.

> ***Recommendation 7:*** *The CBD, UNCCD and UNFCCC should develop in collaboration a framework for an integrated science and technology development research programme.*

Objectives for a collaborative research programme should include (but not necessarily be limited to):

- evaluation of common approaches to biodiversity and ecosystem management in the context of anthropogenic climate change;
- investigation into the role and function of biodiversity in ecosystem functions and services including climate regulation, and their contribution to supporting human health and wellbeing;
- the potential for ecosystem management for mitigation and adaptation;

[13] United Nations Environment Programme.

- an evaluation of possible mechanisms for improving collaboration between the biodiversity, development and climate change research communities;
- the use of existing knowledge and tools for novel application in addressing biodiversity loss, climate change, and improving human livelihoods;
- the impacts of climate change on biodiversity and human populations, their inter-linkages and cross scale effects;
- exchange of existing knowledge and best practice on methods for achieving co-benefits, and managing adverse effects where trade-offs have been required;
- mechanisms for increasing involvement at the grass roots level in science and research, development and implementation of new technologies, exchange of best practice, and communication of success stories and failures.

Crucial to the success of halting the loss of biodiversity and to addressing climate change is the way in which the problem and the potential solutions are communicated. The biodiversity, human livelihoods and climate-change communities have a responsibility for communicating these messages to a broad range of stakeholders at the international, national, and local levels. This will require greater collaboration and the development of novel techniques for communicating the key messages.

> ***Recommendation 8:*** *The CBD, UNCCD and UNFCCC should develop a programme specifically aimed at communicating the interlinkages between biodiversity, climate and human livelihoods.*

The programme should include an investigation into the development of simple metrics specifically to aid communication both within and between the biodiversity, climate and development communities, of progress in achieving respective, and mutually supportive goals.

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Appendix 1 June meeting programme, abstracts and attendee list

Biodiversity–climate interactions: adaptation, mitigation and human livelihoods

Organised by the Royal Society in partnership with the Global Environmental Change Committee, Global Biodiversity Sub-Committee (GBSC)

Tuesday 12 and Wednesday 13 June 2007

Synopsis

There is an urgent need to identify key areas in which biodiversity, climate change and sustainable development science and policy can be coordinated to maximise opportunities for addressing the climate change issue. Identifying and maximising these links will be crucial for constructing future policy for sustainable development. In bringing together scientists and policy makers from these different sectors, the workshop aims to take an integrated approach to identifying knowledge gaps and developing solutions.

The emphasis of this workshop is on the role and function of biodiversity and ecosystems in the climate system. It will assess current knowledge and address specific gaps regarding the ecological impacts of climate change and increased carbon dioxide (CO_2) on marine and terrestrial biodiversity and ecosystem structure and functioning. The role of the biosphere and biodiversity in regulating climate will be investigated, and important biogeochemical and biophysical processes, their characteristics, and magnitude identified, with the aim of enhancing understanding of key positive and negative feedbacks in the climate system. This is an area of major uncertainty, so this information will be used to inform the development of recommendations regarding the future development of climate science, climate prediction and impact assessment models.

Feedback processes in the biosphere, their characteristics and magnitude, vary depending on ecosystem condition. This provides an important link to the role of human populations in the climate system, in protecting biodiversity, and the provision of ecological goods and services. This workshop will therefore also consider the interactions between human activity, the biosphere, and climate in terms of function and impacts.

Emphasis will be given to considering the role that biodiversity should play in adaptation and mitigation strategies within this context. The impacts of such strategies on the provision of ecosystem goods and services and human wellbeing will be discussed, recognising that any possible solutions must take the human dimension into account.

Tuesday 12 June 2007

Session 1: Setting the context

Chair: **Sir John Lawton FRS,** *President, British Ecological Society, UK*

09.00 **Welcome by Lord Martin Rees PRS**,
President, The Royal Society

09.15 **Barry Gardiner MP**
Parliamentary Under-Secretary (Commons): Minister for Biodiversity, Landscape and Rural Affairs, Department for Environment, Food and Rural Affairs (Defra)
Keynote address

09.35 **Dr Ahmed Djoghlaf**
Executive Secretary, Convention on Biological Diversity (CBD)

The international framework for biodiversity and climate change

The work of the IPCC and the Millennium Ecosystem Assessment has made us all aware that climate change negatively impacts natural resource based livelihoods and that it is likely to be the main driver of biodiversity loss in the future. The conservation and sustainable use of biodiversity, on the other hand, can contribute to both climate change mitigation and adaptation activities. Therefore, the vital link between two of the most pressing environmental issues facing our planet – biodiversity conservation and sustainable use, and climate change – needs to be better understood.

Some important emerging links between biodiversity, climate change and human livelihoods can be found in ongoing discussions on avoided emission from deforestation, adaptation and vulnerability, and the conservation of wetlands.

The Convention on Biological Diversity (CBD) set the international framework regarding biodiversity and very early on looked into the relationship between biodiversity and climate change. The CBD integrated climate change components within all of the programme of works of the convention, with the exception of technology transfer and cooperation, built synergies with the United Nations Framework Convention on Climate Change, and convened an Ad Hoc Technical Expert Group on climate change and biodiversity. There remains, however, several challenges and opportunities for the further development of interlinkages between biodiversity, climate change and livelihoods; many of which will need to be addressed through national implementation.

09.55 Professor Harold Mooney
Stanford University, USA
Biodiversity threats and human wellbeing

The Millennium Ecosystem Assessment provided a unique assessment framework for analysing both the direct and indirect drivers of change that are impacting ecosystems as well as the consequences of these changes on the capacity of these systems to deliver benefits to society. The findings of the assessment were disturbing since they showed a large erosion of the Earth's natural capital, with negative consequences, although some ecosystem benefits have been enhanced. Losses of biodiversity, in all of its dimensions, are at the base of the impairment of ecosystem-service delivery capacity. Climate change, coupled with other global changes, is already showing threats to the relationship of societies with their ecosystem base, and hence human wellbeing. The complex interactions and feedbacks between the climate system and biotic systems that are becoming evident indicate the very uncertain future we face. The structural changes in the responses of society to address these threats are enormous. We need concerted innovative efforts at all levels, from science to policy, and from local to global, to address these threats.

10.15 Dr Martin Manning
IPCC Working Group I Support Unit
The IPCC Working Group I 2007 Assessment: Observed and Projected Climate Change

This presentation will review aspects of the Working Group I contribution to the IPCC Fourth Assessment Report relevant to considerations of biodiversity. The Working Group I report is characterised by a higher degree of scientific confidence in observed climate change and its attribution to human activities than ever before. New data show that change consistent with global warming is now pervasive through large-scale aspects of the climate system. Our understanding of the drivers of these changes has improved and attribution of observed change to human activities now extends to many aspects of climate change other than surface warming. This increase in confidence provides a robust platform for considering projections of future climate change. As a result, we now have a much more comprehensive assessment of global average temperature changes and their uncertainties as well as higher confidence in our understanding of underlying physical processes including climate system inertia and committed warming. In relation to issues of biodiversity, the IPCC assessment provides new insights through the geographic patterns of projected change in warming and precipitation that are now better determined and largely independent of emission scenarios. In addition, the very large number of climate simulations run for the Working Group I report has provided an ability to assess changes in extreme weather events which are critical to determining impacts. Although some aspects of projected sea level rise are now better understood, newly observed phenomena in ice sheet discharge have increased uncertainties in this area. A further interaction with biodiversity occurs in the feedback between climate change and the carbon cycle where uncertainties remain large and affect our ability to determine emissions pathways consistent with specific stabilisation targets.

Session 2: Impacts of climate change and CO_2 on biodiversity

Chair: **Dr Carlos Nobre**, Instituto Nacional de Pesquisas Espaciais, Brazil

11.05 Professor Katherine Willis
University of Oxford, UK
Impacts of climate change on biodiversity: a palaeo-perspective

The Secretariat of the Convention on Biological Diversity recently highlighted four key action plans that are needed in response to current and future climate change*: (i) to conserve biodiversity that is especially sensitive to climate change;

* http://www.cbd.int/programmes/outreach/awareness/biodiv-day-2007.shtml

(ii) to preserve habitats so as to facilitate the long-term adaptation of biodiversity; (iii) to improve our understanding of climate change – biodiversity linkages; (iv) to fully integrate biodiversity considerations into mitigation and adaptation plans. Given the apparent immediacy of climate change and the prescriptive nature of these action plans, it is often difficult to see the relevance of examining past changes in climate/biodiversity. Surely we know more than enough already about past patterns of change? What more can such records provide other than a descriptive broad-based framework in which to view the present/future? Are processes that occurred before the onset of anthropogenically-forced climate change of any relevance to applied action plans? This talk argues the contrary and demonstrates that information from longer-term records – of both climate change and the response of organisms to this change – is essential to any planning framework for the future. Specific examples will be given to indicate how longer-term records (longer than 50 years) can provide applied information that is highly relevant to the four action plans outlined above, and contribute towards developing meaningful climate change conservation strategies.

11.25 Dr Camille Parmesan
University of Texas, USA
Impacts of anthropogenically driven climate change on biodiversity

With relatively small changes in recent temperatures (a rise of 0.7 °C over the 20th century), we have documented that half (50%) of all wild species for which we have long-term data have shown a response to local, regional or continental warming[14]. Global warming has affected every major biological group that has been studied (eg from herbs to trees, from plankton to fish, and from insects to mammals) and responses have been seen on all continents and in all major oceans[15,16]. Several recent synthetic, global analyses have concluded that these observed changes in biological systems are indeed caused by climate warming. The consensus among biologists that climate change has impacted a large part of the natural world now mirrors the level of consensus among climate scientists that the warming is caused by humans (in IPCC terms, we are more than 90% sure on both fronts)[1,2,3,17,18].

1) Globally, we are seeing a strong consistent pattern of northward movements of species ranges – from 50 km up to 1000 km shifts over the past 40 years – as well as upward movement in mountainous areas. Tropical species from Central America and Africa are moving into historically temperate zones of the USA and Europe, temperate species are moving into boreal zones of Alaska, Canada and Lapland, and true boreal species are losing total habitable area as woody shrubs invade the tundra, and sea ice disappears.

2) Some species that are adapted to a wide array of environments – globally common, or what we call weedy or urban species – will be most likely to persist. Rare species that live in fragile or extreme habitats are already being affected, and that is expected to continue. We are seeing stronger responses in areas with very cold-adapted species that have also had strong warming trends, such as in Antarctica and in the Artic. Species whose habitat is sea ice are showing drastic declines. This includes the polar bear and the ringed seal in the Arctic, and the Adelie and Emperor penguins in the Antarctic. Mountain-top species, like the pika, are dying off at their lower range boundaries, becoming more and more restricted to the highest elevations. Seventy-four species of montane Harlequin frogs have gone extinct, likely because the climate of these very range-restricted species has become optimal for a deadly fungus. Warm-adapted organisms are also showing negative impacts, and tropical coral reefs have suffered large declines worldwide because of recent high sea-surface temperatures.

3) Spring is earlier (by about two weeks) and autumn is later (by about one week) throughout the Northern Hemisphere. Where sufficient precipitation exists, this has extended the growing season. While this effect is projected to increase agricultural production in Canada, Sweden and Finland, large agriculture areas in the current temperate zones – eg the 'corn belt' of the USA and grain-growing regions in sub-Saharan Africa – are expected to experience continued drying conditions, which will negatively impact production as most of these areas currently do

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not irrigate but rely on natural rainfall. Regional projections of both total amount and seasonal patterns of rainfall are essential to agricultural projections, but often exhibit low consensus across climate models.

4) Forestry has already seen large increases in pest outbreaks throughout the USA, Canada, Europe and Russia. This is both because of pest species moving northward and invading new territory (such as the white pine beetle in the western USA), and because warmer winters and extended growing seasons are allowing many populations to increase their generation time (such as for the mountain pine beetle in Colorado and the spruce bark beetle in Alaska).

5) There are significant differences among taxonomic groups in their strength of spring advancement, which may portend increasing asynchrony of important trophic interactions, such as in insect/host plant systems (with implications for pest outbreaks), and in flowering plant/pollinator systems (with implications for crop pollination). However, explicit studies of changes in synchrony between trophic levels are rare, and high variation of response within a group in the same region suggests broad projections are not possible with our current state of understanding.

6) The observed northward movements of tropical species has implications for human health. Just as we are seeing birds and butterflies coming up from Mexico, human parasites and their wild animal vectors are likely to be shifting northwards as well. However, monitoring of parasites and their vectors in the wild is sparse and often poorly designed, leading to a very poor level of understanding of changes in parasite and vector distributions.

What are the implications of continued warming for biodiversity and human health?

All of the changes in natural systems that have been documented have occurred with only 0.7 °C global average warming. This small amount of warming has already driven 74 species of frog extinct, has killed large areas of coral reef worldwide, has placed many boreal animals at high risk of extinction, and has begun to increase water-borne diseases in humans. Even the most optimistic minimum projections – of 1.8 °C more warming – are more than twice what we have already seen. Under this 'best case' scenario, projections of impacts on wild life have a large range depending on the species group, degree of habitat restriction and geographic region. Examples at the low end are projected extinctions of 4% of birds and 7% of mammals in Mexico, to 6% of plants in Europe. At the upper end, projected extinctions with 2 °C warming range from extinction of 70% of butterflies, 40% of birds and 40% of Proteacea plants in South Africa, to 79% of plants in the Amazon.

Business-as-usual projections lead to a 4–5 °C rise, with some models projecting as much as 6.8 °C rise. This represents a climate the Earth has not seen in several million years – and on Earth humans, as a species, have never seen. Putting current climate change into the context of human evolution, our species, *Homo sapiens*, first emerged some 1.5 million years ago. During the entirety of human evolution, earth has spent the vast bulk of its time in a colder state than present. Periods as warm or warmer than today were very brief, geologically speaking. Aspects of human culture which are generally associated with modern society – such as cultivation of crops, written language, complex and sophisticated art and music – all emerged after a time when temperature became relatively stable on a global scale, about 10,000 years ago. The 'business as usual' projections for anthropogenic climate change will take earth into a climate phase that humans, as a species, have not experienced. Associated projected increases in extreme climate and weather events is a climatic state that humans, as a modern society, have not experienced.

Under this 'worst-case' scenario, projected impacts are severe for nearly every system studied. Worldwide mass extinctions are highly likely. Most cold-adapted species are expected to go extinct – those living in the Arctic and Antarctic and on mountaintops. Many tundra species, such as the caribou, are likely to go extinct. Large areas of boreal forest will die off, with obvious repercussions for the timber industry. Tropical diseases and parasites, along with their insect and mammalian vectors, will have shifted into the USA and Europe, with associated increased risk of human infection.

11.45 Professor Ove Hoegh-Guldberg

University of Queensland, Australia

Climate change and marine ecosystems: is an ecological 'tipping point' looming for marine ecosystems?

Impacts on the Earth's biosphere as a result of recent rapid increases in atmospheric carbon dioxide are already apparent. As in terrestrial ecosystems, changes are occurring across the full range of ecosystems including polar, temperature and tropical systems. Changes in marine ecosystems are being driven primarily by relatively small increases in ocean temperature, acidity and sea level, although other factors such as the coastal desertification and more intense storms are placing increasing pressure on marine ecosystems. It is noteworthy that the current pace of change in ecosystem function has occurred while global average temperature has increased by less than 1 °C, suggesting that future changes (2–6 °C) are likely to be fundamental. Current rates of change will have major if not devastating impacts on marine biodiversity and ecosystem function. The critical level of 500 ppm (atmospheric CO_2) for marine ecosystems is particularly emphasised with respect to the unsustainable impacts beyond this level. Several scenarios will be developed in this paper that will highlight the likely consequences for marine ecosystems, coastal dependents and for future societies.

12.05 Panel Discussion

Chair: Professor Georgina Mace FRS, *Imperial College London, UK*
Defining the knowledge/research gap

Session 3: The role of biodiversity in the climate system

Chair: Dr Josep Canadell, Executive Director, *Global Carbon Project, CSIRO, Australia*

13.45 Dr Michel Loreau
McGill University, Montreal, Canada
Biodiversity and ecosystem functioning: potential implications for the biosphere

The relationship between biodiversity and ecosystem functioning has emerged as a central issue in ecological and environmental sciences during the past decade. Increasing domination of ecosystems by humans is steadily transforming them into depauperate systems. Because ecosystems collectively determine the biogeochemical processes that regulate the earth system, the potential ecological consequences of biodiversity loss have aroused considerable interest.

Recent theoretical and experimental work has showed that plant species diversity enhances the productivity of grassland ecosystems because functional complementarity among species leads to better collective resource use. Similar results have been obtained for a wide range of ecosystems. There is also theoretical and experimental evidence that biodiversity acts in the long term as biological insurance, stabilising ecosystem processes in the face of environmental changes.

The extent and complexity of biodiversity effects, however, are probably strongly underestimated by current knowledge based on simple systems and single ecosystem processes. Interactions between multiple trophic levels, spatial flows in heterogeneous landscapes and cascades of species extinctions are expected to make the relationship between biodiversity and biogeochemical processes complex and highly non-linear. It is currently difficult to provide reliable quantitative estimates of the impacts of current and future biodiversity changes on the entire biosphere and on the climate system. But these impacts are likely to be far-reaching.

14.05 Professor Peter Cox
University of Exeter, UK
The role of ecosystems in the climate system

Ecosystems play important roles in the climate system ranging from the impact of land plants on the albedo of the land-surface and the intensity of the hydrological cycle, to the influence of ocean and land ecosystems on the long-term evolution of Earth's atmospheric composition.

In the context of contemporary climate change, the 'natural' carbon cycle is currently providing a vital service for humankind by absorbing about 50% of anthropogenic CO_2 emissions. Ecosystem processes are responsible for the land carbon sink and much of the ocean carbon sink, so changes in biodiversity have the potential to affect the rate of future climate change through changes in the carbon cycle.

First generation coupled climate-carbon cycle models suggest that natural carbon sinks (especially on the land) may be vulnerable to climate change, which implies a higher airborne fraction of anthropogenic CO_2 emissions in the future and faster climate change. Some models (most notably the Hadley Centre HadCM3-based models) also suggest that climate change could lead to 'dieback' of the Amazonian rainforest, with potentially devastating impacts on biodiversity. However, coupled climate-carbon cycle models currently have a small number of plant functional types (typically 5–15) and an even smaller number of marine phytoplankton types (typically 0–1).

It is not yet clear whether a better representation of biodiversity would lead to greater ecosystem resilience in these models. However, simple modelling suggests that greater biodiversity does result in greater resilience of ecosystem services (such as primary production) to climate change, but only if the rate of climate change is slow relative to the typical species lifetime.

On this basis, it seems more important to model diversity in fast turnover ecosystems (such as soil microbial and marine phytoplankton communities), than in slow turnover ecosystems (such as forests). Furthermore, the simple modelling suggests a critical rate of climate change (as a multiple of species lifetime) beyond which even diverse ecosystems will not be resilient to climate change.

14.25 Dr Richard Betts
Met Office Hadley Centre, UK
Biodiversity – ecosystem and climatic functioning

How important is Darwin's 'entangled bank' for biosphere – climate feedbacks? Would these feedbacks operate differently if the world were not 'clothed in many plants of many kinds'? Does the climate system actually care about 'endless forms most beautiful and most wonderful'?

Examination and quantification of large-scale interactions between the biota and its physical and chemical environment inevitably involve some measure of approximation about the extent to which the diversity of life is considered.
The concepts of the biome and the functional type have been used to powerful effect in advancing our understanding of several feedbacks between ecosystems and climate change by reducing the complexity of life to manageable proportions. The underlying assumption is that this complexity is of secondary importance; however, the implications of this assumption have received relatively little attention.

Diversity among life forms may affect biosphere – climate interactions in several ways. Influences of life on climate, for example through biogeochemical fluxes from vegetation affecting atmospheric composition and the earth's radiation balance, may vary between species or groups of species. Even if the direct effects of different life forms on climate are similar, for example by exchanging carbon with the atmosphere at similar rates, their individual responses to climate change may differ and this may affect the magnitude of feedbacks. Other life forms may exert indirect effects on climate even if their direct effects are small – for example, while insects or grazing animals usually account for only a small proportion of carbon stored in an ecosystem, they may exert a large effect on the fluxes of carbon between the ecosystem and the atmosphere and through disturbance of vegetation. These processes present challenges for earth system science and consequently for the actions and decisions of stakeholders which are informed by this science.

Is diversity important for the response of ecosystems to climate change and/or feedbacks on climate change?
And if diversity is important, does it increase or decrease the stability of the climate system against perturbations?
This presentation asks key questions about the role of biodiversity as a functional component of the climate system, as a starting point for discussion in the breakout groups.

14.45 Breakout Groups

- Impacts on biodiversity
- Biogeochemical processes
- Biodiversity and climate regulation
- Science and policy linkages

See delegate pack insert for the details and location of each breakout group

15.45 Breakout Groups report back to plenary

16.25 Plenary Discussion

Chair: Professor Brian Huntley, *University of Durham, UK*

19.00 After-dinner speaker: Dr Ken Caldeira, *Carnegie Institution of Washington, USA*

Wednesday 13 June 2007

Session 4: Interactions between biodiversity, climate and human livelihoods

Chair: **Sir Gordon Conway FRS**, *Chief Scientist, The Department for International Development, UK*

09.15 **Professor John Shepherd FRS**
The National Oceanography Centre, University of Southampton, UK
Setting the scene

09.35 **Dr Bob Scholes** *The Council for Scientific and Industrial Research, South Africa*, and
Dr Guy Midgely, *The South African National Biodiversity Institute, Pretoria, South Africa*
Impact of climate change driven biodiversity loss on human livelihoods

Recent IPCC projections suggested an increased risk of extinction for 20–30% of species assessed so far if global mean temperature rises a further 1.5–2.5 °C. It remains surprisingly difficult to assess the net impact of such a loss of species on human society and its component livelihoods. The global average projected loss due to climate change conceals vast regional differences in projected biodiversity losses, in different types of ecosystems, and for different species that coexist in ecosystems. It would appear from species modelling that range restricted and rare species are likely most at risk from climate change, and from observations that key ecosystems near critical climate-related thresholds (such as coral reefs) are most sensitive. Many traditional subsistence-type livelihoods that depend on these kinds of species and ecosystems are therefore increasingly at risk, and may suffer threshold-type collapses. More broadly, climate change is likely to affect individual species through altering population demographic processes and constraints. These may also cause threshold type responses when 'demographic bottlenecks' are introduced or removed. More efficient extractive practices that support expanded or new industries, greater trade in and use of wild species, and long distance transport of species are themselves having significant demographic impacts on wild populations. Thus many impacts on human livelihoods are likely to be driven by 'demographic vulnerability' of species – and it should be possible to identify vulnerable species and related livelihoods with better understanding of such 'demographic bottlenecks'. A better understanding of species demographies could therefore open the way to more sustainable use of wild species under climate change.

09.55 **Dr Antonio Nobre**, *Amazon Research Unit, Instituto Nacional de Pesquisas Espaciais, Brazil*
The climate system and its interactions with biodiversity and human livelihoods

After the release of the series of IPCC reports in the last few months, it became clear that massive alterations in the climate system are already happening, and at a fast pace. Despite this, biodiversity is still seen for the most part as a sitting duck, waiting for climate change to strike. Nevertheless several works exploring the biosphere-atmosphere interactions have indicated that the myriad of organisms in natural systems might have much bigger resilience and more than a passive role in climate regulation. In order to explore this possibility for a well-known, less spoiled, massive terrestrial system, we can focus on South America and its impacts on the regional climate. There is much evidence to indicate that South America, east of the Andes, might have had a sufficiently stable climate for at least 25,000 years, and possibly for much longer. The extraordinary diversity of life forms found in its three most extensive biomes, the Amazon and Atlantic forests and the savannas, supports the indication of long-term climate stability. However, whether South America enjoyed a continuous forest cover over millions of years or if it was subjected to periods of partial or total aridity has not been established beyond a certain controversy. Extensive forests, covering most of the continent, requires wet climates or, at least, a less seasonal rainfall distribution. Long dry seasons create a role for fire in opening up forest areas that can be colonised by savannas. Conversely, short or absent dry seasons will favour forest over savannas. The historical vegetation cover in South America is thus rather relevant as proxy for the understanding of the complex biome-atmosphere interactions and control mechanisms. Over thousands or likely millions of years, the rainforest of South America has evolved its luxuriant biota without signs of having been shut-down by climate extremes, like aridity or freezing. Over the same span of time, however, it is very unlikely that external climate forcing remained equally benign, especially considering orbital and other known drivers for planetary-scale stern climate changes. The lingering question then is how on the face of formidable external adversity has this magnificent biome resisted extinction? This question then elicits another one: how will the system respond to the new forcing on climate, given that there is an unprecedented annihilation pressure on forests? Some potential scenarios for impacts on human livelihoods, both within and outside the great domain of Amazonia, have been explored by coupled climate modelling exercises. Uncertainty on these exercises still does not warrant full confidence on the projections. Nevertheless, the destruction of the long-standing climate-forest regulating systems has the potential to adversely impact agriculture, reduce or damage hydro energy production, alter frequency and intensity of extreme events both on land and over seas, among many other damages.

10.15 Dr Dagmar Schröter, *Federal Environment Agency, Austria*
Human activity, global change and its impacts on biodiversity

Humans affect biodiversity, and vice versa, through the altered supply of ecosystem services vital to human wellbeing. The effects of human activity on the biosphere in past decades and today are well documented. The most sensitive ecosystems are tropical and subtropical forests, grasslands, shrublands and savannas, as well as montane grass- and shrublands. We observe a trend towards a more homogenous biosphere, marked by losses of nutrient-poor habitats, traditional cultural landscape patterns, and wilderness. Multiple direct drivers are impacting ecosystems and their services, most prominently habitat changes, exploitation, invasive species, pollution, and climate change. All drivers act in concert. However, their integrated effects are poorly understood. Nevertheless, climate change impacts are likely to be stronger where the human-environment system is already degraded. Amongst the habitat changes, soil erosion is particularly devastating, with lasting effects on the wellbeing and safety of human settlements. The maintenance of soils can determine the course of society toward prosperity or poverty, as exemplified by the Dominican Republic and Haiti. While habitat change is an immediate and strong driver, climate change will kick in to be of greater relative importance in a few decades. Climate change can be influenced only indirectly and on a long-term basis, but land-use change and exploitation are drivers that we influence directly and immediately. Sustainable land management is a formidable challenge and opportunity that requires transdisciplinary approaches, ie the involvement of policy developers, stakeholders and scientists. For example, in some industrialised regions (eg Europe and North America) population growth is minimal or declining, forest area is increasing, and the demand for agricultural land is satisfied. Such releases of land pressure offer the opportunity to counteract negative climate impacts by sustainable land management, such as for example: water saving agricultural practices (such as possibly organic farming), biomass energy production, and the establishment of a well-connected landscape to facilitate species migration.

11.05 Panel Discussion

Chair: Dr Ashok Khosla, *Development Alternatives Group, India*

Session 5: Solutions

Chair: Dr Yadvinder Malhi, *University of Oxford, UK*

13.15 Dr Daniel Murdiyarso, *Center for International Forestry Research, Indonesia*, and **Nevile Kemp**, *Conservation International, Indonesia*
Mitigating climate change through avoiding deforestation for the benefit of biodiversity and sustainable livelihoods

Deforestation is responsible for more than 20% of global carbon emissions, yet avoiding deforestation was regretfully not considered in international climate treaty when the Kyoto Protocol was adopted in 1997. It was only two years ago when the Eleventh session of the Conference of Parties (COP11) to the United Nations Framework Convention on Climate Change (UNFCCC) initiated a two-year process of reducing emissions from deforestation (RED) in developing countries to mitigate global warming. The process is meant to facilitate the exchange of information related to policy approaches, positive incentives, and scientific and methodological issues.

The Stern Review suggests that measures to avoid deforestation could be relatively cheap, but our research found that there will be large social and institutional costs related to any such projects. Setting aside large areas of forest to prevent development is simply not possible in areas where local communities need to make a living, and therefore, we argue that measures to reduce rates of deforestation could be used to promote sustainable livelihoods and forest management. Such a scheme was not allowed under the Clean Development Mechanism (CDM) of the Kyoto Protocol.

This paper demonstrates conservation of existing forests by the community that in turn provides goods and services for the local livelihoods, biodiversity conservation and global climate. The examples from Mamberamo Basin, Papua and Riau Provinces are among potential projects for the new climate regime post-2012. The amount of carbon that is stored and preserved can be enormous, hence such projects can make a big difference in biodiversity conservation and to local communities. The challenges would be the transaction costs including monitoring of carbon stocks and the benefit sharing among key stakeholders.

13.35 Mr Don MacIver, *Environment Canada, Canada*

What are the opportunities and risks for management of biodiversity for adaptation?

Given the current rates of global losses of biodiversity, this may be the last generation of biologists to study natural ecosystems. In many cases, inadequate information exists for good decision-making. However, decisions are urgently needed to reduce the rate of loss of biodiversity by 2010.

Population expansions and associated developments combined with human-induced climate change, added to natural variabilities, will accelerate the loss of biodiversity. Many international agencies and conventions have identified mitigation and adaptation options, including advice to national governments on biodiversity and climate change. Conservation and management strategies need to be designed in a climate envelope that is already in rapid transition and taking into account other multiple stressors. Examples of community-driven biodiversity monitoring programs and climate change modelling will provide further insights into the scale and importance of adaptation actions.

13.55 Dr Peter Bridgewater, Director General, *Ramsar Convention Switzerland*

What is the role for biodiversity research and policy in mitigation and adaptation strategies?

There is clear inter-linkage between biodiversity and climate change in many ways and at many scales. At global policy level there is increasing focus on the twin axes of mitigation against climate change, and also adaptation to it. For both mitigation and adaptation biodiversity has a key and important role. Increasing commonality of purpose and approaches between the Multilateral Environmental Agreements, the UNFCCC on one hand and the family of biodiversity related conventions represented by the CBD on the other, means science, both climate change and biodiversity needs to come together more effectively.

Site-based conservation seems unable to decide what to do in the face of climate change, but the continuing view is that protected areas were even more important than before. Yet protected areas, under climate change scenarios, will become not so much places protected, but places open for evolutionary activity from the range of genetic material contained within. For climate change will certainly change the rates of evolution among species, and probably will increase the role and importance of r-species as opposed to *K*-species.

One key are of biodiversity research which will be useful in this scenario is an understanding of the respective roles and functions of the different hierarchical levels of biodiversity, and how that can be harnessed particularly to manage our way out of the most serious effects of climate change. Similarly, climate change science can help biodiversity researchers and managers by providing more robust predictions and scenarios of change, so biodiversity researchers can use their knowledge to manage species interactions in a better way.

In this way the two sciences behinds climate change and biodiversity reinforce each other, leading to enhanced policy cooperation, in turn enhancing the protection of human well being.

14.15 Breakout Groups

- Effects of climate change on biodiversity dependent livelihoods
- Climate change strategies and vulnerability of ecosystems and human populations
- Ecosystems for enabling adaptation and mitigation
- Achieving science and policy synergies

15.15 Breakout Groups report back to plenary

16.00 Plenary Discussion

Chair: Dr Wolfgang Cramer, *Potsdam Institute of Climate Impact Research, Germany*

17.00 Dr Richard Betts
Met Office Hadley Centre, UK
Workshop reflections and summary

17.30 Close of Workshop

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Appendix 2: Additional text submitted from June workshop presenters

A2.1 Dr Camille Parmesan

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Summary of key research results/messages/recommendations

With relatively small changes in recent temperatures (a rise of 0.7 °C over the 20th century), we have documented that half of all wild species for which we have long-term data have shown a response to local, regional or continental warming (Parmesan & Yohe 2003) (795 out of 1598 species have either changed their distributions or advanced phenologically as predicted from climate warming). Global warming has affected every major biological group that has been studied (eg from herbs to trees, from plankton to fish, and from insects to mammals) and responses have been seen on all continents and in all major oceans (Parmesan & Galbraith 2004; Parmesan 2006). Several recent synthetic, global analyses have concluded that these observed changes in biological systems are indeed caused by climate warming. The consensus among biologists that climate change has impacted a large part of the natural world now mirrors the level of consensus among climate scientists that the warming is caused by humans (in IPCC terms, we are more than 90% sure on both fronts) (Parmesan & Yohe 2003; Parmesan & Galbraith 2004; Parmesan 2006; Root et al 2003; IPCC 2007b).

Globally, we are seeing a strong consistent pattern of poleward movements of species ranges – from 50 km up to 1000 km shifts over the past 40 years – as well as upward movement in mountainous areas. Some species that are adapted to a wide array of environments – globally common, or what we call weedy or urban species – will be most likely to persist. Rare species that live in fragile or extreme habitats are already being affected. For example, species whose habitat is sea ice are showing drastic declines (eg the polar bear, the ringed seal and the Adelie penguin). Several mountain-top species are suffereing range contractions as lower elevations have become climatically unsuitable (eg the American pika and the Apollo butterfly in Europe). Warm-adapted organisms are also showing negative impacts, and tropical coral reefs have suffered large declines worldwide due to recent high sea surface temperatures.

Spring is earlier (by about two weeks) and fall is later (by about one week) throughout the northern hemisphere. These phenological shifts have been associated with large increases in forest pest outbreaks throughout the USA, Canada, Europe and Russia. This is both because of pest species moving northward and invading new territory (eg the pine processionary moth in Europe), and because warmer winters and extended growing seasons have resulted in large population increases (eg the mountain pine beetle in Colorado and the spruce bark beetle in Alaska).

There are significant differences among taxonomic groups in their strength of spring advancement, which may portend increasing asynchrony of important trophic interactions, such as in insect/host plant systems (with implications for pest outbreaks), and in flowering plant/pollinator systems (with implications for crop pollination). However, explicit studies of changes in synchrony between trophic levels are rare, and high variation of response within a group in the same region suggests broad projections are not possible with our current state of understanding.

What are the implications of continued warming for biodiversity and human health?

All documented changes in natural systems have occurred with only 0.7 °C global average warming, with an estimated 50% of wild species already affected. Outbreaks of many human diseases are correlated with above-average temperatures. For example, 60% of the variation in abundance of the *Vibrio vulnificus* bacteria, which infects oysters and other seafood, can be explained by temperatura (Motes et al 1998, Shapiro et al 1998). Thirty to forty-eight per cent of humans that show symptoms of *V. vulnificus* infection die. Further, abundances of *Vibrio cholerae* bacteria in Bangladesh are positively correlated with high sea-surface temperatures (Colwell 1996).

Even the most optimistic projections – of 1.8 °C more warming – are more than twice what we have already seen. Under this 'best case' scenario, projections of impacts on wild life have a large range depending on the species group, degree of habitat restriction and geographic region. Examples at the low end are projected extinctions of 4% of birds and 7% of mammals in Mexico, to 6% of plants in Europe. At the upper end, projected extinctions with 2 °C warming range from extinction of 70% of butterflies, 40% of birds and 40% of Proteacea plants in South Africa, to 79% of plants in the Amazon (IPCC 2007b; Thomas et al 2004).

The 'business as usual' projections for anthropogenic climate change (4–6.8 °C rise) will take Earth into a climate phase that humans have not experienced. Under this 'worst-case' scenario, projected impacts are severe for nearly every system studied. Worldwide mass extinctions are highly likely. Most cold-adapted species are expected to go extinct – those living in the Arctic and Antarctic and on mountaintops. Many tundra species, such as the caribou, are likely to go extinct. Large areas of boreal forest will die off, with obvious repercussions for the timber industry. Tropical diseases and parasites, along with their insect and mammalian vectors, will shift into the USA and Europe, with associated increased risk of human infection.

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Contribution to Conference Summary

The speakers were invited and briefed to speak about a range of topics, from (1) climate research (palaeo-climatology to future climate projections), over (2) impacts of climate change on biodiversity, and (3) impacts of changes in biodiversity on the climate system, to (4) links between climate change, biodiversity and human wellbeing.

Key messages from these four topics

Ad (1) The take home message of the IPCC Fourth Assessment Report on Cilmate Change is: 'It's later than you think.' Reducing greenhouse gas emissions is an absolute must, but will nevertheless only mitigate climate change in the long term. That is, we are committed to substantial changes, mitigation effects will only kick in around mid-century.

Ad (2) Already today, the human–environment system is strongly influenced by climate change. Observations of marine and terrestrial systems confirm that climate change impacts biodiversity. These impacts are various, and cannot be seen in isolation from other global change drivers, such as eg land-use change and atmospheric nitrogen deposition.

Ad (3) Ecosystems and biodiversity impact the climate system in important ways, for example through changes in albedo, carbon sequestration in soils and plants, plant-born volatile organic compounds, and biogenic contribution to nitrogen and ozone cycles. However, such feedbacks are currently not or only scarcely represented in our climate models.

Ad (4) As a milestone in biodiversity and global change research, the Millennium Ecosystem Assessment demonstrated how ecosystems and human wellbeing are intrinsically tied. Environmental degradation threatens the achievement of the Millennium Development Goals. The concept of 'ecosystem services' links biodiversity and human welfare and builds a basis for discussion in conflicts of interest, as well as for multiple criteria analyses and green/red accounting (accounting for the true costs of an activity to the environment and the social system.

Biodiversity protection, climate mitigation and development can sometimes form synergies – such win–win–win situations need to be sought and capitalised on (eg creating sustainable livelihoods by counteracting deforestation in Indonesia). However, conflicts of interest are also widespread, eg if development means intensified land use in regions that still harbour species-rich wilderness. In these cases the concept of ecosystem services can be used for practical decision-making. Participative assessments of changes in provision of the complete range of ecosystem services at stake can best inform discussions on the possible conflicting management aims of different stakeholders.

Land-use changes can mitigate or exacerbate climate change impacts on human wellbeing. Contrasting examples are Haiti (largely deforested, massive soil erosion, land slides, loss of fertile land, hurricane Jeanne 2004 resulted in human crisis, in contrast to neighbouring state Dominican Republic) and Europe (land-use change shows positive trends and may mitigate climate change, eg land-use change alone strengthens carbon sink, but climate change counteracts this especially after 2050).

The conference participants agreed that there should be a new Millennium Ecosystem Assessment. Furthermore, the IPCC should publish a second technical paper on climate change and biodiversity (such a paper was first published in 2002: *Climate Change and Biodiversity*, April 2002, H Gitay, A Su·rez, RT.Watson, DJ Dokken (eds), IPCC, Geneva, Switzerland, pp 85. Available from IPCC Secretariat).

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(3 pages, 5 Dec 2007, 27/07)

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Royal Society submission to DFID's consultation on its Research Strategy 2008–2013
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Royal Society Response to the UK Climate Change Bill Consultation
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Joint Science Academies' statement: sustainability, energy efficiency and climate protection
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Submission to House of Lords S&T Select Committee inquiry on radioactive waste management
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Response to Defra's consultation on the coexistence of GM, conventional and organic crops
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Response to the Environmental Audit Committee's inquiry into the Millennium Ecosystem Assessment
(5 pages, December 2006, 30/06)

Response to RCEP initial consultation on the environmental effects of novel materials and applications
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