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IPCC Technical Paper V

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INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

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Climate Change and Biodiversity

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This is a Technical Paper of the Intergovernmental Panel on Climate Change prepared in response to a request from the United Nations Convention on Biological Diversity. The material herein has undergone expert and government review, but has not been considered by the Panel for possible acceptance or approval.

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This paper was prepared under the auspices of the IPCC Chair, Dr. Robert T. Watson, and administered by the IPCC Working Group II Technical Support Unit.

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PREFACE

This Intergovernmental Panel on Climate Change (IPCC) Technical Paper on Climate Change and Biodiversity is the fifth paper in the IPCC Technical Paper series and was produced in response to a request from the Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA) of the United Nations Convention on Biological Diversity.

This Technical Paper, as all Technical Papers, is based on the material in previously approved/accepted/adopted IPCC assessment reports and special reports and was written by Lead Authors chosen for the purpose. It underwent a simultaneous expert/government review, followed by a final government review. The Bureau of the IPCC acted in the capacity of an editorial board to ensure that the review comments were adequately addressed by the Lead Authors in the finalization of the Technical paper.

The Bureau met in its 25th Session (Geneva, 15-16 April 2002) and considered the major comments received during the final government review. In the light of its observation and requests, the Lead Authors finalized the Technical Paper. The Bureau authorized the release of the paper to SBSTTA and to the public.

We owe a large debt of gratitude to the Lead Authors (listed in the paper) who gave of their time very generously and who completed the paper according to schedule. We also thank David Dokken who assisted the Convening Lead Authors in the preparation and editing of the paper.

R.T. Watson
Chairman of the IPCC
(at the time of completion of the paper)

N. Sundararaman
Secretary of the IPCC
(at the time of completion of the paper)

Climate Change and Biodiversity

This paper was requested by the United Nations Convention on Biological Diversity and prepared under the auspices of the IPCC Chair, Dr. Robert T. Watson.

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EXECUTIVE SUMMARY

At the global level, human activities have caused and will continue to cause a loss in biodiversity[1] through, *inter alia*, land-use and land-cover change; soil and water pollution and degradation (including desertification), and air pollution; diversion of water to intensively managed ecosystems and urban systems; habitat fragmentation; selective exploitation of species; the introduction of non-native species; and stratospheric ozone depletion. The current rate of biodiversity loss is greater than the natural background rate of extinction. A critical question for this Technical Paper is how much might climate change (natural or human-induced) enhance or inhibit these losses in biodiversity?

Changes in climate exert additional pressure and have already begun to affect biodiversity. The atmospheric concentrations of greenhouse gases have increased since the pre-industrial era due to human activities, primarily the combustion of fossil fuels and land-use and land-cover change. These and natural forces have contributed to changes in the Earth's climate over the 20th century: Land and ocean surface temperatures have warmed, the spatial and temporal patterns of precipitation have changed, sea level has risen, and the frequency and intensity of El Niño events have increased. These changes, particularly the warmer regional temperatures, have affected the timing of reproduction in animals and plants and/or migration of animals, the length of the growing season, species distributions and population sizes, and the frequency of pest and disease outbreaks. Some coastal, high-latitude, and high-altitude ecosystems have also been affected by changes in regional climatic factors.

Climate change is projected to affect all aspects of biodiversity; however, the projected changes have to take into account the impacts from other past, present, and future human activities, including increasing atmospheric concentrations of carbon dioxide (CO_2). For the wide range of Intergovernmental Panel on Climate Change (IPCC) emissions scenarios, the Earth's mean surface temperature is projected to warm 1.4 to 5.8°C by the end of the 21st century, with land areas warming more than the oceans, and the high latitudes warming more than the tropics. The associated sea-level rise is projected to be 0.09 to 0.88 m. In general, precipitation is projected to increase in high-latitude and equatorial areas and decrease in the subtropics, with an increase in heavy precipitation events. Climate change is projected to affect individual organisms, populations, species distributions, and ecosystem composition and function both directly (e.g., through increases in temperature and changes in precipitation and in the case of marine and coastal ecosystems also changes in sea level and storm surges) and indirectly (e.g., through climate changing the intensity and frequency of disturbances such as wildfires). Processes such as habitat loss, modification and fragmentation, and the introduction and spread of non-native species will affect the impacts of climate change. A realistic projection of the future state of the Earth's ecosystems would need to take into account human land- and water-use patterns, which will greatly affect the ability of organisms to respond to climate change via migration.

The general effect of projected human-induced climate change is that the habitats of many species will move poleward or upward from their current locations. Species will be affected differently by climate change: They will migrate at different rates through fragmented landscapes, and ecosystems dominated by long-lived species (e.g., long-lived trees) will often be slow to show evidence of change. Thus, the composition of most current ecosystems is likely to change, as species that make up an ecosystem are unlikely to shift together. The most rapid changes are expected where they are accelerated by changes in natural and anthropogenic non-climatic disturbance patterns.

Changes in the frequency, intensity, extent, and locations of disturbances will affect whether, how, and at which rate the existing ecosystems will be replaced by new plant and animal assemblages. Disturbances can increase the rate of species loss and create opportunities for the establishment of new species.

Globally by the year 2080, about 20% of coastal wetlands could be lost due to sea-level rise. The impact of sea-level rise on coastal ecosystems (e.g., mangrove/coastal wetlands, seagrasses) will vary regionally and will depend on erosion processes from the sea and depositional processes from land. Some mangroves in low-island coastal regions where sedimentation loads are high and erosion processes are low may not be particularly vulnerable to sea-level rise.

The risk of extinction will increase for many species that are already vulnerable. Species with limited climatic ranges and/or restricted habitat requirements and/or small populations are typically the most vulnerable to extinction, such as endemic mountain species and biota restricted to islands (e.g., birds), peninsulas (e.g., Cape Floral Kingdom), or coastal areas (e.g., mangroves, coastal wetlands, and coral reefs). In contrast, species with extensive, non-patchy ranges, long-range dispersal mechanisms, and large populations are at less risk of extinction. While there is little evidence to suggest that climate change will slow species losses, there is evidence it may increase species losses. In some regions there may be an increase in

[1] In this Technical Paper, the term biodiversity is used synonymously with biological diversity.

local biodiversity—usually as a result of species introductions, the long-term consequences of which are hard to foresee.

Where significant ecosystem disruption occurs (e.g., loss of dominant species or a high proportion of species, or much of the species redundancy), there may be losses in net ecosystem productivity (NEP) at least during the transition period. However, in many cases, loss of biodiversity from diverse and extensive ecosystems due to climate change does not necessarily imply loss of productivity as there is a degree of redundancy in most ecosystems; the contribution to production by a species that is lost from an ecosystem may be replaced by another species. Globally, the impacts of climate change on biodiversity and the subsequent effects on productivity have not been estimated.

Changes in biodiversity at ecosystem and landscape scale, in response to climate change and other pressures (e.g., changes in forest fires and deforestation), would further affect global and regional climate through changes in the uptake and release of greenhouse gases and changes in albedo and evapotranspiration. Similarly, structural changes in biological communities in the upper ocean could alter the uptake of CO_2 by the ocean or the release of precursors for cloud condensation nuclei causing either positive or negative feedbacks on climate change.

Modeling the changes in biodiversity in response to climate change presents some significant challenges. The data and models needed to project the extent and nature of future ecosystem changes and changes in the geographical distribution of species are incomplete, meaning that these effects can only be partially quantified.

Impacts of climate change mitigation activities on biodiversity depend on the context, design, and implementation of these activities. Land-use, land-use change, and forestry activities (afforestation, reforestation, avoided deforestation, and improved forest, cropland, and grazing land management practices) and implementation of renewable energy sources (hydro-, wind-, and solar power and biofuels) may affect biodiversity depending upon site selection and management practices. For example, 1) afforestation and reforestation projects can have positive, neutral, or negative impacts depending on the level of biodiversity of the non-forest ecosystem being replaced, the scale one considers, and other design and implementation issues; 2) avoiding and reducing forest degradation in threatened/vulnerable forests that contain assemblages of species that are unusually diverse, globally rare, or unique to that region can provide substantial biodiversity benefits along with the avoidance of carbon emissions; 3) large-scale bioenergy plantations that generate high yields would have adverse impacts on biodiversity where they replace systems with higher biological diversity, whereas small-scale plantations on degraded land or abandoned agricultural sites would have environmental benefits; and 4) increased efficiency in the generation and/or use of fossil-fuel-based energy can reduce fossil-fuel use and thereby reduce the impacts on biodiversity resulting from resource extraction, transportation (e.g., through shipping and pipelines), and combustion of fossil fuels.

Climate change adaptation activities can promote conservation and sustainable use of biodiversity and reduce the impact of changes in climate and climatic extremes on biodiversity. These include the establishment of a mosaic of interconnected terrestrial, freshwater, and marine multiple-use reserves designed to take into account projected changes in climate, and integrated land and water management activities that reduce non-climate pressures on biodiversity and hence make the systems less vulnerable to changes in climate. Some of these adaptation activities can also make people less vulnerable to climatic extremes.

The effectiveness of adaptation and mitigation activities can be enhanced when they are integrated with broader strategies designed to make development paths more sustainable. There are potential environmental and social synergies and tradeoffs between climate adaptation and mitigation activities (projects and policies), and the objectives of multilateral environmental agreements (e.g., the conservation and sustainable use objective of the Convention on Biological Diversity) as well as other aspects of sustainable development. These synergies and tradeoffs can be evaluated for the full range of potential activities—*inter alia*, energy and land-use, land-use change, and forestry projects and policies through the application of project, sectoral, and regional level environmental and social impact assessments—and can be compared against a set of criteria and indicators using a range of decisionmaking frameworks. For this, current assessment methodologies, criteria, and indicators for evaluating the impact of mitigation and adaptation activities on biodiversity and other aspects of sustainable development will have to be adapted and further developed.

Identified information needs and assessment gaps include:

- Enhanced understanding of the relationship between biodiversity, ecosystem structure and function, and dispersal and/or migration through fragmented landscapes
- Improved understanding of the response of biodiversity to changes in climatic factors and other pressures
- Development of appropriate resolution transient climate change and ecosystem models especially for quantification of the impacts of climate change on biodiversity at all scales, taking into account feedbacks
- Improved understanding of the local to regional scale impacts of climate change adaptation and mitigation options on biodiversity
- Further development of assessment methodologies, criteria, and indicators to assess the impact of climate change mitigation and adaptation activities on biodiversity and other aspects of sustainable development
- Identification of biodiversity conservation and sustainable use activities and policies that would beneficially affect climate change adaptation and mitigation options.

1. Background and Genesis of the Request for the Technical Paper

The Subsidiary Body for Scientific, Technical, and Technological Advice (SBSTTA) of the United Nations Convention on Biological Diversity (UNCBD) formally requested the IPCC to prepare a Technical Paper on climate change and biodiversity covering three specific topics:

- The impacts of climate change on biological diversity and the impacts of biodiversity loss on climate change
- The potential impact on biological diversity of mitigation measures that may be carried out under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, and identification of potential mitigation measures that also contribute to the conservation and sustainable use of biological diversity
- The potential for the conservation and sustainable use of biological diversity to contribute to climate change adaptation measures.

This request was discussed by the IPCC at its Seventeenth Session (Nairobi, Kenya, 4-6 April 2001) and was approved at the Eighteenth Session (Wembley, United Kingdom, 24-29 September 2001).

The information contained in this Technical Paper, as with any IPCC Technical Paper, is drawn from approved/adopted/accepted IPCC reports—in this case, particularly the Third Assessment Report [TAR, including the Synthesis Report (SYR)], the Special Report on Land Use, Land-Use Change, and Forestry (LULUCF), and the Special Report on the Regional Impacts of Climate Change (RICC). These reports did not attempt to undertake a comprehensive assessment of the relationship between climate change and biodiversity (e.g., they contain limited information on the impact of future changes in biodiversity on climate, implications of climate change on biodiversity at the genetic level, and the potential of biodiversity conservation and sustainable use to contribute to climate change adaptation measures). Hence, the reader should be aware that these limitations in the material contained within previous IPCC reports are reflected in the balance of material presented in this Technical Paper. Some material of relevance to this paper, which was published after completion of the TAR, is listed in Appendix A (none of the material from the provided citations was considered in the text).

This Technical Paper summarizes the material that is in the IPCC reports of relevance to the UNCBD request. Sections 3 and 4 discuss the observed and projected climate change of relevance to biodiversity; Sections 5 and 6 the observed and projected impacts of climate change on biodiversity; Sections 7 and 8 the impacts of climate change mitigation and adaptation activities on biodiversity; Section 9 the assessment methodologies, criteria, and indicators that can be used to evaluate the environmental and socio-economic impacts of mitigation and adaptation activities; and Section 10 the identified information needs and assessment gaps. As appropriate, references to prior IPCC reports are contained in brackets following specific paragraphs (refer to Appendix C for nomenclature).

2. Introduction

2.1. *Definition of Biodiversity in the Context of this Paper*

UNCBD defines biodiversity as "the variability among living organisms from all sources including, *inter alia*, 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." IPCC also emphasizes these three levels—that is, genetic, species, and ecosystem (see Appendix B). Climate change directly affects the functions of individual organisms (e.g., growth and behavior), modifies populations (e.g., size and age structure), and affects ecosystem structure and function (e.g., decomposition, nutrient cycling, water flows, and species composition and species interactions) and the distribution of ecosystems within landscapes; and indirectly through, for example, changes in disturbance regimes. For the purpose of this paper, changes in ecosystem structure and function are assumed to be related to changes in various aspects of biodiversity.

2.2. *Importance of Biodiversity*

This paper considers biodiversity that occurs in both intensively (agriculture, plantation forestry, and aquaculture) and non-intensively[2] (e.g., pastoral lands, native forests, freshwater ecosystems, and oceans) managed ecosystems. It also recognizes the intrinsic value of biodiversity, irrespective of human needs and interests.

Ecosystems provide many goods and services that are crucial to human survival. Some indigenous and rural communities are particularly dependent on many of these goods and services for their livelihoods. These goods and services include food, fiber, fuel and energy, fodder, medicines, clean water, clean air, flood/storm control, pollination, seed dispersal, pest and disease control, soil formation and maintenance, biodiversity, cultural, spiritual, and aesthetic and recreational values. Ecosystems also play a critical role in biogeochemical processes that underlie the functioning of the Earth's systems. [WGII TAR Section 5.1]

2.3. *Pressures on Biodiversity from Human Activities*

The Earth is subjected to many human-induced and natural pressures, collectively referred to as global change. These include pressures from increased demand for resources; selective exploitation or destruction of species; land-use and land-cover

[2] Non-intensively managed includes unmanaged systems.

change; the accelerated rate of anthropogenic nitrogen deposition; soil, water, and air pollution; introduction of non-native species; diversion of water to intensively managed ecosystems and urban systems; fragmentation or unification of landscapes; and urbanization and industrialization. Climate change[3] constitutes an additional pressure on ecosystems, the biodiversity within them, and the goods and services they provide. Quantification of the impacts of climate change alone, given the multiple and interactive pressures acting on the Earth's ecosystems, is difficult. [WGII TAR Section 5.1]

2.4. IPCC Definitions of Impacts, Adaptation, and Mitigation

The projected changes in climate include increasing temperatures, changes in precipitation, sea-level rise, and increased frequency and intensity of some extreme climatic events leading to increased climate variability. The impacts[4] of these projected changes in climate include changes in many aspects of biodiversity and disturbance regimes (e.g., changes in the frequency and intensity of fires, pests, and diseases). Adaptation measures could reduce some of these impacts. Systems are considered to be vulnerable[5] if they are exposed and/or sensitive to climate change and/or adaptation options are limited. Mitigation is defined as an anthropogenic intervention to reduce net greenhouse gas emissions that would lessen the pressure on natural and human systems from climate change. Mitigation options include the reduction of greenhouse gas emissions through the reduction of fossil-fuel use, reduction of the land-based emissions via conservation of existing large pools in ecosystems, and/or the increase in the rate of carbon uptake by ecosystems.

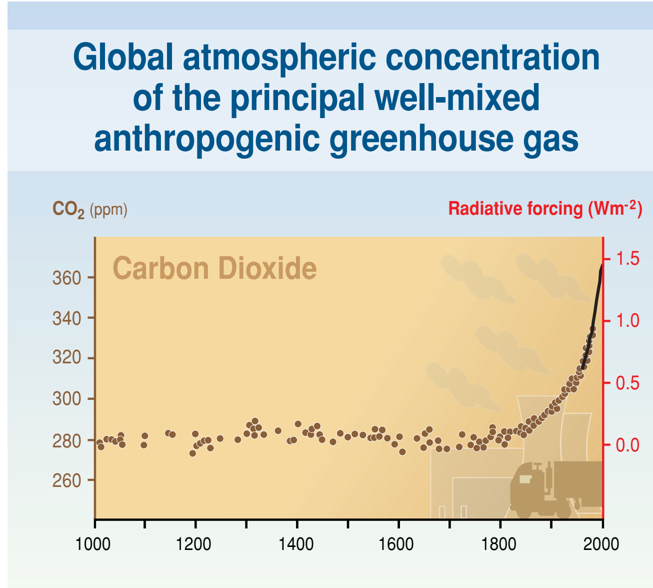

Figure 1: Records of past changes in atmospheric composition over the last millennium demonstrate the rapid rise in CO_2 concentration that is attributable primarily to industrial growth since the year 1750. Early sporadic data taken from air trapped in ice (symbols) matches up with continuous atmospheric observations from recent decades (solid line). CO_2 is well mixed in the atmosphere, and its concentration reflects emissions from sources throughout the globe. The estimated positive radiative forcing resulting from the increasing concentration of CO_2 is indicated on the righthand scale. [SYR Figure 2-1 and WGI TAR Figure SPM-2]

3. Observed Changes in Climate

Observational evidence demonstrates that the composition of the atmosphere is changing [e.g., the increasing atmospheric concentrations of greenhouse gases such as CO_2 and methane (CH_4)], as is the Earth's climate (e.g., temperature, precipitation, sea level, sea ice, and in some regions extreme climatic events including heat waves, heavy precipitation events, and droughts). Because of their observed and potential effects on biodiversity, these changes are summarized below. For example, the concentration of CO_2 in the atmosphere affects the rate and efficiencies of both photosynthesis and water use, thus can affect both the productivity of plants and other ecosystem processes. Climatic factors also affect plant and animal productivity and other ecosystem functions.

3.1. Observed Changes in Atmospheric Concentrations of Greenhouse Gases and Aerosols

Since the pre-industrial era, the atmospheric concentrations of greenhouse gases have increased due to human activities, reaching their highest recorded levels in the 1990s, and most have continued to increase. During the period 1750 to 2000, the atmospheric concentration of CO_2 increased by 31±4%, equivalent to 1.46 Wm^{-2} (see Figure 1), primarily due to the combustion of fossil fuels, land use, and land-use change. Over the 19th and for much of the 20th century the global terrestrial

[3] Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that of the UNFCCC, where climate change refers to a change of climate that is attributable directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. See Appendix B.

[4] The magnitude of the impact is a function of the extent of change in a climatic parameter (e.g., a mean climate characteristic, climate variability, and/or the frequency and magnitude of extremes) and the sensitivity of the system to that climate-related stimuli.

[5] Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. [WGII TAR SPM Box 1]

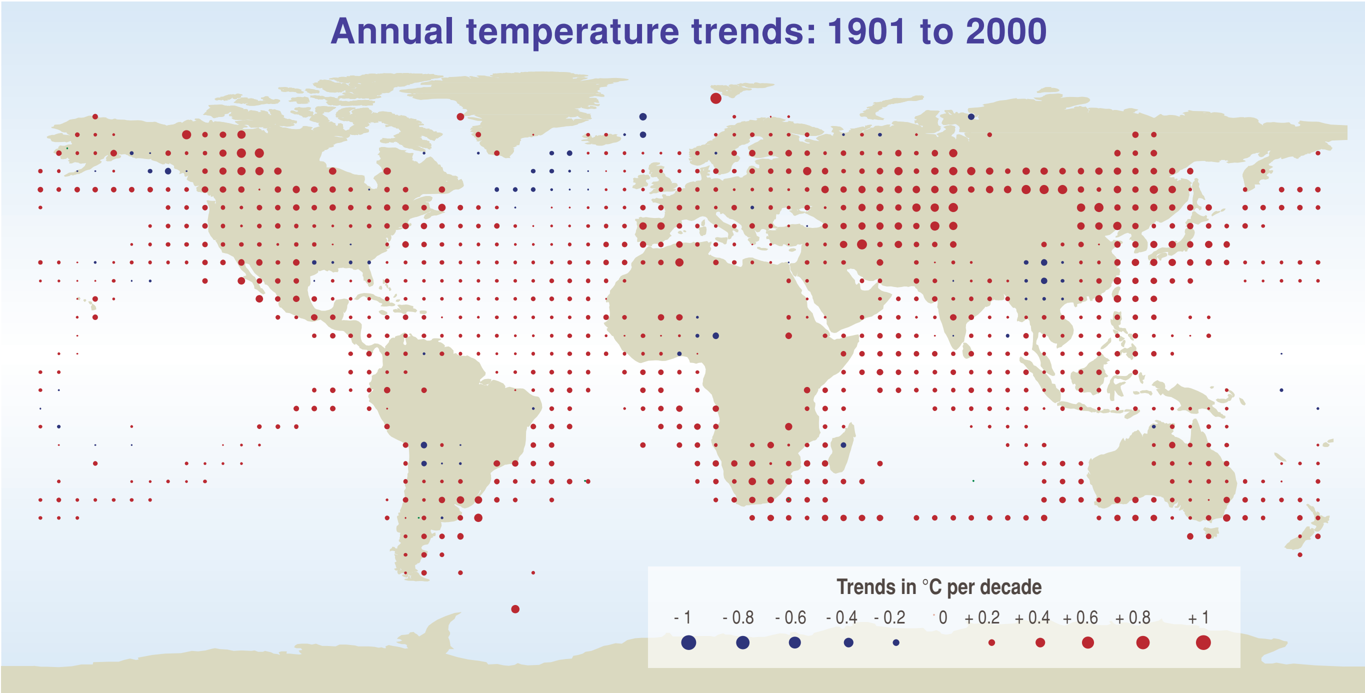

Figure 2: Annual temperature trends for the period 1901 to 2000. Trends are represented by the area of the circle, with red representing increases and blue decreases. Trends were calculated from annually averaged gridded anomalies with the requirement that the calculation of annual anomalies include a minimum of 10 months of data. Trends were calculated only for those grid boxes containing annual anomalies in at least 66 of the 100 years. The warming of land faster than ocean surface is consistent with a signal of anthropogenic warming; however, a component of the pattern of warming at northern mid-latitudes appears to be related to natural climate variations known as the North Atlantic Oscillation and Arctic Oscillation, which themselves might be affected by anthropogenic climate change. [WGI TAR Figures TS-3a and 2.9a]

biosphere was a net source of atmospheric CO_2, but before the end of the 20th century it became a net sink because of a combination of factors—for example, changes in land-use and land management practices, increasing anthropogenic deposition of nitrogen,[6] increased atmospheric concentrations of CO_2, and possibly climate warming. The atmospheric concentration of CH_4 increased by 151±25% from the years 1750 to 2000, equivalent to 0.48 Wm^{-2}, primarily due to emissions from fossil-fuel use, livestock, rice agriculture, and landfills. [WGI TAR Chapters 3 and 4]

3.2. Observed Changes in Earth's Surface Temperature and Precipitation

Over the 20th century there has been a consistent, large-scale warming of both the land and ocean surface (see Figure 2), and it is likely[7] that most of the observed warming over the last 50 years has been due to the increase in greenhouse gas concentrations. The global mean surface temperature has increased by 0.6°C (0.4–0.8°C) over the last 100 years, with 1998 being the warmest year and the 1990s *very likely*[7] being the warmest decade. The largest increases in temperature have occurred over the mid- and high latitudes of northern continents, land areas have warmed more than the oceans, and nighttime temperatures have warmed more than daytime temperatures. Since the year 1950, the increase in sea surface temperature is about half that of the increase in mean land surface air temperature, and the nighttime daily minimum temperatures over land have increased on average by about 0.2°C per decade, about twice the corresponding rate of increase in daytime maximum air temperatures. [WGI TAR Chapters 2 and 12, and WGII TAR SPM]

Precipitation has very likely[7] increased during the 20th century by 5 to 10% over most mid- and high latitudes of Northern Hemisphere continents, but in contrast rainfall has *likely*[7] decreased by 3% on average over much of the subtropical land areas (see Figure 3). Increasing global mean surface temperature is *very likely*[7] to lead to changes in precipitation

[6] Due to the increasing emissions of oxides of nitrogen from industrial, agricultural, and land-use activities.

[7] Using the WGI TAR lexicon, the following words have been used where appropriate to indicate judgmental estimates of confidence: *very likely* (90–99% chance) and *likely* (66–90% chance). When the words *likely* and *very likely* appear in italics, these definitions are applied and a superscript '7' appended; otherwise, they reflect normal usage.

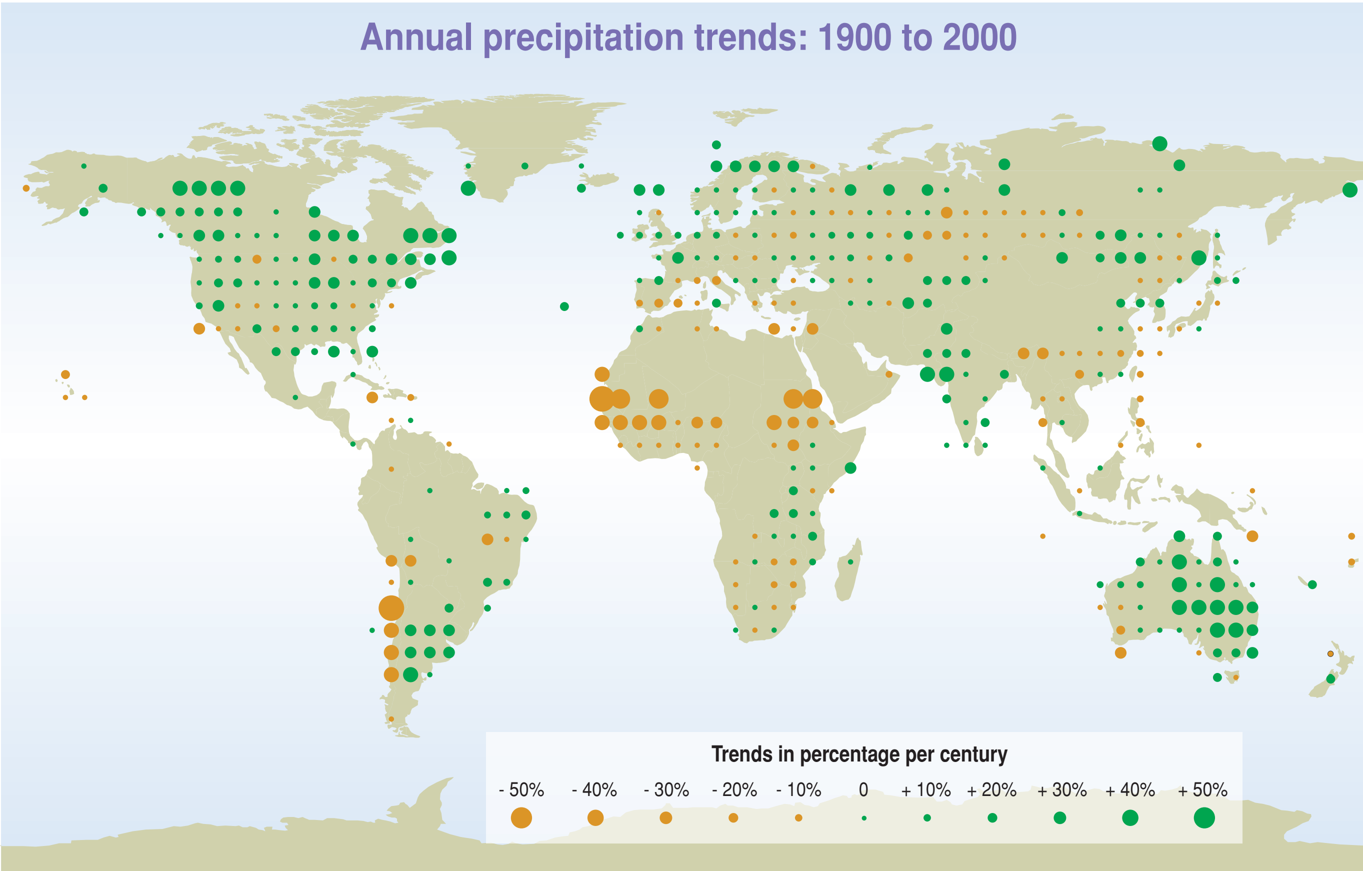

Figure 3: Precipitation during the 20th century has on average increased over continents outside the tropics but decreased in the desert regions of Africa and South America. Trends are represented by the area of the circle, with green representing increases and brown decreases. Trends were calculated from annually averaged gridded anomalies with the requirement that the calculation of annual anomalies include a minimum of 10 months of data. Trends were calculated only for those grid boxes containing annual anomalies in at least 66 of the 100 years. While the record shows an overall increase consistent with warmer temperatures and more atmospheric moisture, trends in precipitation vary greatly from region to region and are only available over the 20th century for some continental regions. [SYR Figure 2-6a and WGI TAR Figure 2-25]

and atmospheric moisture because of changes in atmospheric circulation, a more active hydrological cycle, and increases in the water-holding capacity throughout the atmosphere. There has *likely*[7] been a 2 to 4% increase in the frequency of heavy precipitation (50 mm in 24 hours) events in the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century. There were relatively small increases over the 20th century in land areas experiencing severe drought or severe wetness; in many regions, these changes are dominated by inter- and multi-decadal climate variability with no significant trends evident. [WGI TAR SPM and WGI TAR Sections 2.5, 2.7.2.2, and 2.7.3]

3.3. *Observed Changes in Snow Cover, Sea and River Ice, Glaciers, and Sea Level*

Snow cover and ice extent have decreased. It is *very likely*[7] that the extent of snow cover has decreased by about 10% on average in the Northern Hemisphere since the late 1960s (mainly through springtime changes over America and Eurasia) and that the annual duration of lake- and river-ice cover in the mid- and high latitudes of the Northern Hemisphere has been reduced by about 2 weeks over the 20th century. There has also been a widespread retreat of mountain glaciers in non-polar regions during the 20th century. It is *likely*[7] that Northern Hemisphere spring and summer sea-ice extent has decreased by about 10 to 15% from the 1950s to the year 2000 and that Arctic sea-ice thickness has declined by about 40% during late summer and early autumn in the last 3 decades of the 20th century. While there is no change in overall Antarctic sea-ice extent from the years 1978 to 2000 in parallel with global mean surface temperature increase, regional warming in the Antarctic Peninsula coincided with the collapse of the Prince Gustav and parts of the Larsen ice shelves during the 1990s. [WGI TAR SPM and WGI TAR Chapter 2]

Sea level has risen. Based on tide gauge records, after correcting for vertical land movements, the average annual rise in sea level was between 1 and 2 mm during the 20th century. The observed rate of sea-level rise during the 20th century is (within present uncertainties) consistent with model simulations, and it is *very likely*[7] that the 20th century warming contributed significantly to the observed sea-level rise through thermal expansion of seawater and widespread loss of land ice. [WGI TAR SPM and WGI TAR Sections 2.2.2.5 and 11.2.1]

3.4. Observed Changes in Climate Variability

Warm episodes of the El Niño Southern Oscillation (ENSO) phenomenon have been more frequent, persistent, and intense since the mid-1970s, compared with the previous 100 years. ENSO consistently affects regional variations of precipitation and temperature over much of the tropics, subtropics, and some mid-latitude areas. [WGI TAR SPM and WGI TAR Chapter 2]

3.5. Observed Changes in Extreme Climatic Events

There have been observed changes in some extreme weather and climate events. It is *likely*[7] that there have been higher maximum temperatures, more hot days, and an increase in heat index, and *very likely*[7] that there have been higher minimum temperatures and fewer cold days and frost days over nearly all land areas. In addition, it is *likely*[7] that there has been an increase in summer continental drying and associated risk of drought in a few areas. [WGI TAR SPM and WGI TAR Chapter 2]

4. Projected Changes in Climate

Changes in climate occur as a result of internal variability of the climate system and external factors (both natural and as a

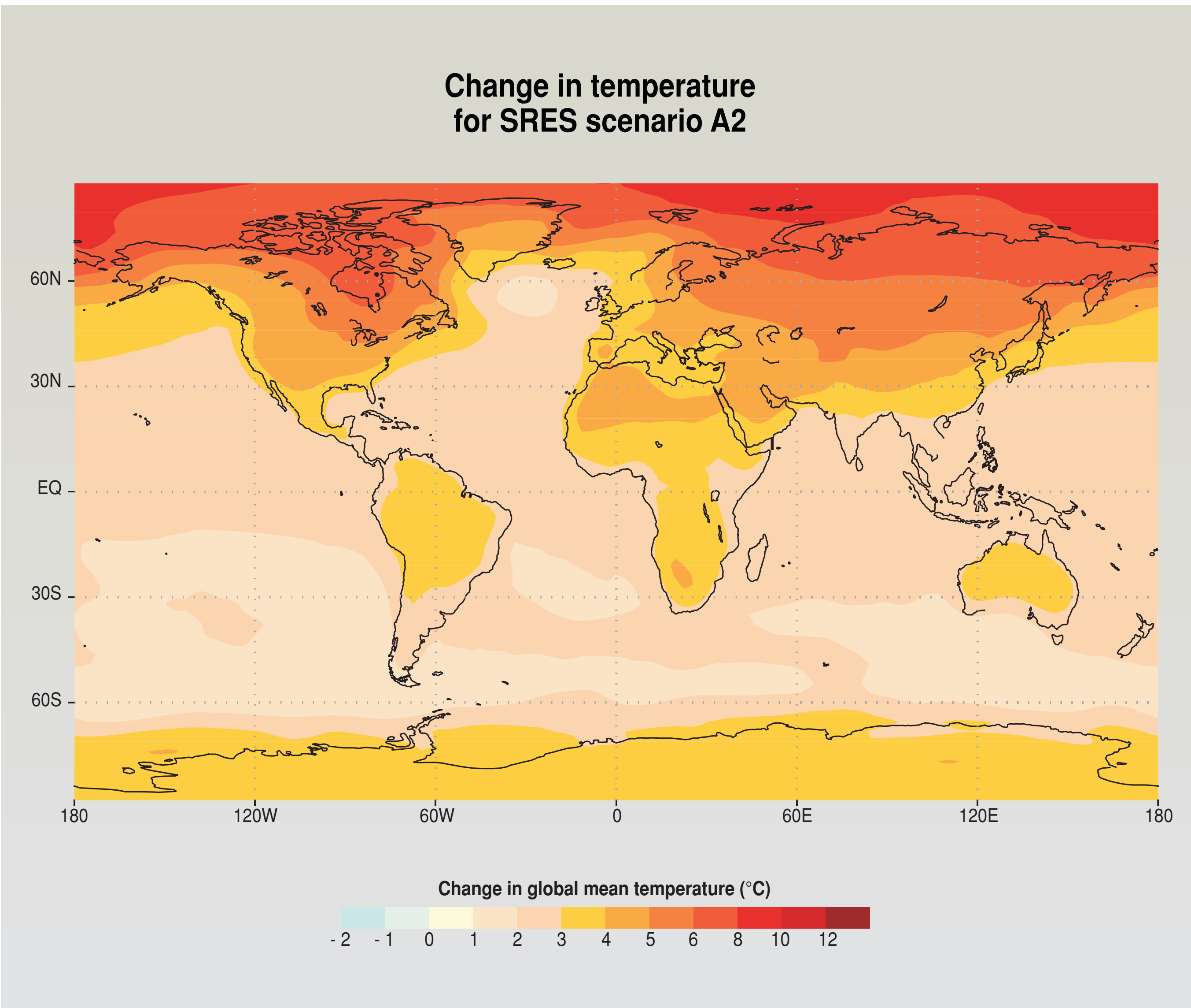

Figure 4: Change of annual mean temperature for the SRES scenario A2. The figure shows the period 2071–2100 relative to the period 1961–1990. The projections were performed by atmosphere-ocean general circulation models. The global mean annual average warming of the models used spans 1.2–4.5°C for A2. [SYR Figure 3-2a and WGI TAR Figures 9.10d,e]

Table 1: 20th century changes in the Earth's atmosphere, climate, and biophysical system.[a] [SYR Table SPM-1]

Indicator/Characteristic	*Observed Changes*
Concentration indicators	
Atmospheric concentration of CO_2	280 ppm for the period 1000–1750 to 368 ppm in year 2000 (31±4% increase).
Terrestrial biospheric CO_2 exchange	Cumulative source of about 30 Gt C between the years 1800 and 2000; but during the 1990s, a net sink of about 14±7 Gt C.
Atmospheric concentration of CH_4	700 ppb for the period 1000–1750 to 1,750 ppb in year 2000 (151±25% increase).
Atmospheric concentration of N_2O	270 ppb for the period 1000–1750 to 316 ppb in year 2000 (17±5% increase).
Tropospheric concentration of O_3	Increased by 35±15% from the years 1750 to 2000, varies with region.
Stratospheric concentration of O_3	Decreased over the years 1970 to 2000, varies with altitude and latitude.
Atmospheric concentrations of HFCs, PFCs, and SF_6	Increased globally over the last 50 years.
Weather indicators	
Global mean surface temperature	Increased by 0.6±0.2°C over the 20th century; land areas warmed more than the oceans (*very likely*[7]).
Northern Hemisphere surface temperature	Increased over the 20th century greater than during any other century in the last 1,000 years; 1990s warmest decade of the millennium (*likely*[7]).
Diurnal surface temperature range	Decreased over the years 1950 to 2000 over land: nighttime minimum temperatures increased at twice the rate of daytime maximum temperatures (*likely*[7]).
Hot days / heat index	Increased (*likely*[7]).
Cold / frost days	Decreased for nearly all land areas during the 20th century (*very likely*[7]).
Continental precipitation	Increased by 5-10% over the 20th century in the Northern Hemisphere (*very likely*[7]), although decreased in some regions (e.g., north and west Africa and parts of the Mediterranean).
Heavy precipitation events	Increased at mid- and high northern latitudes (*likely*[7]).
Frequency and severity of drought	Increased summer drying and associated incidence of drought in a few areas (*likely*[7]). In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades.
Biological and physical indicators	
Global mean sea level	Increased at an average annual rate of 1 to 2 mm during the 20th century.
Duration of ice cover of rivers and lakes	Decreased by about 2 weeks over the 20th century in mid- and high latitudes of the Northern Hemisphere (*very likely*[7]).
Arctic sea-ice extent and thickness	Thinned by 40% in recent decades in late summer to early autumn (*likely*[7]) and decreased in extent by 10-15% since the 1950s in spring and summer.
Non-polar glaciers	Widespread retreat during the 20th century.
Snow cover	Decreased in area by 10% since global observations became available from satellites in the 1960s (*very likely*[7]).
Permafrost	Thawed, warmed, and degraded in parts of the polar, sub-polar, and mountainous regions.
El Niño events	Became more frequent, persistent, and intense during the last 20 to 30 years compared to the previous 100 years.
Growing season	Lengthened by about 1 to 4 days per decade during the last 40 years in the Northern Hemisphere, especially at higher latitudes.
Plant and animal ranges	Shifted poleward and up in elevation for plants, insects, birds, and fish.
Breeding, flowering, and migration	Earlier plant flowering, earlier bird arrival, earlier dates of breeding season, and earlier emergence of insects in the Northern Hemisphere.
Coral reef bleaching	Increased frequency, especially during El Niño events.
Economic indicators	
Weather-related economic losses	Global inflation-adjusted losses rose an order of magnitude over the last 40 years. Part of the observed upward trend is linked to socio-economic factors and part is linked to climatic factors.

[a] This table provides examples of key observed changes and is not an exhaustive list. It includes both changes attributable to anthropogenic climate change and those that may be caused by natural variations or anthropogenic climate change. Confidence levels are reported where they are explicitly assessed by Working Group I.

result of human activities). Emissions of greenhouse gases and aerosols due to human activities change the composition of the atmosphere. Increasing greenhouse gases tend to warm the Earth's climate, while increasing aerosols can either cool or warm. CO_2 concentrations, globally averaged surface temperature, and sea level are projected to increase during the 21st century. Substantial differences are projected in regional changes in climate (see Figures 4 and 5) and sea level as compared to the global mean change. An increase in climate variability and some extreme events is also projected.

The WGI TAR provided revised global and, to some extent, regional climate change projections based on a new series of emissions scenarios from the IPCC Special Report on Emissions Scenarios (SRES). The SRES scenarios, which do not include climate policy interventions, consist of six scenario groups based on narrative storylines. They are all plausible and internally consistent, and no probabilities of occurrence are assigned. They encompass four combinations of demographic, social, economic, and broad technological development assumptions (see Box 1). Each of these scenarios results in a set of greenhouse gas emission trajectories. [WGI TAR SPM and WGI TAR Section 4.3]

4.1. Projected Changes in Atmospheric Concentrations of Greenhouse Gases and Aerosols

All emissions scenarios used in the TAR result in an increase in the atmospheric concentration of CO_2 over the next 100 years. The projected concentrations of CO_2, the primary anthropogenic greenhouse gas, in the year 2100 range from 540 to 970 ppm, compared to ~280 ppm in the pre-industrial era and ~368 ppm in the year 2000. The different socio-economic assumptions (demographic, social, economic, and technological) result in different atmospheric concentrations of greenhouse

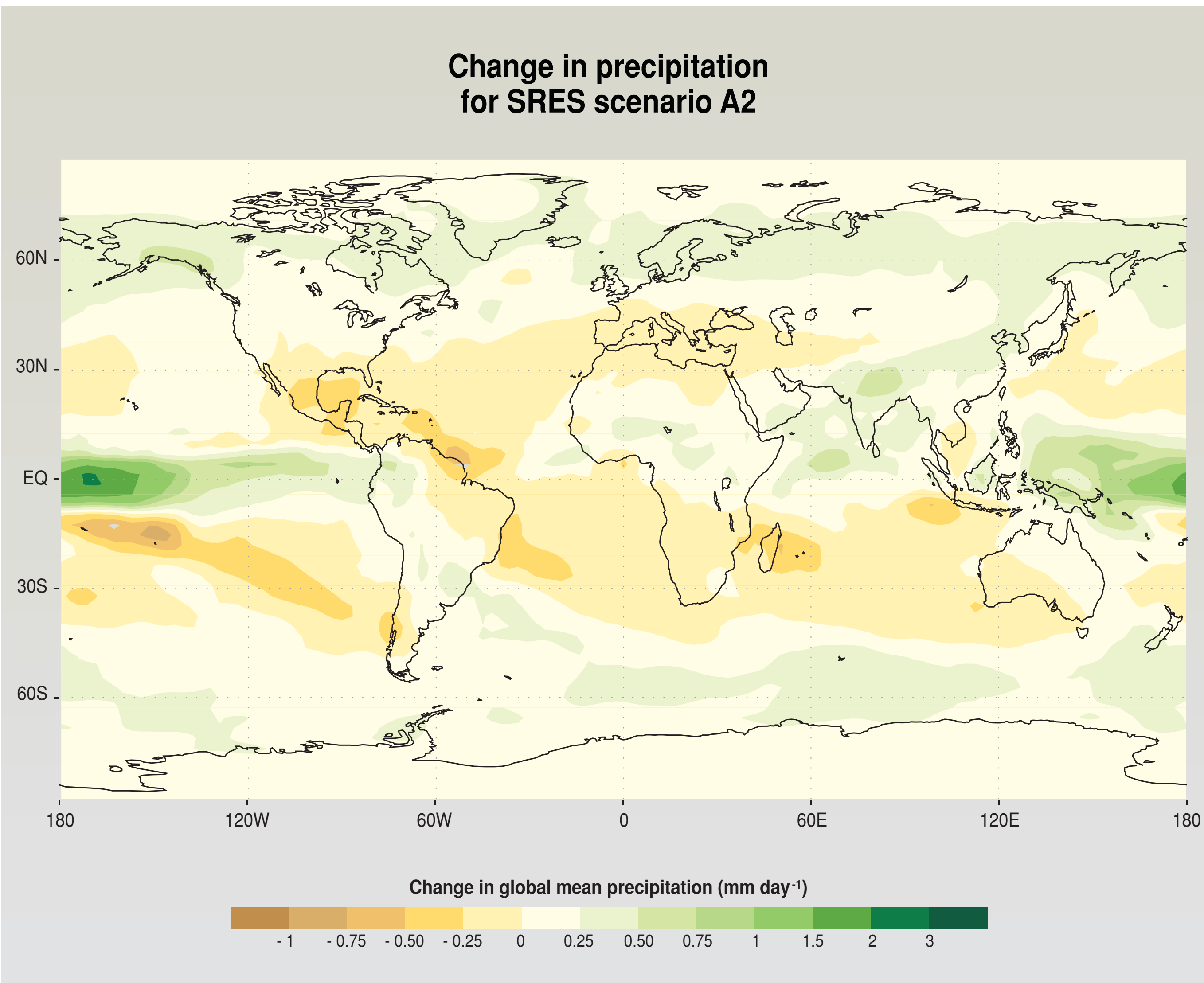

Figure 5: Annual mean change of rainfall for the SRES scenario A2. The figure shows the period 2071–2100 relative to the period 1961–1990. The projections were performed by atmosphere-ocean general circulation models. [SYR Figure 3-3a]

Box 1. The SRES Scenarios
[WGI TAR SPM, WGI TAR Section 4.3, and SRES]

A1. The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B)—where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.

A2. The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describe a convergent world with the same global population, which peaks in mid-century and declines thereafter, as in the A1 storyline but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

gases and aerosols. Further uncertainties, especially regarding the persistence of the present terrestrial removal processes (carbon sinks) and the magnitude of the climate feedback on the terrestrial biosphere, cause a variation of about -10 to +30% in the year 2100 concentration, around each scenario. Therefore the total range in the year 2100 is 490 to 1,260 ppm (75 to 350% above the pre-industrial level). [WGI TAR Section 3.7.3.3]

The IPCC scenarios include the possibility of either increases or decreases in anthropogenic aerosols, depending on the extent of fossil-fuel use and policies to abate sulfur emissions. Sulfate aerosol concentrations are projected to fall below present levels by the year 2100 in all six illustrative SRES scenarios, whereas natural aerosols (e.g., sea salt, dust, and emissions leading to sulfate and carbon aerosols) are projected to increase as a result of changes in climate. IPCC projections do not include changes in natural aerosols. [WGI TAR SPM, WGI TAR Section 5.5, and SRES Section 3.6.4]

4.2. Projected Changes in Earth's Surface Temperature and Precipitation

The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100, with nearly all land areas warming more rapidly than the global average. The projected global average increases are about two to ten times larger than the central value of observed warming over the 20th century and the projected rate of warming is *very likely*[7] to be without precedent during at least the last 10,000 years. For the periods 1990 to 2025 and 1990 to 2050, the projected increases are 0.4 to 1.1°C and 0.8 to 2.6°C, respectively. The most notable areas of warming are in the land masses of northern regions (e.g., North America, and northern and central Asia), which exceed global mean warming in each climate model by more than 40%. In contrast, the warming is less than the global mean change in south and southeast Asia in summer and in southern South America in winter (e.g., see Figure 4). [WGI TAR Sections 9.3.3 and 10.3.2]

Globally averaged annual precipitation is projected to increase during the 21st century, with both increases and decreases in precipitation of typically 5 to 20% projected at the regional scale. Globally averaged annual precipitation, water vapor, and evaporation are projected to increase during the 21st century. Precipitation is *likely*[7] to increase over high-latitude regions in both summer and winter. Increases are also projected over northern mid-latitudes, tropical Africa and Antarctica in winter, and in southern and eastern Asia in summer. Australia, Central America, and southern Africa show consistent decreases in winter rainfall (e.g., see Figure 5). Larger year-to-year variations in precipitation are *very likely*[7] over most areas where an increase in mean precipitation is projected. [WGI TAR Sections 9.3.1-2 and 10.3.2]

4.3. Projected Changes in Climate Variability and Extreme Climatic Events

Models project that increasing atmospheric concentrations of greenhouse gases will result in changes in daily, seasonal, inter-annual, and decadal variability in temperature. There is projected to be a decrease in diurnal temperature range in many areas, with nighttime lows increasing more than daytime highs. The majority of models show a general decrease in daily variability of surface air temperature in winter and increased daily variability in summer in the Northern Hemisphere land areas. Although future changes in El Niño variability differ from model to model, current projections show little change or a small increase in amplitude for El Niño events over the next 100 years. Many models show a more El Niño-like mean response in the tropical Pacific, with the central and eastern equatorial Pacific sea surface temperatures projected to warm more than the western equatorial Pacific and with a corresponding mean eastward shift of precipitation. Even with little or no change in El Niño strength, global warming is *likely*[7] to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions. There is no clear agreement between models concerning the changes in frequency or structure of other naturally occurring atmosphere-ocean circulation patterns such as the North Atlantic Oscillation. [WGI TAR Sections 9.3.5-6 and WGII TAR Section 14.1.3]

The amplitude and frequency of extreme precipitation events are very likely[7] to increase over many areas and thus the return periods for extreme precipitation events are projected to decrease. This would lead to more frequent floods. A general drying of the mid-continental areas during summer is *likely*[7] to lead to increases in summer droughts and could increase the risk of wildfires. This general drying is due to a combination of increased temperature and potential evaporation that is not balanced by increases in precipitation. It is *likely*[7] that global warming will lead to an increase in the variability of Asian summer monsoon precipitation. [WGI TAR Section 9.3.6, WGII TAR Chapters 4 and 9, and WGII TAR Section 5.3]

More hot days and heat waves and fewer cold and frost days are very likely[7] over nearly all land areas. Increases in mean temperature will lead to increases in hot weather and record hot weather, with fewer frost days and cold waves. [WGI TAR Sections 9.3.6 and 10.3.2, and WGII TAR Sections 5.3, 9.4.2, and 19.5]

High-resolution modeling studies suggest that over some areas the peak wind intensity of tropical cyclones is likely[7] to increase over the 21st century by 5 to 10% and precipitation rates may increase by 20 to 30%, but none of the studies suggest that the locations of the tropical cyclones will change. There is little consistent modeling evidence for changes in the frequency of tropical cyclones. [WGI TAR Box 10.2]

There is insufficient information on how very small-scale phenomena may change. Very small-scale phenomena such as thunderstorms, tornadoes, hail, hailstorms, and lightning are not simulated in global climate models. [WGI TAR Section 9.3.6]

4.4. Projected Changes in Snow Cover, Sea and River Ice, Glaciers, and Sea Level

Glaciers and ice caps are projected to continue their widespread retreat during the 21st century. Northern Hemisphere snow cover, permafrost, and sea-ice extent are projected to decrease further. The Antarctic ice sheet is *likely*[7] to gain mass because of greater precipitation, while the Greenland ice sheet is *likely*[7] to lose mass because the increase in runoff will exceed the precipitation increase. [WGI TAR Section 11.5.1]

Global mean sea level is projected to rise by 0.09 to 0.88 m between the years 1990 and 2100, with substantial regional variations. For the periods 1990 to 2025 and 1990 to 2050, the projected rises are 0.03 to 0.14 m and 0.05 to 0.32 m, respectively. This is due primarily to thermal expansion of the oceans and loss of mass from glaciers and ice caps. The projected range of regional variation in sea-level change is substantial compared to projected global average sea-level rise, because the level of the sea at the shoreline is determined by many additional factors (e.g., atmospheric pressure, wind stress, and thermocline depth). Confidence in the regional distribution of sea-level change from complex models is low because there is little similarity between model results, although nearly all models project greater than average rise in the Arctic Ocean and less than average rise in the Southern Ocean. [WGI TAR Sections 11.5.1-2]

5. Observed Changes in Terrestrial and Marine Ecosystems Associated with Climate Change

Human activities have led to changes in ecosystems and attendant loss of biodiversity in many regions. These ecosystem changes are primarily due to factors such as changing land-use patterns, and the degradation of many ecosystems primarily due to soil degradation, water quantity and quality degradation, habitat loss, modification and fragmentation, selective exploitation of species, and the introduction of non-native species. Climate and climate change can affect ecosystems and the biodiversity within them in many ways (see Box 2); climate change has already contributed to observed changes in terrestrial (including inland waters) and marine ecosystems in recent decades, both beneficial and adverse. [WGII TAR Sections 5.1-2]

5.1. Observed Changes in Terrestrial (including Freshwater) Species Distributions, Population Sizes, and Community Composition

The IPCC evaluated the effect of climate change on biological systems by assessing 2,500 published studies. Of these, 44 studies, which included about 500 taxa, met the following criteria: 20 or more years of data; measuring temperature as one

Box 2. Climate Change and Ecosystems
[WGII TAR Sections 5.5.3, 5.6.4, 6.3.7, 16.2.3.4, and 16.2.6.3, and WGII SAR Section A.2]

Climate is the major factor controlling the global patterns of vegetation structure, productivity, and plant and animal species composition. Many plants can successfully reproduce and grow only within a specific range of temperatures and respond to specific amounts and seasonal patterns of precipitation, and may be displaced by competition from other plants or may fail to survive if climate changes. Animals also have distinct temperature and/or precipitation ranges and are also dependent on the ongoing persistence of their food species.

Changes in mean, extremes, and climate variability determine the impacts of climate change on ecosystems. Climate variability and extremes can also interact with other pressures from human activities. For example, the extent and persistence of fires—such as those along the edges of peat-swamp forests in southern Sumatra, Kalimantan, and Brazil during recent El Niño events—show the importance of the interaction between climate and human actions in determining the structure and composition of forests and land-use patterns.

of the variables; the authors of the study finding a statistically significant change in both a biological/physical parameter and the measured temperature; and a statistically significant correlation between the temperature and the change in the biological/physical parameter. Some of these studies investigated different taxa (e.g., bird and insect) in the same paper. Of a total of 59 plants, 47 invertebrates, 29 amphibians and reptiles, 388 birds, and 10 mammal species, approximately 80% showed change in the biological parameter measured (e.g., start and end of breeding season, shifts in migration patterns, shifts in animal and plant distributions, and changes in body size) in the manner expected with global warming, while 20% showed change in the opposite direction. Most of these studies have been carried out (due to long-term research funding decisions) in the temperate and high-latitude areas and in some high-altitude areas. These studies show that some ecosystems that are particularly sensitive to changes in regional climate (e.g., high-altitude and high-latitude ecosystems) have already been affected by changes in climate. [SYR Q2.21 and WGII TAR Sections 5.2 and 5.4]

There has been a discernible impact of regional climate change, particularly increases in temperature, on biological systems in the 20th century. In many parts of the world, the observed changes in these systems, either anthropogenic or natural, are coherent across diverse localities and are consistent in direction with the expected effects of regional changes in temperature. The probability that the observed changes in the expected direction (with no reference to magnitude) could occur by chance alone is negligible. Such systems include, for example, the timing of reproduction or migration events, the growing season length, species distributions, and population sizes. These observations implicate regional climate change as a prominent contributing causal factor. There have been observed changes in the types, intensity, and frequency of disturbances (e.g., fires, droughts, blowdowns) that are affected by regional climatic change and land-use practices, and they in turn affect the productivity of and species composition within an ecosystem, particularly at high latitudes and high altitudes. Frequency of pests and disease outbreaks have also changed especially in forested systems and can be linked to changes in climate. Extreme climatic events and variability (e.g., floods, hail, freezing temperatures, tropical cyclones, droughts) and the consequences of some of these (e.g., landslides and wildfire) have affected ecosystems in many continents. Climatic events such as the El Niño event of the years 1997–1998 had major impacts on many terrestrial ecosystems—both intensively and non-intensively managed (e.g., agriculture, wetlands, rangelands, forests)—affecting the human populations that rely on them. [SYR Q2.21, WGII TAR Figure SPM-2, and WGII TAR Sections 5.4, 5.6.2, 10.1.3.2, 11.2, and 13.1.3.1]

Changes in the timing of biological events (phenology) have been observed. Such changes have been recorded for many species [WGII TAR Section 5.4.3.1 and WGII TAR Table 5-3], for example:

- Warmer conditions during autumn-spring affect the timing of emergence, growth, and reproduction of some cold-hardy invertebrate species.
- Between the years 1978 and 1984, two frog species at their northern range limit in the United Kingdom started spawning 2-3 weeks earlier. These changes were correlated with temperature, which also showed increasing trends over the study period.
- Earlier start of breeding of some bird species in Europe, North America, and Latin America. In Europe, egg-laying has advanced over the last 23 years; in the United Kingdom, 20 of 65 species, including long-distance migrants, advanced their egg-laying dates by an average of 8 days between the years 1971 and 1995.
- Changes in insect and bird migration with earlier arrival dates of spring migrants in the United States, later autumn departure dates in Europe, and changes in migratory patterns in Africa and Australia.
- Mismatch in the timing of breeding of bird species [e.g., Great Tit (*Parus major*)] with other species, including their food species. This decoupling could lead to birds hatching when food supplies may be scarce.
- Earlier flowering and lengthening of the growing season of some plants (e.g., across Europe by about 11 days from the years 1959 to 1993).

Many species have shown changes in morphology, physiology, and behavior associated with changes in climatic variables. For example, painted turtles grew larger in warmer years and reached sexual maturity faster during warm sets of years; body weight of the North American wood rat (*Neotoma sp.)* has declined with a increase in temperature over the last 8 years; juvenile red deer (*Cervus elaphus*) in Scotland grew faster in warmer springs leading to increases in adult body size; and some frogs begin calling earlier (to attract mates) or call more during warm years. [WGII TAR Section 5.4.3.1.3]

Changes in species distribution linked to changes in climatic factors have been observed. Possible climatically associated shifts in animal ranges and densities have been noted on most continents, in the polar regions, and within major taxonomic groups of animals (i.e., insects, amphibian, birds, mammals) [WGII TAR Sections 5.4.3.1.1 and 13.2.2.1], for example:

- The ranges of butterflies in Europe and North America have been found to shift poleward and up in elevation as temperatures have increased. A study of 35 non-migratory butterflies in Europe showed that over 60% shifted north by 35–240 km over the 20th century. Population increases of several species of forest butterflies and moths in central Europe in the early 1990s, including the gypsy moth (*Lymantria dispar*), have been linked to increased temperatures, as have poleward range expansions of several species of damsel and dragonflies (Odonata*)* and cockroaches, grasshoppers, and locusts (Orthoptera*)*.
- The spring range of Barnacle Geese (*Branta leucopsis)* has moved north along the Norwegian coast. The ranges of some birds have moved poleward in Antarctica. The elevational range of some birds in the Costa Rican tropical cloud forest may also be shifting.

Changes in climatic variables have led to increased frequency and intensity of outbreaks of pests and diseases accompanied by range shifts poleward or to higher altitudes of the pests/ disease organisms. For example, spruce budworm outbreaks frequently follow droughts and/or dry summers in parts of their range. The pest-host dynamics can be affected by the drought increasing the stress of host trees and the number of spruce budworm eggs laid (e.g., the number of spruce budworm eggs laid at 25°C is up to 50% greater than the number laid at 15°C). Some outbreaks have persisted in the absence of late spring frosts killing new growth on trees, the budworm's food source. The distribution of vector-borne diseases (e.g., malaria and dengue) and food- and water-borne (e.g., diarrhea) infectious diseases, thus the risk of human diseases, have been affected by changes in climatic factors. For example, in Sweden, tick-borne encephalitis incidence increased after milder winters and moved northward following the increased frequency of milder winters over the years 1980 to 1994. [WGII TAR Sections 5.6.2-3, 9.5.1, and 9.7.8]

Changes in streamflow, floods, droughts, water temperature, and water quality have been observed and they have affected biodiversity and the goods and services ecosystems provide. Evidence of regional climate change impacts on elements of the hydrological cycle suggests that warmer temperatures in some regions lead to intensification of the hydrological cycle. Peak streamflow has shifted back from spring to late winter in large parts of eastern Europe, European Russia, and North America in recent decades. The increasing frequency of droughts and floods in some areas is related to variations in climate (e.g., droughts in Sahel and in northeast and southern Brazil, and floods in Colombia and northwest Peru). Lakes and reservoirs, especially located in semi-arid parts of the world (e.g., those in parts of Africa) respond to climate variability by pronounced changes in storage, leading to complete drying up in many cases. In the savanna regions of Africa, the incidence of seasonal flow cessation may be on the increase. Changes in rainfall frequency and intensity combined with land-use change in watershed areas has led to increased soil erosion and siltation in rivers. This along with increased use of manure, chemical fertilizers, pesticides, and herbicides as well as atmospheric nitrogen deposition affects river chemistry and has led to eutrophication, with major implications for water quality, species composition, and fisheries. Changes in streamflows have affected the goods and services from these ecosystems (e.g., fish production from freshwater fisheries, water flow from wetlands). Increases in water temperatures have caused an increase in summer anoxia in deep waters of stratified lakes with possible effects on their biodiversity. Increased winter water temperatures have been observed to negatively impact egg viability in yellow perch (a coldwater species). [WGI TAR SPM, WGII TAR SPM, WGII TAR Sections 4.3.6, 10.2.1.1-2, 10.2.5.3, 10.4.1, 14.3, and 19.2.2.1, WGII TAR Table 4-6, and WGII SAR Sections 10.6.1.2 and 10.6.2.2]

High-latitude ecosystems in the Northern Hemisphere have been affected by regional climate change. For example, extensive land areas in the Arctic show a 20th century warming trend in air temperature of as much as 5°C, in contrast to areas of cooling in eastern Canada, the north Atlantic, and Greenland. The warmer climate has increased growing degree-days by 20% for agriculture and forestry in Alaska, and boreal forests are expanding north at a rate equal to about 100 to 150 km per °C. Altered plant species composition, especially forbs and lichens, has been observed in the tundra. Higher ground temperatures and deeper seasonal thawing stimulate thermokarst development in relatively warm discontinuous permafrost. Due to thermokarst, some boreal forests in central Alaska have been transformed into extensive wetlands during the last few decades of the 20th century. The area of boreal forest burned annually in western North America has doubled in the last 20 years, in parallel with the warming trend in the region. Similar trends have been noted for Eurasian forests. [WGII TAR Sections 1.3.1, 5.2, 5.6.2.2.1, 5.9, 10.2.6, 13.2.2.1, 14.2.1, 15.2, 16.1.3.1, and 16.2.7.3]

5.2. Observed Changes in Coastal and Marine Systems

Coral reefs have been adversely affected by rising sea surface temperatures. Many coral reefs occur at or close to temperature tolerance thresholds. Increasing sea surface temperatures have been recorded in much of the tropical oceans over the past several decades. Many corals have undergone major, although often partially reversible, bleaching episodes when sea surface temperatures have risen by 1°C above the mean seasonal sea surface temperatures in any one season, and extensive mortality has occurred for a 3°C rise. This typically occurs during El Niño events. For example, widespread bleaching on the Great Barrier Reef, leading to death of some corals, occurred in 1997–1998, and was associated with a major El Niño event where sea surface temperature anomalies were the most extreme in the past 95 years. The coral bleaching events of 1997–1998 were the most geographically widespread—with coral reefs throughout the world being affected, leading to death of some corals. Bleaching events are also associated with other stresses such as pollution and disease. [SYR Q2 and WGII TAR Sections 6.4.5 and 12.4.7]

Diseases and toxicity have affected coastal ecosystems. Changes in precipitation frequency and intensity, pH, water temperature, wind, dissolved CO_2, and salinity, combined with anthropogenic pollution by nutrients and toxins, can all affect water quality in estuarine and marine waters. Some marine-disease organisms and algal species, including those associated with toxic blooms, are strongly influenced by one or more of these factors. In recent decades there has been an increase in reports of diseases affecting coral reefs and seagrasses, particularly in the Caribbean and temperate oceans. Increased water temperatures associated with El Niño events have been correlated with Dermo disease (caused by the protozoan parasite *Perkinsus marinus*) and multinucleated spore unknown (MSX) disease in oysters along the U.S. Atlantic and Gulf coasts. [WGII TAR Sections 6.3.8 and 12.4.7]

Changes in marine systems, particularly fish populations, have been linked to large-scale climate oscillations. Climatic factors affect the biotic and abiotic elements that influence the numbers and distribution of marine organisms, especially fish. Variations (with cycles of 10–60 years or more) in the biomass volume of marine organisms are dependent on water temperature and other climatic factors. Examples include the periodic fluctuations in the climate and hydrographic regime of the Barents Sea, which have been reflected in variations in commercial fish production over the last 100 years. Similarly, in the northwest Atlantic Ocean records of cod catches over a period from 1600–1900 showed a clear correlation between water temperature and catch, which also involved changes in the population structure of cod over cycles of 50–60 years. Shorter term variations in North Sea cod have been related to a combination of overfishing and warming over the past 10 years. Sub-decadal events, such as El Niño events, affect fisheries (such as herrings, sardines, and pilchards) off the coasts of South America and Africa, and decadal oscillations in the Pacific are linked to decline of fisheries off the west coast of North America. The anomalous cold surface waters that occurred in the northwest Atlantic in the early 1990s changed the fish species composition in the surface waters on the Newfoundland shelf. [WGI TAR Section 2.6.3, WGII TAR Sections 6.3.4, 10.2.2.2, 14.1.3, and 15.2.3.3, and WGII TAR Box 6-1]

Large fluctuations in the abundance of marine birds and mammals across parts of the Pacific and western Arctic have been detected and may be related to changing regimes of disturbances, climate variability, and extreme events. Persistent changes in climate can affect the populations of top predators through affecting the abundance of organisms in the food chain. For example, along the Aleutian Islands, the fish population driven by climatic events and overfishing has changed, thus changing the behavior and population size of killer whales and sea otters (consequently affecting the kelp forests). Seabird abundances are dependent on specific fish species, particularly during breeding season, and are sensitive to small changes in the ocean environment such as that resulting from climate change. Decline of some seabird species, and increased abundance of a few common ones and changes in some species ranges have been associated with changes in current systems (e.g., those in California). However, changes in population parameters and ranges could be influenced by changes in prey-fish populations and bird-migration patterns and thus cannot be clearly attributed to the changes in oceanic currents or climate change. It has been argued that long life spans, and the genetic variation within some large populations, may enable seabirds to survive adverse short-term environmental events as evidenced by the response to El Niño and La Niña events in the tropical Pacific. However, small populations tied to restricted habitat, such as the Galapagos Penguin, may be adversely affected. [WGII TAR Section 6.3.7]

6. Projected Impacts of Changes in Mean Climate and Extreme Climatic Events on Terrestrial (including Aquatic) and Marine Ecosystems

Climate change is projected to affect individuals, populations, species, and ecosystem composition and function both directly (e.g., through increases in temperature and changes in precipitation and in the case of aquatic systems changes in water temperature, sea level, etc.) and indirectly (e.g., through climate changing the intensity and frequency of disturbances such as wildfires). The impacts of climate change will depend on other significant processes such as habitat loss and fragmentation (or unification, for example, in the case of previously isolated water bodies in freshwater systems) and the introduction of non-native species (especially invasive species).

No realistic projection of the future state of Earth's ecosystems can be made without taking into account human land- and water-use patterns—past, present, and future. Human use will endanger some terrestrial and aquatic ecosystems, enhance the survival of others, and greatly affect the ability of organisms to adapt to climate change via migration. The relative impact of climate change and other factors such as land use, biotic invasions, and pollution on endangered species are likely to vary regionally. Thus, in some ecosystems, climate change is likely to have less impact on endanged or threatened species than other factors.

Concern over species becoming rare or extinct is warranted because of the goods and services provided by ecosystems and the species themselves. Most of the goods and services provided by species (e.g., pollination, natural pest control) are derived from their roles within systems. Other valuable services are provided by species contributing to ecosystem resilience and productivity. The recreational value (e.g., sport hunting, wildlife viewing) of species is large both in market and non-market terms. Species loss could also impact the cultural and religious practices of peoples around the world. Losses of species can lead to changes in the structure and function of the affected ecosystems, and loss of revenue and aesthetics. Understanding the role species, or groups of species, play in ecosystem services is necessary to understand the risks and possible surprises associated with species loss.

6.1. Modeling Approaches Used for Projecting Impacts of Climate Change on Ecosystems and the Biodiversity within Them

Modeling the changes in biodiversity in response to climate change presents some significant challenges. It requires projections of climate change at high spatial and temporal resolution and often depends on the balance between variables that are poorly projected by climate models (e.g., local precipitation and evaporative demand). It also requires an understanding of how species interact with each other and how these interactions affect the communities and ecosystems of which they are a part. In addition, the focus of attention in the results of these models is often particular species that may be rare and show unusual biological behavior.

Most models of ecosystem changes are not well suited to projecting changes in regional biodiversity. A large literature is developing on modeling the response of ecosystems to climate and global changes. Most of these models simulate changes in a small patch of land and are used to project changes in productivity or local species dominance. They are not necessarily well suited for assessing changes in regional biodiversity. Another field of modeling deals with long-term changes in vegetation and associated faunal distributions at regional to global scales under climate change. These models usually deal with ecosystems or biomes [i.e., the collection of ecosystems within a particular climatic zone with similar structure but differing species (e.g., the "temperate forest biome")]. Again they are not well suited for projecting changes in biodiversity as they usually assume that ecosystems or biomes will simply shift location while retaining their current composition, function, and structure (see Box 3). There is only a small, but steadily increasing, literature on modeling changes in biodiversity *per se* at regional to global scales. [WGII TAR Section 5.2]

Models need to deal with the spatial interactions between ecosystems within landscapes to capture the responses of ecosystems to pressures, including climate change (see Box 3). Most vegetation models still treat the patches of vegetation as

Box 3. Modeling Approaches Used for Projecting Impacts
[WGII TAR Sections 5.2 and 5.4, and WGII TAR Box 5-2]

Many modeling results at regional to global scales presented in IPCC reports and thus this Technical Paper were obtained by using two conceptually different assumptions about the way ecosystems (thus biomes) will respond to global change. The "ecosystem movement" approach assumes that ecosystems will migrate relatively intact to new locations that are close analogs to their current climate and environment. This is clearly a gross simplification of what will actually happen. Basic ecological knowledge suggests that the "ecosystem movement" paradigm is most unlikely to occur in reality because of different climatic tolerance of the species involved, including within-species genetic variability, different longevities, different migration abilities, and the effects of invading species. It is an idealized working paradigm that has the advantage that the well-demonstrated relationship between ecosystem range and existing climate can be used to project new ecosystem distributions under changed climate scenarios. As such, these models are useful for screening scenarios of climate change for potential significant effects.

The alternative approach, "ecosystem modification," assumes that as climate and other environmental factors change there will be *in situ* changes in species composition and dominance. These will occur as some species decline in abundance or become locally extinct while others increase in abundance. The longevity of individuals, the age structure of existing populations, and the arrival of invading species will moderate these changes. The outcome will be ecosystem types that may be quite different from those that we see today. Paleoecological data indicate that ecosystem types broadly similar to those seen today did exist in the past, but there also occurred combinations of dominant species not observed today.

The problem with the "ecosystem modification" approach is that it is very difficult to use in practical forecasting of possible changes because of the lack of detailed information about the current distribution of each of the species and our understanding of how they interact. Thus, most global and regional studies assessing the potential impacts of climate change have had to use the "ecosystem movement" approach. They also tend to be limited to projecting the changes in vegetation distributions with the implicit, and often invalid, assumption that animal populations will track the vegetation components of an ecosystem. However, observational and experimental studies show many cases where animals respond to climate and environmental change well before any significant changes in the vegetation.

a matrix of discrete units with little interaction between each unit. However, modeling studies have shown that significant errors in predicting vegetation changes can occur if the spatial interactions of landscape elements are treated inadequately. For example, the spread of fires is partly determined by the paths of previous fires and the subsequent vegetation regrowth. It is currently not possible to simulate global or regional vegetation change at the landscape scale; thus, the challenge is to find rules for incorporating landscape phenomena into models with a much coarser resolution. [WGII TAR Section 5.2.4.1]

Another challenge is to develop realistic models of plant and animal migration. Paleoecological, modeling, and observational data suggest that dispersal may not be a significant problem for many species in adapting to climate change, providing the matrix of suitable habitats are not too fragmented. However, in habitats fragmented by human activities that are common over much of the Earth's land surface, opportunities for migration will be limited and restricted to only a portion of the species pool. [WGII TAR Section 5.2]

6.2. Projected Impacts on the Biodiversity of Terrestrial and Freshwater Systems

This section assesses the impacts of climate change at individual organism level, populations, and species. It then considers the impacts in ecosystems in terms of their structure and function, mostly in non-intensively managed ecosystems and landscapes.

Overall, biodiversity is forecast to decrease in the future due to multiple pressures, in particular increased land-use intensity and the associated destruction of natural or semi-natural habitats. The multiple pressures on biodiversity are occurring independent of climate change, so a critical question is how much might climate change enhance or inhibit these losses in biodiversity?

6.2.1. Projected Impacts on Individuals, Populations, Species, and Ecosystems

This section presents some examples of how individuals, populations, and species may be affected by climate change and some other pressures arising from human activities. Changes in behavior, reductions in abundance, or losses of species can lead to changes in the structure and functioning of affected ecosystems. These changes can, in turn, lead to the loss of further species and a cascading effect on biodiversity and the opening of the system to invasion by non-native species and further disruption. Thus, the impacts of climate change, and their effects on biodiversity, can also be assessed at the level of ecosystems and within the context of ecosystems and their distribution within landscapes. They must also be assessed within the framework of changing regimes of disturbances, climate variability, and extreme events.

Independent of climate change, biodiversity is forecast to decrease in the future due to multiple pressures, in particular increased land-use intensity and the associated destruction of natural or semi-natural habitats. The most significant pressures are habitat degradation, loss and fragmentation (or habitat unification, especially in the case of freshwater bodies), the introduction of invasive species, and direct effects on reproduction, dominance, and survival through chemical and mechanical treatments. Increases in nitrogen deposition and atmospheric CO_2 concentration favor groups of species that share certain physiological or life history traits common amongst invasive plant species thus allowing them to capitalize upon global change. The doubling of nitrogen input into the terrestrial nitrogen cycle due to human activities may accelerate losses of biological diversity. The impacts of nitrogen deposition on plant communities may be greatest in nutrient-poor ecosystems where native plants that are adapted to such soils may not be able to compete with faster growing invasive species when nutrients are no longer limiting. In some cases there may be an increase in local biodiversity, usually as a result of species introductions, the longer term consequences of which are hard to foresee. It is also possible that locally more intensive land use may reduce the demand for intensive use or land-use change at other locations, so reducing biodiversity loss in those locations (see Section 7). [WGII TAR Sections 5.2.3 and 5.7]

While there is little evidence to suggest that climate change will slow species losses, there is evidence that it may increase species losses. Paleoecology data suggest that biota at the global scale should produce an average of three new species per year (several orders of magnitude slower than the estimated current extinction rate) but with large variation about that mean between geological eras. Pulses of speciation and extinction events sometimes appear to be associated, in the long term, with climate change, although moderate oscillations of climate do not necessarily promote speciation despite forcing changes in species' geographical ranges. Many of the Earth's species are already at risk of extinction due to pressures arising from natural processes and human activities. Climate change will add to these pressures especially for those with limited climatic ranges and/or restricted habitat requirements. [WGII TAR Sections 5.2.3 and 5.4.1]

Changes in phenology are expected to occur in many species. Changes in phenology, such as the date of bud break, hatching, migration, etc., have already been observed for many species (see Section 5.1). These changes are usually closely linked with simple climate variables such as maximum or minimum temperatures or accumulated degree-days; projections of the direction and approximate amount of change are feasible. Observed trends such as earlier bud break and earlier flowering are expected to continue. However, there are situations where the factors controlling the physiological changes may not change in concert (e.g., a plant responds to signals from both temperature and day length) or the phenological response of one species may not match that of other food or predator species leading to mismatches in timing of critical life stages or behaviors. Here the outcomes are harder to project. [WGII TAR Sections 5.4.3.1 and 5.5.3.2, and WGII TAR Table 5-3]

The general impact of climate change is that the habitats of many species will move poleward or upward from their current locations. Climatically associated shifts in animal ranges and densities have already been noted in many parts of the world and within each major taxonomic group of animals (see Section 5.1). The most rapid changes are expected where they are accelerated by changes in natural and anthropogenic disturbance patterns. [WGII TAR Sections 13.2.2.1 and 16.2.7.2]

Species that make up a community are unlikely to shift together. It is more likely that species will respond to changing climate and disturbance regimes individualistically, with substantial time lags and periods of reorganization. This will disrupt established ecosystems and create new assemblages of species that may be less diverse and include more "weedy" species (i.e., those that are highly mobile and can establish quickly). [WGII TAR Sections 5.2, 10.2.3.1, and 19.1]

Ecosystems dominated by long-lived species (e.g., long-lived trees) will often be slow to show evidence of change and slow to recover from climate-related stresses. Changes in climate often affect vulnerable life stages such as seedling establishment, while not being sufficient to cause increased mortality among mature individuals. Changes in these systems will lag many years or decades behind the climate change but can be accelerated by disturbances that lead to mortality. Similarly, migration to suitable new habitats may also lag decades behind climate change, because dispersal from existing to new habitats may be slow and often the new habitats will have been occupied by weedy species that were able to disperse and establish quickly. Where climate-related stresses, including pests and diseases, cause increased mortality of long-lived species, recovery to a state similar to the previous stand may take decades to centuries, if it is achieved at all. [SYR Q5.8 and WGII TAR Sections 5.2.2 and 5.6.2]

Forested ecosystems will be affected by climate change directly and via interactions with other factors, such as land-use change. Ecosystem and climate models suggest that, on a broad scale, the climatic zones suitable for temperate and boreal plant species may be displaced by 200–1,200 km northward by the year 2100 (as most mid- to high-latitude land masses are projected to warm by 2–8°C). Paleoecological evidence suggests that in the past most plant species migrated at only 20–200 km per century although this may have been limited by the rates of climate change at that time. For many plant species, current migration rates will be even slower due to fragmentation of suitable habitats by human activities. Thus, the poleward movement of forest cover may lag behind changes in temperature by decades to centuries, as occurred for migration of different tree species after the last glaciation. It is also questionable whether soil structural development could keep pace with the changing climate. Increased frequency and intensity of fires and changes caused by thawing of permafrost will also affect ecosystem functioning. The species composition of forests is likely to change and new assemblages of species may replace existing forest types that may be of lower species diversity. [SYR Q3.7 and Q3.12, SYR Figures 3-1 to 3-3, WGII TAR Sections 5.2, 5.6, 13.2.2.1, 15.2, and 16.2.7, and WGII SAR Section 1.3]

Most soil biota have relatively wide temperature optima, so are unlikely to be adversely affected directly by changes in temperatures, although some evidence exists to support changes in the balance between soil functional types. Soil organisms will be affected by elevated atmospheric CO_2 concentrations and changes in the soil moisture regime where this changes organic inputs to the soil (e.g., leaf litter) and the distribution of fine roots in soils. The distribution of individual species of soil biota may be affected by climate change where species are associated with specific vegetation and are unable to adapt at the rate of land-cover change. [WGII TAR Section 13.2.1.2]

The effects of temperature-dependent changes on lakes and streams would be least in the tropics, moderate at mid-latitudes, and pronounced in high latitudes where the largest changes in temperature are expected. Extreme water temperatures can kill organisms, while more moderate water temperature variations control biological processes (physiological rates and behavioral performance, and influence habitat preference). Thermal optima for many coldwater taxa from the mid- and high latitudes are less than 20°C; summer temperatures could exceed thermal tolerances for some species in the future. However, species have varying tolerance ranges for temperature and thus shifts in temperature can produce changes in species composition that can affect the overall productivity of individual freshwater ecosystems and their utility to humans. Effect of warming on stream and river ecosystems will be strongest in humid regions, where streamflows are less variable and biological interactions control organism abundance (e.g., in small streams where large groundwater discharges currently maintain relatively low maximum water temperatures in summer). Species extinctions will occur at the lower latitude boundaries of distributions if summer temperatures increase in streams and shallow unstratified lakes and ponds, where cooler water refuges are not available. For instance, in the southern Great Plain of the United States, summer water temperatures of 38–40°C already approach the lethal limits for many native stream fish. With projected climate warming, stream fish habitats are likely to decline significantly across the United States for coldwater and coolwater species. Some tropical species of zooplankton have reproductive temperature thresholds close to current temperatures and thus their distributions are likely to be affected. Experimental increases in stream temperature during autumn—from ambient, near 10°C, to about 16°C—are found to be lethal to 99% of stonefly (*Soyedina carolinensis*) larvae. Increased rates of microbial respiration with higher temperatures suggest that food resources for invertebrates feeding on seasonally available detritus from terrestrial vegetation might increase in the short term following its input to streams. However, higher microbial respiration rates will increase organic-matter decomposition rates and may shorten the period over which detritus is available to invertebrates. Also climate-related changes in lake water levels will have large effects on near-shore biotic assemblages. With declining water levels, lakes might become more separated from their bordering wetlands, and this could impact some species. For example, Northern pike, which spawn in flooded sedge meadows in early spring and whose young remain in the meadows for about 20 days after hatching, would be especially affected by low spring water levels. [WGII SAR Sections 10.6.1, 10.6.2.2, and 10.6.3.1-2]

Increased temperatures will alter thermal cycles of lakes and solubility of oxygen and other materials, and thus affect ecosystem structure and function. Reduced oxygen concentration could lead to altered community structure, usually characterized by fewer species, especially if exacerbated by eutrophication related to land-use practices. Local extinctions are more likely when warm summer temperatures and anoxia erode the deep coldwater refuge (from predator or from thermal stress) in a lake, required by particular species. In high-latitude lakes, temperature rise would also result in loss of winter ice cover as ice-cover duration and ice break-up dates are among the determinants of species composition, particularly that of diatom species. Higher temperatures of shallow water layers could decrease the nutritional quality of edible phytoplankton or shift the species composition of the phytoplankton community reducing more nutritious diatom taxa and increase less nutritious cyanobacteria and green algae. [WGII TAR Sections 13.2.2.3 and 13.2.3.2, and WGII SAR Section 10.6.1]

Climate change will have a pronounced effect on freshwater ecosystems through alterations in hydrological processes. The combined effects of climate change (e.g., temperature and precipitation) and changes to watersheds and riparian shorelines due to human activities are projected to affect the hydrological processes of many freshwater ecosystems. The largest effects of changes in hydrological processes on productivity in streams and rivers will result from reduction of streamflows projected for some mid-latitudes, changes in the amount and form of winter precipitation and the timing of snowmelt, and increases in the magnitude or frequency of extreme events (floods and droughts). Reduced streamflows (due to lower precipitation and/or increased evapotranspiration) would increase the probability of intermittent flow in smaller streams. Drying of streambeds for extended periods could reduce ecosystem productivity because of the restricted aquatic habitat; water quality could worsen with expanded oxygen deficit; and intense competition and predation could reduce total biomass. Recovery of stream invertebrates with the resumption of flow could be slow. The potential for intermittent flow may be particularly great where groundwater component to river flow is low and decreasing. Climate change will have its most pronounced effect on wetlands through alterations in hydrological regimes, specifically the nature and variability of the wet and dry seasons and the number and severity of extreme events. [WGII TAR Sections 4.4, 5.7, and 5.8.2, and WGII SAR Section 10.6.2.1]

Changes in the frequency, intensity, extent, and locations of disturbances will affect whether and how existing ecosystems reorganize and the rate at which they are replaced by new plant and animal assemblages. Disturbances can both increase the rate of species loss and create opportunities for the establishment of new species [SYR Q4.18 and WGII TAR Section 5.2], for example:

- ***Changes in disturbance regimes associated with climate change include changes in the frequency, intensity, and location of disturbances, such as fires and outbreaks of pests.*** Fire frequency is expected to increase in most regions due to the effects of warmer summer temperatures and possibly increased growth of flammable fine fuels (e.g., small shrubs and grasses). In some regions increased precipitation may counter these effects and the frequency and intensity of disturbances may remain unchanged or decrease. The populations of many pest species are limited by low temperatures during parts of their life cycle, and climate warming is expected to lead to more pest outbreaks in some regions. [WGII TAR Sections 5.3.3.2, 5.5.3, and 5.6.3, and WGII SAR Section 13.4]
- ***The effect of interactions between climate change and changes in disturbance regime and their effect on biotic interactions may lead to rapid changes in vegetation composition and structure. However, the quantitative extent of these changes is hard to project due to the complexity of the interactions.*** Spruce budworm in boreal forests provides an example of the complexity of the interactions between disturbances, pests, and climate change. Outbreaks of spruce budworm frequently follow droughts and/or dry summers, which lead to increased stress of host trees and increase the number of spruce budworm eggs laid. Drought and warmer temperatures affect spruce budworm phenology and dynamics by changing its interaction with the frosts, the host tree, its parasites, and birds that prey on budworm. The spruce budworm's northern range may shift north with increasing temperatures, which, if accompanied by increased drought frequency, could lead to outbreaks of increasing frequency and severity leading to major ecological changes. On its southern boundary, the range of many of the warblers that feed on spruce budworms could shift poleward, perhaps with their loss from latitudes below 50°N. If biological control mechanisms are replaced by chemical control mechanisms (e.g., pesticides), this may ultimately lead to a different set of problems as there are both economic and social issues relating to large-scale pesticide applications. Another example of the interactions between changes in climate and disturbance regimes is the unusually early or late arrival of rains in highly seasonal areas (e.g., the wet-dry tropics). For example, the Miombo woodlands of south central Africa are sensitive to the arrival of spring rains and might undergo significant changes in plant dominance and consequently animal populations if there is a shift in the rainfall patterns along with changes in fire regimes and grazing pressures. Our ability to forecast changes arising from such processes depends as much upon having high-resolution climate scenarios that

include relevant variables, such as the amount and intensity of specific rainfall events, as on having models of the biological responses. [WGII TAR Sections 5.5, 5.6.2-3, and 10.2.3]

- ***Changing disturbance regimes can interact with climate change to affect biodiversity—for example, via rapid, discontinuous ecosystem "switches."*** Changes in the grazing and fire regime associated with land management practices during the past century are thought to have increased the woody-plant density over large areas of Australia and southern Africa. Large-scale ecosystem changes (e.g., savanna to grassland, forest to savanna, shrubland to grassland) clearly occurred in the past (e.g., during the climatic changes associated with glacial and inter-glacial periods in Africa), but diversity losses were ameliorated as species and ecosystems had time to undergo geographical shifts. Changes in disturbance regimes and climate over the coming decades are likely to produce equivalent threshold effects in some areas. [WGII TAR Sections 5.4-5, 10.2.3, 11.2.1, 12.4.3, and 14.2.1]

The data and models needed to project the extent and nature of future ecosystem changes and changes in the geographical distribution of species are incomplete, meaning that these effects can only be partially quantified. The integrated response of ecosystems to atmospheric changes such as elevated CO_2 is uncertain, although a number of studies have addressed individual species responses to elevated CO_2 in experimental forests and grassland systems. For example, increased atmospheric CO_2 may increase water-use efficiency in grass species significantly, which may increase grass fuel load and even increase water supply to deeper rooted trees. Recent analysis of tree/grass interactions in savannas suggests that rising atmospheric CO_2 may increase tree densities, with this kind of ecosystem switch having major implications for grazing and browsing animals and their predators. Increased fuel loads can in turn lead to more frequent or intense fires, possibly reducing tree survival and decreasing stored carbon. The final outcome depends on the precise balance between opposing pressures and is likely to vary with species composition, spatially and through time as that balance shifts. Photosynthesis in C_3 plants is expected to respond more strongly to CO_2 enrichment than in C_4 plants. If this is the case, it may lead to an increase in geographic distribution of C_3 plants (many of which are woody plants) at the expense of the C_4 grasses. These processes depend on soil characteristics and climatic factors, namely temperature, precipitation, and number of frost days. The rate and duration of the shift in C_3 and C_4 distribution is likely to be affected by human activities (e.g., where a high grazing pressure may create more establishment sites for the C_4 grasses). [WGII TAR Sections 5.5-6]

Models of changes in the global distribution of vegetation are often most sensitive to variables for which we have only poor projections (e.g., water balance) and inadequate initial data (fine resolution fragmentation data). Models that simulate the change in abundance of important species or "functional groups" of species on a year by year (or seasonal) basis in response to the output of general circulation models (GCMs) are being developed and used for assessments of the overall carbon storage potential of the terrestrial biosphere. It is too early at this stage to place much reliance on the outputs for specific biomes or ecosystems. Their results show the sensitivity of ecosystems to the treatment of water use and especially the balance between changes in water availability due to climate change (often decreased availability in a warmer climate) and response to higher CO_2 concentrations in the atmosphere (often increased water-use efficiency). This means that model output can vary significantly depending on the GCM used, as these have tended to produce different inter-annual variability in precipitation and thus water availability. Other challenges are to simulate the loss of vegetation due to disturbances such as fire, blowdown, ice storms, or pest attacks and the migration of species or groups of species to new locations. Other studies have shown the sensitivity of the models to assumptions about dispersal and thus the ability to migrate. Modification of the IMAGE2 model to include unlimited dispersal, limited dispersal, and no dispersal results in significantly different patterns of vegetation change especially in high-latitude regions. [WGII TAR Sections 5.2.2, 5.2.4.1, and 10.2.3.2]

6.2.2. Biodiversity and Changes in Productivity

Changes in biodiversity and the changes in ecosystem functioning associated with them may affect biological productivity (see Box 4). These changes may affect critical goods and services upon which human societies rely (e.g., food and fiber). They may also affect the total sequestration of carbon in ocean and terrestrial ecosystems, which can affect the global carbon cycle and the concentration of greenhouse gases in the atmosphere.

At the global level, net biome productivity appears to be increasing. Modeling studies, inventory data, and inverse analyses provide evidence that, over the past few decades, terrestrial ecosystems have been accumulating carbon. Several effects contribute to this. Plants are responding to changes in land-use and land management practices (e.g., reforestation and regrowth on abandoned land), increasing anthropogenic deposition of nitrogen, atmospheric concentrations of CO_2, and possibly climate warming. [WGI TAR Section 3.2.2, WGII TAR Section 5.6.1.1, and LULUCF Section 1.2.1]

Where significant ecosystem disruption occurs (e.g., loss of dominant species or losses of a high proportion of species, thus much of the redundancy), there may be losses in NEP during the transition. The loss of biodiversity from diverse and extensive ecosystems does not necessarily imply a loss in productivity. The global distribution of biodiversity is correlated with global temperature and precipitation patterns, among other factors. Rapid climate change is expected to disrupt these patterns (usually with the loss of biodiversity) for periods of at least decades to centuries as ecosystems change and reform. It is possible that changes in productivity may be less than those

Box 4. Productivity and Associated Terms
[WGI TAR Section 3.2.2 and WGII TAR Section 5.2]

Productivity can be measured in several ways, including net primary productivity (NPP), net ecosystem productivity (NEP), and net biome productivity (NBP). Plants are responsible for the vast majority of uptake of carbon by terrestrial ecosystems. Most of this carbon is returned to the atmosphere via a series of processes including respiration, consumption (followed by animal and microbial respiration), combustion (e.g., fires), and chemical oxidation. Gross primary productivity (GPP) is the total uptake through photosynthesis whereas NPP is the rate of accumulation of carbon after losses due to plant respiration and other metabolic processes in maintaining the plant's living systems are taken into account. The consumption of plant material by animals, fungi, and bacteria (heterotrophic respiration) returns carbon to the atmosphere and the rate of accumulation of carbon over a whole ecosystem and over a whole season (or other period of time) is NEP. In a given ecosystem, NEP is positive in most years and carbon accumulates even if only slowly. However, major disturbances such as fires or extreme events that cause the death of many components of the biota release greater than usual amounts of carbon. The average accumulation of carbon over large areas and/or long time periods is NBP. Mitigation responses based on the long-term sequestration of carbon rely on increasing the NBP.

in biodiversity. However, globally, the impacts of climate change on biodiversity and the subsequent effects on productivity have not been estimated. Some theories and experimental studies suggest there is a degree of redundancy in most ecosystems and the contribution to production by a species that is lost from an ecosystem will often be replaced by that of another species (sometimes an invasive species). [SYR Q3.18, WGII TAR Sections 5.2, 5.6.3.1, 10.2.3.1, 11.3.1, and 12.5.5, and WGII SAR Section 1.2]

The role of biodiversity in maintaining ecosystem structure, functioning, and productivity is still poorly understood, and this issue has not been directly assessed in IPCC reports. However, it is an area of active theoretical and experimental research, and rapid advances in understanding can be expected. [WGII TAR Section 13.2.2]

6.3. Projected Impacts on Biodiversity of Coastal and Marine Ecosystems

Marine and coastal systems are affected by many human activities (e.g., coastal development, tourism, land clearance, pollution, and over-exploitation of some species) leading particularly to the degradation of coral reefs, mangroves, seagrass, coastal wetlands, and beach ecosystems. Climate change will affect the physical, biological, and biogeochemical characteristics of the oceans and coasts at different time and space scales, modifying their ecological structure and functions. This in turn could exert feedbacks on the climate system.

6.3.1. Projected Impacts on Ecosystems in Coastal Regions

Coral reefs will be impacted detrimentally if sea surface temperatures increase by more than 1°C above the seasonal maximum. Coral bleaching is likely to become widespread by the year 2100 (see Section 5.2 for observed impacts on coral reefs) as sea surface temperatures are projected to increase by at least 1–2°C. In the short term, if sea surface temperatures increase by more than 3°C and if this increase is sustained over several months, it is likely to result in extensive mortality of corals. In addition, an increase in atmospheric CO_2 concentration and hence oceanic CO_2 affects the ability of the reef plants and animals to make limestone skeletons (reef calcification); a doubling of atmospheric CO_2 concentrations could reduce reef calcification and reduce the ability of the coral to grow vertically and keep pace with rising sea level. The overall impact of sea surface temperature increase and elevated CO_2 concentrations could result in reduced species diversity in coral reefs and more frequent outbreaks of pests and diseases in the reef system. The effects of reducing the productivity of reef ecosystems on birds and marine mammals are expected to be substantial. [WGII TAR Sections 6.4.5 and 17.2.4]

Sea-level rise and changes in other climatic factors may affect a range of freshwater wetlands in low-lying regions. For example, in tropical regions, low-lying floodplains and associated swamps could be displaced by saltwater habitats due to the combined actions of sea-level rise, more intense monsoonal rains, and larger tidal or storm surges. Saltwater intrusion into freshwater aquifers is also potentially a major problem. [WGII TAR Sections 6.4 and 17.4]

Currently eroding beaches and barriers are expected to erode further as the climate changes and sea level rises. Coastal erosion, which is already a problem on many coastlines for reasons other than accelerated sea-level rise, is likely to be exacerbated by sea-level rise and adversely affect coastal biodiversity. A 1-m increase in sea level is projected to cause the loss of 14% (1,030 ha) of the land mass of Tongatapu island, Tonga, and 80% (60 ha) of that on Majuro Atoll, Marshall Islands, with consequent changes in overall biodiversity. Similar processes are expected to affect endemic plant species in Cuba, endangered and breeding bird species in Hawaii and other islands, and the loss of important pollinators such as flying foxes (*Pteropus sp.)* in Samoa. [WGII TAR Sections 6.4.2, 14.2.1.5, and 17.2.3]

Globally, about 20% of coastal wetlands could be lost by the year 2080 due to sea-level rise, with significant regional variations. Such losses would reinforce other adverse trends of wetland loss resulting primarily from other human activities. [WGII TAR Section 6.4.4]

The impact of sea-level rise on coastal ecosystems (e.g., mangroves, marshes, seagrasses) will vary regionally and will depend on erosion processes from the sea and depositional processes from land, for example:

- ***The ability of mangroves to adapt to rising sea level will vary regionally.*** Mangroves occupy a transition zone between sea and land that is subject to erosion processes from the sea and depositional processes from land. The impact of climate change on mangroves will therefore be a function of the interaction between these processes and sea-level rise. For example, mangroves in low-island coastal regions where sedimentation loads are high and erosion processes are low may be better able to respond to sea-level rise because deposited sediments will create new habitat for mangrove colonization. In some cases, where mangroves are unable to migrate inland in response to sea-level rise, there may be a collapse of the system (e.g., the Port Royal Wetland in Jamaica). [WGII TAR SPM and WGII TAR Sections 6.4.4, 14.2.3, 14.3, and 17.2.4]
- ***In some areas, the current rate of marsh elevation gain is insufficient to offset relative sea-level rise.*** The response of tidal marshes to sea-level rise is affected by sediment supply and the backshore environment. In general, tidal marsh accretion tracks sea-level rise and fluctuations in the rate of sea-level rise, but the maximum sustainable rate of accretion is variable. In areas where sediment supply is low or the backshore environment contains a fixed infrastructure, marsh front erosion can occur in concert with sea-level rise causing a substantial loss of coastal wetlands. [WGII TAR Section 6.4.4]
- ***The ability of fringing and barrier reefs to reduce impacts of storms and supply sediments can be adversely affected by sea-level rise.*** Fringing and barrier reefs perform the important function of reducing storm impacts on coastlines and supplying sediments to beaches. If these services are reduced, ecosystems landward of the foreshore would become more exposed and therefore more susceptible to change. Their deterioration or loss could have significant economic impacts. [WGII TAR Sections 6.4.1-2]
- ***The availability of sediment supply, coupled with increases in temperature and water depth as a consequence of sea-level rise, will adversely impact the productivity and physiological functions of seagrasses.*** This is expected to have a negative effect on fish populations that depend on the seagrass beds. Further, it could undermine the economic foundation for many small islands that often rely on "stable" coastal environments to sustain themselves. [WGII TAR Sections 6.4.4 and 17.4.2.3, and RICC Section 9.3.1.3]
- ***Deltas that are deteriorating—as a result of low sediment supply, subsidence, and other stresses—will be particularly susceptible to accelerated inundation, shoreline recession, and wetland deterioration.*** Deltas are particularly susceptible to sea-level rise, which will exacerbate the negative effects of anthropogenically reduced sediment supply rates, as in the Rhone, Ebro, Indus, and Nile deltas. Groundwater extraction may result in land subsidence and a relative rise in sea level that will increase the vulnerability of deltas, as projected in Thailand and China. Where local rates of subsidence and relative sea-level rise will not be balanced by sediment accumulation, flooding and marine processes will dominate and lead to significant land loss on the outer delta from wave erosion. For example, with the projected sea-level rise, large portions of the Amazon, Orinoco, and Paraná/Plata deltas will be affected. If vertical accretion rates resulting from sediment delivery and *in situ* organic matter production do not keep pace with sea-level rise, waterlogging of wetland soils will lead to death of emergent vegetation, a rapid loss of elevation due to decomposition of the below-ground root mass, and ultimately submergence and erosion of the substrate. [WGII TAR Sections 6.4.1-3]

6.3.2. Projected Impacts on Marine Ecosystems

The mean distribution of plankton and marine productivity in the oceans in many regions could change during the 21st century with projected changes in sea surface temperature, wind speed, nutrient supply, and sunlight. Increasing atmospheric concentrations of CO_2 would decrease seawater pH. Surface nutrient supply could be reduced if ocean stratification reduces the supply of major nutrients carried to the surface waters from the deep ocean. In regions limited by supply of deep ocean nutrients, stratification would reduce marine productivity and thus the strength of the export of carbon by biological processes; whereas, in regions where light is limiting, stratification could increase the light exposure of marine organisms, and thus increase productivity. [WGI TAR Sections 3.2 and 5.5.2.1]

Climate change will have both positive and negative impacts on the abundance and distribution of marine biota. The impacts of fishing and climate change will affect the dynamics of fish and shellfish. Climate change impacts on the ocean system include sea surface temperature-induced shifts in the geographic distribution of marine biota and compositional changes in biodiversity, particularly in high latitudes. The degree of the impact is likely to vary within a wide range, depending on the species and community characteristics and the region-specific conditions. It is not known how projected climate changes will affect the size and location of the warm pool in the western and central Pacific but, if more El Niño-like conditions occur, an easterly shift in the center of tuna abundance may become more persistent. The warming of the north Pacific Ocean will compress the distributions of sockeye salmon (*Oncorhynchus nerka*), essentially squeezing them out of the north Pacific and into the Bering Sea. There are clear linkages with the intensity and position of the Aleutian Low Pressure system in the Pacific Ocean and the production trends of many of the commercially important fish species. [WGII TAR Section 6.3.4]

Climate change could affect food chains, particularly those that include marine mammals. For example, extended ice-free seasons in the Arctic could prolong the fasting of polar bears and affect the nutritional status, reproductive success, and ultimately the abundance of the seal population. Reduced ice cover and access to seals would limit hunting success by polar bears and foxes with resulting reduction of bear and fox populations. Reductions in sea ice in the Arctic and Antarctica could alter the seasonal distributions, geographic ranges, migration patterns, nutritional status, reproductive success, and ultimately the abundance of marine mammals. [WGII TAR Section 6.3.7]

Marine ecosystems can be affected by climate-related factors, and these changes in turn could act as additional feedbacks on the climate system. Long-term projections of biological responses are hampered by inadequate scenarios for upper ocean physical and chemical conditions under altered climate regimes and by a lack of understanding concerning physiological acclimation and genetic adaptations of species to increasing partial pressure of CO_2. Some phytoplankton species cause emission of dimethyl sulfide to the atmosphere which has been linked to the formation of cloud condensation nuclei. Changes in the abundance or distribution of such phytoplankton species may cause additional feedbacks on climate change. [WGI TAR Sections 3.2.3 and 5.2.2]

6.4. Vulnerable Species and Ecosystems (Terrestrial, Coastal, and Marine)

Many of the Earth's species are already at risk of extinction due to pressures arising from natural processes and human activities. Climate change will add to these pressures for many threatened and vulnerable species. For a few, climate change may relieve some of the existing pressures.

Some species are more susceptible to climate change than others. Species with limited climatic ranges and/or restricted habitat requirements are typically the most vulnerable to extinction. Many mountainous areas have endemic species with narrow habitat requirements which could be lost if they cannot move up in elevation. Biota restricted to islands (e.g., birds) or peninsulas (e.g., the Cape Floral Kingdom including the fynbos region at the southern tip of South Africa) face similar problems. Additionally, biota with particular physiological or phenological traits (e.g., biota with temperature-dependent sex determination like sea turtles and crocodiles, amphibians with a permeable skin and eggs) could be especially vulnerable. Impacts of climate change on these species are likely due to direct physiological stress, habitat loss or alteration, and/or changes in disturbance regime. The probability of species going extinct increases when ranges are restricted, habitat decreases, and population numbers decline. In contrast, species with wide non-patchy ranges, rapid dispersal mechanisms, and large populations normally are at less risk of extinction. For some threatened species, habitat availability will increase (e.g., warmwater fish are projected to benefit in shallow lakes in cool temperate regions), possibly reducing vulnerability. [WGII TAR Sections 5.4.1, 5.7.3, 17.2.3, and 19.3.3.1]

The risk of extinction will increase for many species, especially those that are already at risk due to factors such as low population numbers, restricted or patchy habitats, limited climatic ranges, or occurrence on low-lying islands or near the top of mountains. Many animal species and populations are already threatened and are expected to be placed at greater risk by the interactions between climate change rendering portions of current habitat unsuitable, and land-use change fragmenting habitats and raising obstacles to species migration. Without appropriate management, rapid climate change, in conjunction with other pressures, will cause many species that currently are classified as critically endangered to become extinct, and several of those that are labeled endangered or vulnerable to become much rarer, and thereby closer to extinction, in the 21st century. [WGII TAR Sections 5.4.3 and 17.2.3]

Geographically restricted ecosystems are potentially vulnerable to climate change. Examples of geographically restricted, vulnerable ecosystems include, but are not limited to, coral reefs, mangrove forests and other coastal wetlands, high mountain ecosystems (upper 200 to 300 m), prairie wetlands, remnant native grasslands, ecosystems overlying permafrost, and ice-edge ecosystems. The specific threats to some of these ecosystems are discussed in detail elsewhere in this paper.

Regional variation in the impacts of climate change on biodiversity is expected because of multiple interactions between drivers of biodiversity loss. For example, one study based on expert assessment and qualitative modeling concluded that ecosystems in Mediterranean climates and grassland ecosystems are likely to experience the greatest proportional change in biodiversity during this century because of the substantial influence of all drivers of biodiversity change. They concluded that dominant factors determining biodiversity decline will be climate change in polar regions and land-use change in tropics. Temperate ecosystems were estimated to experience the least biodiversity change because major land-use changes have already occurred. [WGII TAR Sections 3.3.3.3, 5.2.3.1, 6.4, and 19.3]

Many important reserve systems may need to be extended in area or linked to other reserves, but for some such extensions are not possible as there is simply no place to extend them. As many species are expected to move poleward or up in altitude with increasing temperatures, the locations of reserves may need to allow for such movement. This may necessitate larger areas being conserved or appropriately designed networks of reserves linked by dispersal corridors (see Section 8). Even with these efforts, some species may not be conserved because they are presently as far poleward or as high in altitude as they can be, or confined to small islands. [WGII TAR Section 13.2.2.4 and WGII TAR Box 5-7]

6.5. Impacts of Changes in Biodiversity on Regional and Global Climate

Changes in genetic or species biodiversity can lead to changes in the structure and functioning of ecosystems and their interaction with the water, carbon, nitrogen, and other major biogeochemical cycles and so affect climate. Changes in diversity at ecosystem and landscape scales in response to climate change and other pressures could further affect regional and global climate. Changes in trace gas fluxes are most likely to exert their effect at the global scale due to rapid atmospheric mixing of greenhouse gases, whereas the climate feedbacks from changes in water and energy exchange occur locally and regionally.

Changes in community composition and ecosystem distribution due to climate change and human disturbances may lead to feedbacks that affect regional and global climate. In high-latitude regions, changes in community composition and land cover associated with warming are likely to alter feedbacks to climate. Tundra has a three- to six-fold higher winter albedo than boreal forest, but summer albedo and energy partitioning differ more strongly among ecosystems within either tundra or boreal forest than between these two biomes. If regional surface warming continues, reductions in albedo are likely to enhance energy absorption during winter, acting as a positive feedback to regional warming due to earlier melting of snow and over the long term the poleward movement of treeline. Surface drying and a change in dominance from mosses to vascular plants would also enhance sensible heat flux and regional warming in tundra during the active growing season. Boreal forest fires, however, may promote cooling because post-fire herbaceous and deciduous forest ecosystems have higher albedo and lower sensible heat flux than does late successional pre-fire vegetation. Northern wetlands contribute 5 to 10% of global CH_4 emissions to the atmosphere. As temperature, hydrology, and community composition change and as permafrost melts, there is a potential for release of large quantities of greenhouse gases from northern wetlands, which may provide a further positive feedback to climate warming. [WGII TAR Sections 5.9.1-2]

Human actions leading to the long-term clearing and loss of woody vegetation have and continue to contribute significantly to greenhouse gases in the atmosphere. In many cases the loss of species diversity associated with forest clearing leads to a long-term transition from a forest to a fire and/or grazing-maintained, relatively low diversity grassland with significantly lower carbon content than the original forest. Deforestation and land-clearing activities contributed about a fifth of the greenhouse gas emissions (1.7±0.8 Gt C yr^{-1}) during the 1990s with most being from deforestation of tropical regions. A total of 136±55 Gt C have been released to the atmosphere due to land clearing since the year 1850. [SYR Q2.4 and LULUCF Section 1.2]

Changes in land surface characteristics—such as those created by land-cover change—can modify energy, water, and gas fluxes and affect atmospheric composition, creating changes in local, regional, and global climate. Evapotranspiration and albedo affect the local hydrological cycle, thus a reduction in vegetative cover may lead to reduced precipitation at local and regional scales and change the frequency and persistence of droughts. For example, in the Amazon basin, at least 50% of precipitation originates from evapotranspiration from within the basin. Deforestation reduces evapotranspiration, which could reduce precipitation by about 20%, producing a seasonal dry period and increasing local surface temperatures by 2°C. This could, in turn, result in a decline in the area of wet tropical rainforests and their permanent replacement by floristically poorer drought-deciduous or dry tropical forests or woodlands. [WGI TAR Section 3.4.2, WGII TAR Sections 1.3.1, 5.7, and 14.2.1, RICC Section 6.3.1, and WGII SAR Section 1.4.1]

6.6. Projected Impacts on Traditional and Indigenous Peoples

Traditional[8] and indigenous peoples depend directly on diverse resources from ecosystems and biodiversity for many goods and services (e.g., food and medicines from forests, coastal wetlands, and rangelands). These ecosystems are projected to be adversely affected by climate change and are already under stress from many current human activities.

The livelihood of indigenous peoples will be adversely affected if climate and land-use change lead to losses in biodiversity, including losses of habitats. Adverse impacts have been projected for species such as caribou, marine birds, seals, polar bears, tundra birds, and other tundra-grazing ungulates that are important as food sources for many traditional and indigenous people, especially those in the Arctic. Reef ecosystems provide many goods and services and changes in these due to climate change will affect people that depend on them. In some terrestrial ecosystems, adaptation options (such as efficient small-scale or garden irrigation, more effective rain-fed farming, changing cropping patterns, intercropping and/or using crops with lower water demand, conservation tillage and coppicing of trees for fuelwood) could reduce some of the impacts and reduce land degradation. [WGII TAR Sections 5.5.4.3, 5.6.4.1, 6.3.7, and 17.2.4, and WGII SAR Section 7.5]

Climate change will affect traditional practices of indigenous peoples in the Arctic, particularly fisheries, hunting, and reindeer husbandry. High-latitude marine fisheries are very productive. Climate-induced changes in sea ice, ocean currents, nutrient availability, salinity, and the temperature of the ocean waters will affect the migration routes, population structure, and ultimately the catch of different fish species. Climate

[8] "Traditional peoples" here refers to local populations who practice traditional lifestyles that are often rural. Traditional people may, or may not, be indigenous to the location.

warming is likely to also alter husbandry practices. Concerns include the presence of deep snow with an ice surface that stops the animals from obtaining forage, lichens, and grasses; destruction of vegetation as a result of heavy grazing; exposure of soil that encourages the establishment of southerly weedy species under a warmer climate; and an increased likelihood of damage from more frequent tundra fires. [WGII TAR Sections 16.2.8.2.5-6]

Shifts in the timing or the ranges of wildlife species due to climate change could impact the cultural and religious lives of some indigenous peoples. Many indigenous people use wildlife as integral parts of their cultural and religious ceremonies. For example, birds are strongly integrated into Pueblo Indian (USA) communities where birds are viewed as messengers to the gods and a connection to the spirit realm. Among Zuni Indians (USA), prayer sticks, using feathers from 72 different species of birds, are used as offerings to the spirit realm. Many ethnic groups in sub-Saharan Africa use animal skins and bird feathers to make dresses for cultural and religious ceremonies, such as skirts and headgear for leaders and priests/priestesses. For example, in Boran (Kenya) ceremonies, the selection of tribal leaders involves rituals requiring Ostrich feathers. Wildlife plays similar roles in cultures elsewhere in the world. [WGII TAR Section 5.4.3.3]

Sea-level rise and climate change, coupled with other environmental changes, will affect some, but not all, very important and unique cultural and spiritual sites in coastal areas, thus the people that reside there. Communities in many of the coastal zones in South America have established traditional values, including aesthetic and spiritual aspects associated with habitat features that will be degraded or destroyed by sea-level rise and inundation. The unique cultures that have developed over millennia in Polynesia, Melanesia, and Micronesia depend on the resource-rich and diverse high-volcanic and limestone islands in the region, such as Vanuatu, Fiji, and Samoa, which are unlikely to be seriously threatened by climate change. On the other hand, resource-poor, low-reef islands and atolls, which have developed equally distinctive traditional identities over centuries—such as the Tuvaluan, Kiribati, Marshallese, and Maldivian cultures—are more sensitive to sea-level change and storm surges and thus their cultural diversity could be seriously threatened. Indigenous people in the Arctic are particularly sensitive to climate change. Coastal erosion and retreat as a result of thawing of ice-rich permafrost already are threatening communities and heritage sites. [WGII TAR Sections 16.2.8.1 and 17.2.10]

6.7. Regional Impacts

Biodiversity is recognized to be an important issue for many regions. From a global perspective, different regions have varied amounts of biodiversity with varying levels of endemic species. The major impacts on biodiversity in each region are summarized in Boxes 5 to 12. Since biodiversity underlies many of the goods and services on which humans depend, the consequences of the impacts on biodiversity on human livelihoods are also examined, including the impacts on traditional and indigenous peoples.

A limitation of the material is that there are few region- and country-specific studies; however, the impacts presented in Sections 6.2 and 6.3 are applicable to many regions, mostly due to similarities in ecosystems (e.g., the impacts on coral reefs and rangelands are very similar in many parts of the world).

Recent estimates indicate that 25% (~1,125 species) of the world's mammals and 12% (~1,150 species) of birds are at a significant risk of global extinction. One measure of the magnitude of this problem is the speed at which species at risk are being identified. For example, the number of bird species considered at risk has increased by almost 400 since the year 1994, and current population sizes and trends suggest an additional 600–900 soon could be added to these lists. The number of animals threatened with extinction varies by region (see Table 2). Global patterns of total diversity are reflected in the number of species at risk in each region, in that areas with more total species are likely to have more at risk.

Adaptation options may minimize some of the impacts of climate change and these are examined in Section 8.1.

Table 2: State of some of the world's vertebrate wildlife. For each region, the table lists the number of critically endangered / endangered / vulnerable species. [WGII TAR Table 5-5]

Geographical Region[a]	*Totals*	*Amphibians*	*Reptiles*	*Birds*	*Mammals*
Africa	102 / 109 / 350	0 / 4 / 13	2 / 12 / 34	37 / 30 / 140	63 / 63 / 163
Asia and Pacific	148 / 300 / 739	6 / 18 / 23	13 / 24 / 67	60 / 95 / 366	69 / 163 / 283
Europe and Central Asia	23 / 43 / 117	2 / 2 / 8	8 / 11 / 10	6 / 7 / 40	7 / 23 / 59
Western Asia	7 / 11 / 35	0 / 0 / 0	2 / 4 / 2	2 / 0 / 20	3 / 7 / 13
Latin America	120 / 205 / 394	7 / 3/ 17	21 / 20/ 35	59 / 102 / 192	33 / 80 / 150
North America	38 / 85 / 117	2 / 8 /17	3 / 12 / 20	19 / 26 / 39	14 / 39 / 41

[a] For full description of which countries are in which regions, see WGII TAR Section 5.4.1.1 or the original reference for the information in the table: UNEP, 2000: *Global Environment Outlook 2000*. United Nations Environmental Programme, Nairobi, Kenya.

Box 5. Biodiversity and Impacts of Climate Change in Africa
[WGII TAR Sections 10.1.2 and 10.2.3.2-3, and RICC Section 2.3]

Regional Characteristics: Africa occupies about one-fifth of the global land surface. There is a lot of diversity of climate, landform, biota, culture, and economic circumstance within the region. It is a predominantly tropical, hot, and dry region with small areas of temperate (cool) climates in the extreme south and north and at high altitudes. Most of the human population occurs in the subhumid and semi-arid zones. Corresponding to the tropics of Capricorn and Cancer are the vast desert regions of the Kalahari-Namib and the Sahara. The formal and informal economies of most African countries are strongly based on natural resources: agriculture, pastoralism, logging, ecotourism, and mining. Many systems, but particularly tropical forests and rangelands, are under threat from population pressures and systems of land use that have led to loss of biodiversity and degradation of land and aquatic ecosystems.

Important Features of Biodiversity: Africa contains about a fifth of all the known species of plants, mammals, and birds in the world, and a sixth of the amphibians and reptiles. This biodiversity is concentrated in several centers of endemism. The Cape Floral Kingdom (corresponding approximately with a vegetation formation locally known as fynbos), occupying only 37,000 km^2 at the southern tip of Africa, has 7,300 plant species, of which 68% occur nowhere else in the world. The adjacent Succulent Karoo on the west coast of southern Africa contains 4,000 species, of which 2,500 are endemic. Other major centers of plant endemism are Madagascar, the mountains of Cameroon, and the island-like Afromontane habitats that stretch from Ethiopia to South Africa at altitudes above ~2,000 m. The rich African mammal biodiversity (especially ungulates) is located in the savannas and tropical forests. World antelope and gazelle biodiversity (more than 90% of the global total of 80 species) is concentrated in Africa. A median of ~4% (varies between countries from 0 to 17%) of the continental land surface is in formally declared conservation areas. A very large fraction of biodiversity in Africa (especially in central and northern Africa) occurs principally outside formally conserved areas due to a relatively low rate of intensive agricultural transformation on the continent.

About a fifth of the southern African bird species migrate on a seasonal basis within Africa, and a further tenth migrate annually between Africa and the rest of the world. A similar proportion can be assumed for Africa as a whole. One of the main within-Africa migratory patterns involves waterfowl, which spend the austral summer in southern Africa and winter in central Africa. Palaearctic migrants spend the austral summer in locations such as Langebaan Lagoon, near Cape Town, and the boreal summer in the wetlands of Siberia.

Socio-Economic Linkages: The semi-arid areas of the Sahel, the Kalahari, and the Karoo have historically supported nomadic societies, which respond to the intra-annual rainfall seasonality and the large inter-annual variability through migration. Nomadic pastoral systems are intrinsically quite robust to fluctuating and extreme climates (since that is what they evolved to cope with), provided they have sufficient scope for movement and some social stability. The prolonged drying trend in the Sahel since the 1970s has demonstrated the vulnerability of such groups to climate change when they cannot migrate because the wetter end of their migration areas is already densely occupied, and the permanent water points fail at the drier end. The result has been widespread loss of human life and livestock, and substantial changes to the social system.

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Africa

Projected impacts of climate change include:

- Many thousands of plants are potentially affected by climate change, particularly the floristically diverse fynbos and Karoo, both of which occur in winter rainfall regions at the southern tip of the continent, and are threatened particularly by a shift in rainfall seasonality (e.g., a reduction in winter rainfall amounts or an increase in summer rainfall, which would alter the fire regime critical to regeneration in the fynbos). The montane centers of biodiversity (e.g., those in east Africa) are particularly threatened by increases in temperature, since many represent isolated populations with no possibility of vertical or horizontal migration. Increase in size of the Sahara may negatively impact survival of palaearctic migratory birds by forcing longer migration pathways.
- Projected changes in climate during the 21st century could alter the distribution of antelope species.
- Major rivers are highly sensitive to climate variation; average runoff and water availability is projected to decrease in Mediterranean and southern countries of Africa, which would affect their biodiversity. There is a possible projected decrease of plankton-eating pelagic freshwater fisheries.

Box 5. Biodiversity and Impacts of Climate Change in Africa (continued)

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Africa (continued)

- There are several globally important wetland areas in Africa (e.g., Okavanga Delta). Decreases in runoff could lead to a reduction in area of these resources.
- Extension of ranges of infectious disease vectors could occur and affect some wildlife species. Phenology of insect pests and diseases is projected to change, potentially resulting in increased agricultural and forestry losses, as well as unknown consequences in many ecosystems.
- Increases in droughts, floods, and other extreme events would add to stresses on many ecosystems.
- Desertification would be exacerbated by reductions in average annual rainfall or increases in average evaporative demand; either or both would lead to reduced runoff and soil moisture, especially in southern, north, and west Africa.
- At particular risk of major biodiversity loss are plants and animals that have limited mobility and occur in reserves on flat and extensive landscapes, areas where rainfall regime may change seasonality (e.g., the southern Cape), where tree/grass balance are sensitive to CO_2 conditions and/or climatic factors, and where fire/other disturbance regime could change.
- Ecosystems that are particularly vulnerable to climate change include fynbos, some rangelands (including the Karoo), cloud/montane forests, and wetlands (especially riparian) in arid/semi-arid areas.
- Significant local and global extinctions of plant and animal species, many of which are an important resource for African people, are projected and would impact rural livelihoods, tourism, and genetic resources.

Box 6. Biodiversity and Impacts of Climate Change in Asia
[WGII TAR Sections 11.1.4 and 11.2.1, and RICC Sections 7.3, 10.2, and 11.2-3]

Regional Characteristics: Based on broad climatic and geographical features, the Asia region can be divided into four sub-regions: boreal, arid and semi-arid, temperate, and tropical Asia. Human activities through the ages have brought profound changes to the landscape of parts of this region. Except for boreal forests, many forests have been cleared or become degraded. Broad plains have been cultivated and irrigated in some cases for thousands of years, and rangelands/grasslands have been used for livestock grazing. Freshwater aquatic ecosystems in Asia have high flora and fauna diversity.

Important Features of Biodiversity: Temperate forests in Asia are a globally important resource because of their high degree of endemism and biological diversity. The tropical Asian region is ecologically rich in biodiversity including that of the present varieties of crops and the past ancestors and tropical forest species. Some parts of the region have been identified as centers of diversity of a great many crops and other economically important plants that originate in this part of the world. Forests in Asia are home to over 50% of the world's terrestrial plant and animal species; the rainforests of southeast Asia alone contain about 10% of the world's floral diversity. Tropical moist forests and woodlands are important resources that provide the majority of wood as fuel in some countries. A tenth of the world's known high-altitude plants and animal species occur in the Himalayas. Some of the high- and mid-altitude areas are also centers of origin for many crop and fruit-tree species; as such, they are important sources of genes for their wild relatives.

Socio-Economic Linkages: The major freshwater ecosystems have been stressed by land-use and land-cover change, recreational activities, and pollution, and the flows of major rivers have been affected by hydroelectric and industrial development projects down the river including that in the estuaries. The changes in aquatic habitat have also affected fisheries in lower valleys and deltas; the absence of nutrient-rich sediments has a detrimental effect on fish productivity. Reduced flows in lower valley catchments have also resulted in eutrophication and poor water quality.

Most semi-arid lands in Asia (mostly in central Asia) are classified as rangelands/grasslands. Humans and their livestock depend heavily on the rangelands of the region; almost two-thirds of the domestic livestock are supported on rangelands. About 10% of this is classified as having some soil constraints, indicating either that it shows significant soil degradation or that it is desertified; approximately 70% of Mongolian pastures are facing degradation. In some high-altitude zones, biodiversity is being lost or endangered because of land degradation and the overuse of resources (e.g., in 1995, about 10% of the known species in the Himalayas were listed as "threatened").

Current rapid urbanization, industrialization, and economic development have led to increasing pollution, land and water degradation, and loss of biodiversity.

Box 6. Biodiversity and Impacts of Climate Change in Asia (continued)

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Asia

Projected impacts of climate change include:

- Species in high-elevation ecosystems are projected to shift higher. In the higher elevated areas, the rates of vegetation change are expected to be slow, and colonization success would be constrained by increased erosion and overland flows such as in the highly dissected and steep terrains of the Himalayan mountain range; weedy/invasive species with a wide ecological tolerance will have an advantage over others. In temperate Asia, species are likely to shift polewards and boreal forest species projected to show large shifts (up to 400 km) in the next 50 years.
- There may be a decline of conifer forests in northeast China and broad-leaved forests in east China may shift northward by up to several hundred kilometers. Frequency and intensity of forest fires and pest outbreaks in the boreal forests are likely to increase. Forest ecosystems in boreal Asia are projected to be affected by floods and increased volume of runoff as well as melting of permafrost.
- Deltaic coastal ecosystems in China could be detrimentally affected by sea-level rise. Sea-level rise could cause large-scale inundation of freshwater wetlands along the coastline and recession/loss of flat coastal habitats.
- With projected increases in temperature and decreases in precipitation, water quality might deteriorate and eutrophication might be exacerbated (e.g., in some lakes in Japan).
- Mangroves (e.g., those in the Sundarbans) and coral reefs are particularly vulnerable due to climate change. The Sundarbans supports a diversity of wildlife and is at great risk due to rising sea level. These coastal mangrove forests provide habitat for species such as Bengal tigers, Indian otters, spotted deer, wild boars, estuarine crocodiles, fiddler crabs, mud crabs, three marine lizard species, and five marine turtle species. With a 1-m rise in sea level, the Sundarbans will disappear, which will spell the demise of the Bengal tiger and other wildlife, and could adversely affect local human populations.
- With the projected decrease in productivity (of 40 to 90%), climate change is likely to represent an additional stress on rangelands and affect many people's livelihoods. Both climate change and human activities will further influence the levels of the Caspian and Aral Seas with implications for biodiversity and the people.

Box 7. Biodiversity and Impacts of Climate Change in Australia and New Zealand
[WGII TAR Section 12.1 and RICC Section 4.3]

Regional Characteristics: This region consists of Australia, New Zealand, and their outlying tropical and mid-latitude islands. The total land area is 8 million km^2. Australia is a large, relatively flat continent reaching from the tropics to mid-latitudes, with relatively nutrient-poor soils, a very arid interior, and highly variable rainfall; whereas, New Zealand is much smaller, mountainous, and fairly moist. The ecosystems in the region have been subject to significant human influences, both before and after European settlement 200 years ago. Both countries have significant populations of indigenous peoples who generally have lower economic and health status.

Important Features of Biodiversity: The isolated evolutionary history of Australia and New Zealand has led to a very high level of endemism (e.g., 77% of mammals, 41% of birds, and 93% of plant species are endemic, including many species of eucalypts). New Zealand is regarded as one of the world's 25 biodiversity "hot spots." Areas such as those in western Australia and north Queensland have a high level of endemism. Australia has the biggest reef system (i.e., the Great Barrier Reef) in the world. Australia is one of the 12 recognized "mega-diversity" countries and the center of origin of the widely used *Eucalyptus* genus. Disruption in forest composition is most likely to occur where fragmentation of the forest reduces the potential for dispersal of new, more suitable species. Alpine systems, despite covering a small area, are important for many plant and animal species, many of which are listed as threatened.

Box 7. Biodiversity and Impacts of Climate Change in Australia and New Zealand (continued)

Socio-Economic Linkages: Many parts of the region have been subject to significant human influences, especially after European settlement, particularly from widespread vegetation clearance, the use of fire as a management tool, and from the introduction of non-native plants and animals. Owing to millions of years of isolation, its ecosystems are extremely vulnerable to introduced species (e.g., sheep, cattle, rabbits), pests, diseases, and weeds. These activities have led to a loss of biodiversity in many ecosystems (and of some ecosystems as a whole an increase in weedy species), to fragmentation of ecosystems, and to secondary salinization.

In Australia, rangelands cover about two-thirds of the country and are important for meat and wool production, but are under stress from human activity mostly due to animal production, from introduced animals such as rabbits, and from inappropriate management. These stresses have led to problems of land degradation, salinization, and woody weed invasion.

In Australia, 50% of the forest cover in existence at the time of European settlement still exists, although about half of that has been logged. Nationally, land clearing still exceeds planting, although this varies greatly between regions and is occurring mainly in woodlands. Pressures on forests and woodlands as a whole are likely to decrease as a result of recent legislation relating to protection of forests in some Australian states, and as interest in carbon sequestration increases. In New Zealand, 25% of the original forest cover remains, with 77% in the conservation estate, 21% in private hands, and 2% state owned. Legal constraints on native wood production mean that only about 4% is currently managed for production, and clear-felling without replacement has virtually ceased.

Wetlands continue to be under threat despite being listed as Ramsar and World Heritage sites. Large numbers are already destroyed due to water storage; hydroelectric and irrigation schemes; dams, weirs, and river management works; de-snagging and channelization; changes to flow, water level, and thermal regimes; toxic pollution and destruction of nursery and spawning or breeding areas; and use of wetlands for agriculture.

The Great Barrier Reef is facing over-exploitation; coral bleaching, often associated with El Niño events; and increasing pollution and turbidity of coastal waters by sediment loading, fertilizers, pesticides, and herbicides—but still to a lesser extent than many other coral reefs in the world. Progress has been made to ensure that reef exploitation is ecologically sustainable.

In both countries, the indigenous peoples (i.e., Aborigines and Torres Straits Islanders of Australia, and the Maori of New Zealand) depend on many terrestrial, coastal, and marine ecosystems both for use as traditional sources of food and materials and for their cultural and spiritual significance—hence likely to be adversely affected by climate change. The indigenous people in Australia are particularly vulnerable to climate change, since they generally live in isolated rural conditions exposed to climatic disasters and thermal stress, and in areas more likely to increase in the prevalence of water- and vector-borne diseases.

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Australia and New Zealand

Projected impacts of climate change include:

- Projected drying trends over much of the region and change to a more El Niño-like average state is likely to affect many ecosystems, especially semi-arid ones.
- Increases in the intensity of heavy precipitation events and region-specific changes in the frequency of tropical cyclones would affect ecosystems due to flooding, storm surges, and wind damage.
- Although many species will be able to adapt, climate change is expected to reduce the overall biodiversity in individual ecosystems.
- Changes in forest and woodland composition due to climate change are most likely to occur where fragmentation of the forest and woodland reduces the potential for migration of new, more suitable species.
- Ecosystems that are particularly vulnerable to climate change include coral reefs, arid and semi-arid habitats in southwest and inland Australia, freshwater wetlands in the coastal zone, and alpine systems.
- Some New Zealand ecosystems would become vulnerable to invasive species.

Box 8. Biodiversity and Impacts of Climate Change in Europe
[WGII TAR Section 13.2.2, RICC Sections 5.1.2 and 5.3.1.6, and WGII SAR Section 3.2.3]

Regional Characteristics: Although much of Europe originally was covered by forest, natural vegetation patterns have been transformed through human activities, particularly land-use and land-cover change including that for intensive agriculture and urbanization. Only in the most northerly mountains and in parts of northern, eastern, and central European Russia has the forest cover been relatively unaffected by human activity. A considerable part of the continent, however, is covered by forest/woodland that has been planted or regenerated on previously cleared land. The Arctic coastal regions of northern Europe and the upper slopes of the highest mountains are characterized by mostly lichens, mosses, herbs, and shrubs. The inland parts of northern Europe, with milder but still cool climate, have coniferous trees. The largest vegetation zone in Europe—cutting across the middle portion of the continent from the Atlantic to the Ural—is a belt of mixed deciduous and coniferous forest. Much of the Great European Plain is covered with areas of tall grasses; further to the east, Ukraine is characterized by a flat and comparatively dry region with short grasses. The Mediterranean region is covered by vegetation that has adapted to generally dry and warm conditions; natural vegetation tends to be more sparse in the southern and eastern parts of the Mediterranean basin.

Important Features of Biodiversity: Europe in the past had a large variety of wild mammals, including deer, elk, bison, boar, wolf, and bear. Many species of animals have become extinct at least locally, or have been greatly reduced in number. Some vertebrate species, however, have been reintroduced in the 20th century after they became locally extinct, and some have recovered due to protection or restoration of habitats such as wetlands. Native mountain animals have survived human encroachment on their habitats; chamois and ibex are found in the higher elevations of the Pyrenees and Alps. Europe still has many smaller mammals and many native bird species. A significant proportion of surviving semi-natural habitats of high conservation value is enclosed within protected sites, which are especially important as refuges for threatened species. Nature reserves tend to form habitat “islands” for species in landscapes dominated by other land uses, and form an important conservation investment across the whole of Europe.

Socio-Economic Linkages: Europe at present is predominantly a region of fragmented natural or semi-natural habitats in a highly urbanized landscape. A large proportion of Europe is farmed, and about one-third of the area is arable, with cereals being the predominant crop. Natural ecosystems generally are confined to poor soils; while agriculture occupies more fertile soils. The European forest—an important climate-sensitive economic sector—is affected by high deposition rates of nitrogen and sulfur. Key environmental pressures relate to biodiversity, landscape, soil, land, and water degradation (largely due to pollution).

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Europe

Projected impacts of climate change include:

- Ecosystems are projected to change in composition, structure, and function with poleward and upward range extension of some species: Permafrost will decline; trees and shrubs will extend into northern tundra; and broad-leaved trees may encroach coniferous forests. In the southern boreal forests, the coniferous species are expected to decline because of a concurrent increase of deciduous tree species.
- Most climate change scenarios suggest a possible overall northward displacement of the climatic zone that is suitable for boreal forests by several hundred of kilometers by the year 2100.
- In mountain regions, higher temperatures will lead to an upward shift of biotic and cryospheric zones and perturb the hydrological cycle. As a result of a longer growing season and higher temperatures, European alpine areas will shrink because of upward migration of tree species. There will be redistribution of species, with, in some instances, a threat of extinction due to lack of possibility to migrate upward, either because they cannot move rapidly enough or because the zone is absent.
- Flood hazard will increase across much of Europe; risk would be substantial for coastal areas where flooding will increase erosion and result in loss of coastal wetlands. Estimated coastal wetland losses by the 2080s range from 0–17% for the Atlantic coast, through 84–98% for the Baltic coast, to 81–100% for the Mediterranean coast, and any surviving wetlands may be substantially altered. This would have serious consequences for biodiversity in Europe, particularly for wintering shorebird and marine fish populations.
- Loss of important habitats (wetlands, tundra, isolated habitats) would threaten some species, including rare/endemic species and migratory birds. Snowmelt-dominated watersheds will experience earlier spring peak flows and possible reductions in summer flows and water levels in streams and lakes. This will impact aquatic ecosystems.

Box 8. Biodiversity and Impacts of Climate Change in Europe (continued)

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Europe (continued)

- Plant species richness can decline in areas with Mediterranean-type ecosystems if climate becomes more arid.
- Higher winter temperatures could increase the distribution range of some introduced species (e.g., *Nothofagus procera* in Britain).
- Where ranges of species are already fragmented they may become even more fragmented, with regional disappearances of species, if they cannot persist, adapt, or migrate.
- With climate change, valued communities within protected areas may dissociate, leaving species with nowhere to go. Particular species populations in sites that lie near their current maximum temperature limits could be expected to become extinct if climate warms beyond these limits. As a result of climate change, nature reserve communities may lose species at a faster rate than potential new species can colonize, leading to a long period of impoverishment for many reserves. Thus, biological diversity in nature reserves is under threat from rapid climate change. Networks of habitats and habitat corridors will be required to facilitate migration.

Box 9. Biodiversity and Impacts of Climate Change in Latin America
[WGII TAR Section 14.1.2 and RICC Sections 6.3.1 and 6.3.3]

Regional Characteristics: The Latin America region is remarkably heterogeneous in terms of climate, topography, ecosystems, human population distribution, and cultural traditions. The surface of the Latin American region is ~19.93 million km^2. Mountain ranges and plateaus play an important role in determining not only the regional climate and hydrological cycle, but also its biodiversity. The Amazon River, by far the world's largest river in terms of streamflow, plays an important role in the water cycle and water balance of much of South America. Land-use changes have become a major force driving changes in ecosystems. Many ecosystems are already at risk, without the additional stresses expected from climatic change. There are ~570 million animal units on the sub-continent, and over 80% of them are fed from rangelands. Latin America has about 23% of the world's arable land although—in contrast with other regions—it maintains a high percentage of non-intensively managed ecosystems. Pre-Colombian cultures had developed a number of community-farming activities in the high plateaus, where the largest proportion of Latin America indigenous communities are still settled.

Important Features of Biodiversity: Latin America possesses a large variety of ecosystems, ranging from the Amazonian tropical rain forest, cloud forest, Andean *Paramos*, rangelands, shrublands, deserts, grasslands, and wetlands. Rangelands cover about one-third of the land area of Latin America. Forests occupy ~22% of the region and represent ~27% of global forest cover. Latin America is known as home to some of Earth's greatest concentrations of biodiversity, both terrestrial and marine, its genetic diversity being among the richest in the world. Seven of the world's most diverse and threatened areas are in Latin America and the Caribbean.

Mountain ranges are the source regions of massive rivers (e.g., the tributary rivers of the Amazonia and Orinoco basins) and are important for biodiversity. The Amazon rainforest contains the largest number of animal and plant species in Latin America. Temperate and arid zones in this region contain important genetic resources, in terms of wild and domesticated genotypes of many crop species.

Coastal and inland wetlands have very high animal biodiversity and also contribute to the region's genetic diversity. One of the largest coral reef systems in the world dominates the offshore area of the western Caribbean Sea. Coastal forests, mainly mangroves, are lost at a rate of approximately 1% per year, leading to a decline in nurseries and refuge for fish and shellfish species.

Socio-Economic Linkages: Many ecosystems (e.g., corals, mangroves, and other wetlands) are already at risk due to human activities, and climatic change will be an additional stressor. Many indigenous peoples and local communities depend on different ecosystems (e.g., forest, savannas, and coastal wetlands) for subsistence livelihood and cultural values.

Box 9. Biodiversity and Impacts of Climate Change in Latin America (continued)

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Latin America

Projected impacts of climate change include:

- Increase in the rate of biodiversity loss.
- Adverse impacts on cloud (mist) forests, tropical seasonally dry (deciduous) forests and shrublands, low-lying habitats (coral reefs and mangroves), and inland wetlands.
- Loss and retreat of glaciers would adversely impact runoff and water supply in areas where glacier melt is an important water source, thus affecting the seasonality of systems like *Paramos* lagoons that are rich in biodiversity.
- More frequent floods and droughts, with floods increasing sediment loads and causing degradation of water quality in some areas.
- Mangrove ecosystems will be degraded or lost by sea-level rise at a rate of 1–1.7% per year and will lead to decline in some fish species.
- Climate change could disrupt lifestyles in mountain villages by altering already marginal food production and the availability of water resources and the habitats of many species that are important for indigenous peoples.
- Climate change might have some beneficial effects on freshwater fisheries and acquaculture, although there could be some significant negative effects, depending on the species and on the specific climate changes at the local level.

Box 10. Biodiversity and Impacts of Climate Change in North America
[WGII TAR Sections 5.6.2.2.1, 6.3.6, 15.1.2, and 15.3.2, and RICC Section 8.3]

Regional Characteristics: The North American region is diverse in terms of its geological, ecological, climatic, and socio-economic structures. Highly urbanized and industrial zones, intensively managed agriculture, forests, and non-renewable resource extraction all represent large-scale highly managed resources and human-dominated ecosystems. Within this context, however, there are large areas of non-intensively managed ecosystems. Temperature extremes in the region span the range of -40 to +40°C. The Great Plains (including Canadian prairies) and southeastern United States experience more severe weather (e.g., thunderstorms, tornadoes, and hail) than any other region in the world. Virtually all sectors within North America are vulnerable to climate change to some degree in some subregions.

Important Features of Biodiversity: Non-forest terrestrial ecosystems are the single largest type of land surface cover (>51%) in North America. They are extremely diverse and include non-tidal wetlands (bogs, fens, swamps, and marshes), tundra, rangelands (grasslands, deserts, and savannas), and agricultural land (crop and pasture). Non-forest ecosystems are the source of most surface flow and aquifer recharge in the western Great Plains and the extreme northern regions of North America. North America contains ~17% of the world's forests and these forests contain about 14–17% of the world's terrestrial biospheric carbon. At mid-latitudes, site-specific conditions and history, human management, air pollution, and biotic effects (e.g., herbivory) may be much stronger controllers of forest productivity, decomposition, and carbon balance than climate change or CO_2 enrichment. Canada contains ~24% of the global total wetlands. There is strong evidence that there has been significant warming at high latitudes: Boreal forests are expanding north at a rate equal to about 100 km per °C; higher ground temperatures and deeper seasonal thawing in relatively warm discontinuous permafrost has led to some boreal forests in central Alaska being transformed into extensive wetlands during the past several decades; and, in the tundra, plant species composition (especially forbs and lichens) have changed.

The state of terrestrial wildlife in North America varies geographically, by taxa, and by habitat association. A minimum estimate of the number of species at risk can be found in Table 2. While the North American region has relatively few endemic species (relative to other regions), it does contain large populations of some migratory species such as waterfowl. Recent studies suggest climate-linked changes in the distributions of some butterflies, birds, and plants, and shifts in the timing of bird migrations, egg laying, and in plant phenologies and emergence of hibernating mammals.

Box 10. Biodiversity and Impacts of Climate Change in North America (continued)

Socio-Economic Linkages: Mid-latitude wetlands have been greatly affected by a variety of human activities over the last 200 years. More than 50% of the original wetlands in the United States have been destroyed for agriculture, impoundment, road building, and other activities and most of the remaining have been altered by harvest, grazing, pollution, hydrologic changes, and invasion by non-native species. High-latitude wetlands have had much lower levels of human disturbance. Rangelands provide a wide variety of goods and services, including forage, water, and habitat for wildlife and domestic animals, and open space for recreational activities. Recreational activity associated with forests contributes to income and employment in every forested region of North America. Consumptive and non-consumptive uses of wildlife provide billions of dollars to local economies in North America. Many indigenous communities undertake hunting, fishing, and other resource-based activities for subsistence and are already being affected by changes in wildlife harvesting opportunities and wage-based employment. Climate change is projected to affect wildlife numbers (especially those of migratory species) and habitats, thus affecting traditional patterns of wildlife harvesting, and traditional lifestyles would be at risk of disappearing. The tundra on the mainland is the home of the majority of the Inuit population. It also provides the major breeding and nesting grounds for a variety of migratory birds and the major summer range and calving grounds for Canada's largest caribou herd, as well as habitat for a number of plant and animal species critical to the subsistence lifestyles of indigenous peoples. The tundra on the mainland is projected to be substantially reduced, thus affecting indigenous peoples (see also Box 11).

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in North America

Projected impacts of climate change include:

- Snowmelt-dominated watersheds in western North America could experience earlier spring peak flows and possible reductions in summer flows leading to possible aquatic ecosystem impacts.
- Geographic ranges of species are expected to continue to shift northward and upward in altitude, but many species cannot move across the land surface as rapidly as climate is projected to change and/or there may be barriers to range shifts. The timing of migration and other phenological phenomena will also likely continue to change. The faster the rate of climate change, the greater the probability of ecosystem disruption and species extinction.
- Increased temperatures could reduce subarctic ecosystems. Loss of migratory wildfowl and mammal breeding and forage habitats may occur within the taiga/tundra, which is projected to nearly disappear from mainland areas. Parts of this area support plant and animal species critical to the subsistence lifestyles of indigenous peoples.
- Sea-level rise and increased frequency of storm surges would result in enhanced coastal erosion, coastal flooding, and loss of coastal wetlands, particularly in Louisiana, Florida, and much of the U.S. Atlantic coast. Approximately 50% of North American coastal wetlands could be inundated. In some areas, wetlands may be squeezed between advancing seas and engineered structures.
- El Niño events are linked to declines of fisheries off the west coast of North America and feeding areas for salmon may become less productive, potentially leading to reduced catches.
- Stream fish habitats are projected to decline across the United States by 47% for coldwater, 50% for coolwater, and 14% for warmwater species.
- Unique non-intensively managed ecosystems such as tundra, some coastal salt marshes, prairie wetlands, arid and semi-arid landscapes, and coldwater ecosystems are vulnerable and effective adaptation is unlikely.
- Climate change may cause changes in the nature and extent of several disturbance factors (e.g., fire, insect outbreaks) in forested areas. The area of boreal forest burned annually in western North America has doubled in the last 20 years, despite improved detection and suppression efforts, roughly in parallel with warming in the region. Climate change also appears to be accelerating the seasonal development of some insect species. Changes in ranges and/or outbreak frequency have been projected for a number of injurious insect pests. These changes could lead to changes in the underlying structure and species composition of some forested areas with possible concomitant changes to biodiversity.
- Invasive species are expected to increase and increase the vulnerability of existing ecosystems.

Box 11. Biodiversity and Impacts of Climate Change in the Polar Regions
[WGII TAR Sections 16.2.3.4 and 16.3.1-2, and RICC Sections 3.2 and 3.4]

Regional Characteristics: The Arctic and Antarctica contain ~20% of the world's land area. Although similar in many ways, the two polar regions are different in that the Arctic is a frozen ocean surrounded by land, whereas Antarctica is a frozen continent surrounded by ocean (IPCC reports include the sub-Antarctic islands in this region). The polar regions include some very diverse landscapes and are a zone marginal for many species; however, many organisms thrive in their terrestrial and marine ecosystems. Antarctica is the driest and the coldest continent and is devoid of trees. The Arctic includes the boreal forests, tussock grasslands, and shrublands.

Important Features of Biodiversity: Both the Arctic and Antarctica are very important for marine mammals including seals and whales, and many migratory bird species. Polar bears, caribou, and musk-oxen are characteristic terrestrial animals in the Arctic, as are the penguin species in Antarctica. The terrestrial ecosystems in Antarctica are comparatively simple, constrained by an exposed land area that is very cold. Only 2% of the Antarctic surface is not covered by ice. There are a number of microscopic plants that are found mainly in crevices and cavities of exposed rocks, and the poorly developed soil harbors bacteria, algae, yeast and other fungi, lichens, and even moss spore (though usually in a dormant stage). The coastal region is particularly hospitable to the vegetation of lichens and mosses. Meltwater in the area helps to support herbaceous species including grasses. On the Antarctic Peninsula and sub-Antarctic islands, some species of invertebrates survive in the harsh environment by super-cooling or anhydrobiosis mechanisms. The Dry Valleys are one of the world's most extreme desert regions.

Socio-Economic Linkages: Although the population in the Arctic is relatively small, most indigenous communities lead traditional lifestyles and are highly dependent on biodiversity for their survival. Changes in the distribution and abundance of sea and land animals will impact negatively on traditional lifestyles of native communities. On the other hand, if the climate ameliorates, conditions will favor the northward expansion of forestry and agriculture, with a consequential expansion of population and settlements. Indigenous communities, in which traditional lifestyles are followed, have little capacity and few options for adaptation to climate change.

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Polar Regions

Projected impacts of climate change include:

- Climate change in polar regions (especially in the Arctic) is expected to be among the greatest of any region on the Earth and will have major physical and ecological impacts.
- Climate change is likely to result in alterations to many ecosystems in the Arctic during the 21st century. Tundra could shrink by two-thirds; boreal forest could advance further to the north; and some of the northern wetlands and peatlands could dry, whilst others may appear as a result of changing hydrology and drainage conditions.
- Animals that migrate great distances, such as whales and seabirds, may be affected through changes in food availability during migration. Many of the world's shorebird species and other polar species breed on the Arctic tundra, which may be affected by changes in habitat distribution. Wildlife migration into the area will be limited by habitat availability.
- Some of the streams that currently freeze to their beds will retain a layer of water beneath the ice, which will be beneficial to invertebrates and fish populations. Thinner ice cover will increase the solar radiation penetrating to the underlying water, thereby increasing photosynthetic production of oxygen and reducing the potential for winter fish kills. However, a longer ice-free season will increase the depth of water mixing, and lead to lower oxygen concentrations and increased stress on coldwater organisms. Warming will lead to a shortened ice season and decreased ice-jam flooding, which will benefit the many northern communities located near river floodplains. In contrast, reductions in the frequency and severity of ice-jam flooding would have a serious impact on northern riparian ecosystems—particularly the highly productive river deltas, where periodic flooding has been shown to be critical to the survival of adjacent lakes and ponds.
- Permafrost will become warmer and is likely to reduce by 12–22% by the year 2050. Deeper seasonal thawing will improve the drainage conditions and stimulate the release of soil nutrients to biota. Drying or wetting associated with permafrost melt and drainage can be expected to reduce bryophyte communities (drying) or lead to an increase in their frequency where drainage is impeded. Equilibrium shift between moss, lichen, and herb communities can be expected.
- Less sea ice will reduce ice edges, which are prime habitats for marine organisms in the polar regions.

Box 11. Biodiversity and Impacts of Climate Change in the Polar Regions (continued)

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Polar Regions (continued)

- The decrease in the extent and thickness of sea ice may lead to changes in the distribution, age structure, and size of populations of marine mammals. In the Arctic, seal species that use ice for resting and polar bears that feed on seals are particularly at risk. In Antarctica, Crabeater seals and Emperor penguins that are dependent on sea ice will be disadvantaged. By contrast, Chinstrap penguins in open water may increase in number. Due to the close relationship between seasonal sea-ice cover and dominance of either krill or salps, marine mammals such as whales, seals, and seabirds that depend on krill will be disadvantaged. Due to the importance of krill to many food chains, whole food webs of marine ecosystems may be adversely affected by climate change and increased levels of ultraviolet-B (UV-B) radiation.
- Polar regions are highly vulnerable to climate change and have low adaptive capacity.

Box 12. Biodiversity and Impacts of Climate Change in Small Island States
[WGII TAR Sections 17.1-2 and RICC Section 9.3]

Regional Characteristics: The Small Island States considered here are mainly located in the tropics and the subtropics. These Small Island States span the ocean regions of the Pacific, Indian, and Atlantic as well as the Caribbean and Mediterranean seas. Many of these islands rarely exceed 3-4 m above present mean sea level; even on the higher islands, most of the settlements, economic activity, infrastructure, and services are located at or near the coast. They thus share many common features (i.e., small physical size surrounded by a large expanse of ocean, limited natural resources, proneness to natural disasters and extreme events), which serve to illustrate their vulnerability to the projected impacts of climate change.

Important Features of Biodiversity: Small islands are variable in their marine, coastal, and terrestrial biodiversity. Some are very rich. For example, coral reefs have the highest biodiversity of any marine ecosystem, with some 91,000 described species of reef taxa. Endemism among terrestrial flora is high in Fiji (58%), Mauritius (46%), Dominican Republic (36%), Haiti (35%), and Jamaica (34%). Contrastingly, other island ecosystems such as low-reef islands tend to have both low biodiversity and endemism. One of every three known threatened plants are island endemics; among birds, ~23% of island species are threatened, compared with only 11% of the global bird population.

Socio-Economic Linkages: Coral reefs, mangroves, and seagrasses are important ecosystems in many small islands and are significant contributors to the economic resource base of many of these countries. Although significant land clearance has been a feature of many Small Island States over decades of settlement, extensive areas of some islands (e.g., about half of the total land in Solomon Islands, Vanuatu, Dominica, and Fiji) are covered by forests and other woodlands. Forests also are of great socio-economic importance as sources of timber, fuel, and many non-wood products. The capacity of species and ecosystems such as mangroves to shift their ranges and locations in response to climate change will be hindered by land-use practices that have fragmented existing habitats.

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Small Island States

Projected impacts of climate change include:

- Coral reefs will be negatively affected by bleaching and by reduced calcification rates which can lead to the loss of many reef-associated communities and species. Consequently, loss of revenues from key sectors such as tourism and fisheries could be expected.
- Mangrove, seagrass beds, other coastal ecosystems, and the associated biodiversity would be adversely affected by rising temperatures and accelerated sea-level rise.
- Saltwater intrusion into freshwater habitats will affect their biodiversity.
- Increases in typhoon/hurricane frequency or wind speed could negatively impact some habitats.

Box 12. Biodiversity and Impacts of Climate Change in Small Island States (continued)

Impacts of Climate Change on Biodiversity and Vulnerable Ecosystems in Small Island States (continued)

- Inundation and flooding of low-lying forested areas in islands will lead to the loss of some endemic bird species, as the majority of threatened bird species are found in forested habitats. Impacts of climate change on these species are likely to be due to direct physiological stress and changes/loss in habitat caused by changes in disturbance regimes, such as fires.
- A rise in sea level will have a serious impact on atoll agroforestry and the pit cultivation of taro which are important for many island communities. Erosional changes in the shoreline will disrupt populations, and the combined effects of freshwater loss and increased storm surges will stress freshwater plants and increase vulnerability to drought.

7. Potential Impacts on Biodiversity of Activities Undertaken to Mitigate Climate Change

Mitigation is defined as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. Actions that reduce net greenhouse gas emissions reduce the projected magnitude and rate of climate change and thereby lessen the pressure on natural and human systems from climate change. Therefore, mitigation actions are expected to delay and reduce damages caused by climate change, providing environmental and socio-economic (including biodiversity) benefits. Some activities have positive or negative impacts on biodiversity, independent of their effect on the climate system. [SYR SPM, SYR Q6 and Q7, and WGIII TAR Glossary]

In this section, the biodiversity implications of climate change mitigation activities are addressed. Broader environmental and social implications are discussed in Section 9. These activities include, among others, carbon sequestration and emission avoidance from land management activities, including those addressed in Articles 3.3 and 3.4 of the Kyoto Protocol; increased energy efficiency or generation efficiency; increased use of low-carbon or carbon-free energy systems, including biomass energy, solar-, wind-, and hydropower; and biological uptake in the oceans. The IPCC Special Report on Land Use, Land-Use Change, and Forestry—which focused on issues related to land use and the Kyoto Protocol—is a primary source of information for this section. The Working Group III contribution to the Third Assessment Report is a primary source for mitigation activities discussion, but contains less information on biodiversity.

Forests, agricultural lands, and other terrestrial ecosystems offer significant carbon sinks mitigation potential through changes in land use (i.e., afforestation and reforestation), avoided deforestation, and agriculture, grazing land, and forest management. The estimated global potential of biological mitigation options is on the order of 100 Gt C (cumulative) by the year 2050, equivalent to about 10–20% of projected fossil-fuel emissions during that period, although there are substantial uncertainties associated with this estimate. The largest biological potential is projected to be in subtropical and tropical regions. [SYR SPM, SYR Q6 and Q7, and WGIII TAR Glossary]

The production of greenhouse gas offsets should be placed in the context of the many goods and services that ecosystems produce. Human demand for goods and services place pressures on biodiversity. Greenhouse gas offsets can compete with or complement other ecosystem uses and biodiversity conservation. [WGIII TAR Chapter 4 ES]

7.1. Potential Impact of Afforestation, Reforestation, and Avoided Deforestation on Biodiversity

The global mitigation potential of post-1990 afforestation, reforestation, and slowing deforestation activities is projected to be 60–87 Gt C on 700 Mha between 1995–2050, with 70% in tropical forests, 25% in temperate forests, and 5% in boreal forests. [WGII SAR Section 24.4.2.2 and WGII SAR Table 24-5]

Afforestation, reforestation, and avoided deforestation projects with appropriate management, selection criteria, and involvement of local communities can enhance conservation and sustainable use of biodiversity. There are management options to realize the synergies between carbon sequestration and biodiversity, such as adopting longer rotation periods, altering felling unit sizes, altering edge lengths, creating a multi-aged mosaic of stands, minimizing chemical inputs, reducing or eliminating measures to clear understorey vegetation, or using mixed species planting including native species. [LULUCF Section 2.5.1.1.1]

Afforestation, reforestation, and avoided deforestation projects may have off-site consequences, including implications for biodiversity. For example, conserving forests that would have otherwise have been deforested for agricultural land may displace farmers to lands outside the project's boundary. This has been termed "leakage." Projects may also yield off-site benefits, such as the adoption of new land management approaches outside a project's boundary through technology diffusion or the reduction of pressure on biologically diverse natural forests. [LULUCF Section 5.3.3]

7.1.1. Potential Impacts of Reducing Deforestation on Biodiversity

In addition to climate change mitigation benefits, slowing deforestation and/or forest degradation could provide substantial biodiversity benefits. Primary tropical forests contain an estimated 50–70% of all terrestrial species. Tropical forests are currently experiencing significant rates of deforestation (averaging 15 Mha annually during the 1980s, and emitting 1.6±1.0 Gt C yr^{-1}). Tropical deforestation and degradation of forests are major causes of global biodiversity loss. They also reduce the availability of habitats and cause local loss of species, population, and genetic diversity. The mitigation potential of slowing rates of tropical deforestation has been estimated to be about 11–21 Gt C over 1995–2050 on 138 Mha. [WGIII TAR Section 4.3.2, LULUCF Sections 1.4.1 and 2.5.1.1.1, and WGII SAR Section 24.4.2.2]

Projects to avoid deforestation in threatened or vulnerable forests that are biologically diverse and ecologically important can be of particular importance for biodiversity. Although any project that slows deforestation or forest degradation will help to conserve biodiversity, projects in threatened/vulnerable forests that are unusually species-rich, globally rare, or unique to that region can provide the greatest biodiversity benefits. Projects that protect forests from land conversion or degradation in key watersheds have potential to substantially slow soil erosion, protect water resources, and conserve biodiversity. Projects that are designed to promote reduced-impact logging as a carbon offset may produce fewer biodiversity ancillary benefits than forest protection (i.e., not logging) at the site level, but may provide larger socio-economic benefits to local owners and prove to be a more viable option, particularly in areas where the communities are largely dependent on the forest for their livelihood. Protecting the most threatened ecosystems does not always provide the greatest carbon benefits. In Brazil, for example, the least well-protected and most threatened types of forests are along the southern boundary of Amazonia, where reserve establishment is relatively expensive and forests contain less biomass (carbon) than in central Amazonia. Forest protection may also have negative social effects such as displacement of local populations, reduced income, and reduced flow of products from forests. Conflicts between protection of natural systems and other functions can be minimized by appropriate land use on the landscape and appropriate stand management and use of environmental and social assessments. [LULUCF Sections 2.5.1.1.1 and 5.5.1, and WGIII TAR Section 4.4]

Pilot projects that were designed to avoid emissions by reducing deforestation and forest degradation have produced marked environmental and socio-economic ancillary benefits, including biodiversity conservation, protection of watersheds, improved forest management and local capacity-building and employment in the local enterprises. Examples of avoided deforestation projects with ancillary biodiversity benefits can be found in Box 5.1 and Table 5.2 of the IPCC Special Report on Land Use, Land-Use Change, and Forestry (e.g., the Rio Bravo Conservation and Management Project in Belize). [LULUCF Section 5.5.1 and LULUCF Box 5-1]

7.1.2. Potential Impacts of Afforestation and Reforestation on Biodiversity

In the context of Article 3.3 of the Kyoto Protocol, both afforestation and reforestation refer to the conversion of land under other uses to forest. Afforestation is defined as the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources. Reforestation is defined as the direct human-induced conversion of non-forested land to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources on land that was forested but that has been converted to non-forested land. For the Kyoto Protocol's first commitment period (2008–2012), reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989.

Afforestation and reforestation projects can have positive, neutral, or negative impacts on biodiversity depending on the level of biodiversity of the non-forest ecosystem being replaced, the scale being considered (e.g., stand versus landscape), and other design and implementation issues (e.g., non-native versus native species, single versus multiple species). Afforestation and reforestation activities that replace native non-forest ecosystems (e.g., species-rich native grasslands) with non-native species, or with a single or few species of any origin, reduce the on-site biodiversity. Their landscape and regional-scale biodiversity impact can be negative or positive, depending on the context, design, and implementation. Afforestation and reforestation can be neutral, or can increase or benefit biodiversity when replacing a land use that is degraded with regard to biodiversity or promoting the return, survival, and expansion of native plant and animal populations. Where afforestation or reforestation is done to restore degraded lands, it is also likely to have other environmental benefits, such as reducing erosion, controlling salinization, and protecting watersheds. [LULUCF Sections 2.5.1, 2.5.2.2, 3.5, 3.6.1, and 4.7.2.4]

Afforestration that results in water use greater than that by the existing vegetation can cause significant reduction of streamflow, which could have a negative impact on in-stream, riparian, wetland, and floodplain biodiversity. For example, the water yield from catchments in South Africa was significantly reduced when they were planted with pines and eucalypts. [WGIII TAR Section 4.4.1 and LULUCF Section 4.7.2.4]

Although plantations usually have lower biodiversity than natural forests, they can reduce pressure on natural forests by serving as sources of forest products, thereby leaving greater areas for biodiversity and other environmental services. At the site level, plantations can negatively affect biodiversity if they replace species-rich native grassland, wetland, heathland, or shrubland habitats, but plantations of non-native or native species can be designed to enhance biodiversity by encouraging the protection or restoration of natural forests. For example, in Mpumalanga province of South Africa, expansion of commercial plantations (*Eucalyptus sp*. and pines) has led to significant declines in several endemic and threatened species of grassland birds and suppression of ground flora. Generally, plantations of few species, especially if they are non-native, are likely to have more limited fauna and flora than native forest stands. Multi-species, well-spaced plantations (subject to sustainable forest management) established at biodiversity-poor sites can enrich biodiversity. In addition, studies also show that even single-species tree plantations in the tropics/subtropics (e.g., *Eucalyptus grandis*) can, if appropriately spaced, allow the establishment of diverse native understorey species by providing shade and modifying microclimates. [WGIII TAR Section 4.4.1 and LULUCF Sections 2.5.1.1.1, 4.7.2.4, and 5.5.2]

7.2. Potential Impacts on Biodiversity of Land Management for Climate Mitigation Purposes

Land management actions to offset greenhouse gas emissions can have an impact on overall environmental quality including soil quality and erosion, water quality, air quality, and wildlife habitat; in turn, these can have impacts on terrestrial and aquatic biodiversity.

7.2.1. Potential Impacts of Agroforestry

Agroforestry activities can sequester carbon and have beneficial effects on biodiversity. Agroforestry (i.e., the combination of trees with agricultural crops to form complex, multi-species production systems) can increase carbon storage on the land where it replaces areas with only annual crops or degraded land. The ancillary benefits of agroforestry activities include increased food security, increased farm income, decreasing soil erosion, and restoring and maintaining above- and below-ground biodiversity. Where agroforestry replaces native forest, biodiversity is usually lost; however, agroforestry can be used to enhance biodiversity on degraded sites, often resulting from prior deforestation. Agroforestry systems tend to be more biologically diverse than conventional croplands, degraded grasslands or pastures, and the early stages of secondary forest fallows. Therefore, the challenge is to avoid deforestation where possible, and, where it cannot be avoided, to use local knowledge and species to create agroforestry habitats with multiple values to both the farmer and local flora and fauna. [LULUCF Fact Sheet 4.10]

7.2.2. Potential Impacts of Forest Management

Forest management activities that can be used to sequester carbon in above- and below-ground biomass and soil organic carbon may also have positive or negative effects on biodiversity. Examples of such activities include assisted regeneration, fertilization, fire management, pest management, harvest scheduling, and low-impact harvesting (see Box 13). [LULUCF Table 4.1]

7.2.3. Potential Impacts of Agriculture Sector Mitigation Activities

Activities and projects in the agricultural sector to reduce greenhouse gas emissions and increase carbon sequestration can promote sustainable agriculture, promote rural development, and may enhance or decrease biodiversity. There are a large number of agricultural management activities that can be used to sequester carbon in soils (i.e., intensification, irrigation, conservation tillage, erosion control, and rice management; see Box 14). They may have positive or negative effects on biodiversity, depending on the practice and the context in which it is applied. These activities include adopting farmer-centered participatory approaches and careful consideration of local or indigenous knowledge and technologies, promoting cycling and use of organic materials in low-input farming systems, and using agro-biodiversity such as the use of locally adapted crop varieties and crop diversification. Agricultural practices that enhance and preserve soil organic carbon can also lead to increases or decreases in CH_4 and N_2O emissions. [LULUCF Sections 2.5.1.1 and 2.5.2.4.2, LULUCF Table 4-1, and LULUCF Fact Sheets 4.1-4.5]

7.2.4. Potential Impacts of Grassland and Grazing Land Management

Activities and projects in grazing lands can increase carbon sequestration and may enhance or decrease biodiversity. Grasslands management activities that can be used to sequester carbon in soils include grazing management, protected grasslands and set-asides, grassland productivity improvements, and fire management (see Box 15). Most promote biodiversity; some such as fertilization may decrease on-site biodiversity. [LULUCF Table 4.1]

7.3. Potential Impacts of Changing Energy Technologies on Biodiversity

Mitigation options in the energy sector that may affect biodiversity include increasing the efficient use of fuelwood and charcoal as energy sources; renewable energy sources such as biomass energy; wind-, solar-, and hydropower; and injection of CO_2 into underground reservoirs and the deep ocean. Increased efficiency in the generation or use of fossil-fuel-based energy will reduce fossil-fuel use, thereby reducing the biodiversity impacts caused by the mining, extraction, transport, and combustion of fossil fuels.

7.3.1. Efficient Wood Stoves and Biogas for Cooking and their Potential Impacts on Biodiversity

Fuelwood conservation measures, such as efficient cookstoves and biogas, have the potential to reduce pressure on forests and thus conserve biodiversity. Fuelwood in many regions is traditionally the dominant biomass extracted from forests, with

Box 13. Forest Management Activities

Improved regeneration is the act of renewing tree cover by establishing young trees naturally or artificially—generally, before, during, or promptly after the previous stand or forest has been removed. Forest regeneration includes practices such as changes in tree plant density through human-assisted natural regeneration, enrichment planting, reduced grazing of forested savannas, and changes in tree provenances/genetics or tree species. Regeneration techniques can influence species composition, stocking, and density and can increase or decrease biodiversity. [LULUCF Fact Sheet 4.12]

Fertilization, which is the addition of nutrient elements to increase growth rates or overcome a nutrient deficiency in the soil, is unlikely to result in positive environmental benefits if not done optimally. In some cases it may have several negative environmental impacts (e.g., increased emissions of nitrous oxide (N_2O) and nitrogen oxides (NO_x) to air, ground, and water and changes in soil processes). [LULUCF Fact Sheet 4.13]

Forest fire management—which is used to regulate the recycling of forest biomass from fires, maintain healthy forest ecosystems, and reduce emissions of greenhouse gases—has environmental impacts that are difficult to generalize because in some ecosystems fires are an essential part of the succession cycle. Restoring near-historical fire regimes may be an important component of sustainable forestry but may also require practices such as access (road construction) that may create indirect deleterious environmental effects. [LULUCF Fact Sheet 4.14]

Pest management is the application of strategies to maintain a pest's population within tolerable levels. Where biocides are used to control pests, this activity may result in reduced biodiversity. On the other hand, where pest management prevents large-scale forest die-off, it can increase landscape, recreational, watershed, and other benefits. [LULUCF Fact Sheet 4.15]

Harvest quantity and timing, including pre-commercial and commercial thinnings, selection, and clear-cut harvesting—will affect the quality and quantity of timber produced, having implications for carbon storage and biodiversity. Harvest scheduling can have positive or negative impacts on biodiversity, recreation, and landscape management. [LULUCF Fact Sheet 4.16]

Reduced-impact harvesting minimizes disturbance to soil and damage to the remaining vegetation and will, in most cases, have positive environmental benefits regarding biodiversity, recreation, and landscape management. [LULUCF Fact Sheet 4.17]

significant implications for biodiversity. The fuelwood used from forests is largely for subsistence activities such as cooking and can be reduced substantially through improved wood-burning stoves and more efficient charcoal-making technology. Wood is also used to generate charcoal for industrial applications (e.g., in Brazil). Fuelwood and charcoal consumption in tropical countries is estimated to increase from 1.3 billion m^3 (0.33 Gt C yr^{-1}) in the year 1991 to 3.4 billion m^3 (0.85 Gt C yr^{-1}) by the year 2050. Biogas derived from anaerobic decomposition of crop waste and cattle dung can be a potential substitute for fuelwood at the household or community levels. Thus, mitigation activities aimed at reducing fuelwood use for cooking and heating through efficiency improvements (improved stoves and biogas) can significantly reduce pressure on forests and thereby contribute to biodiversity conservation. [WGIII TAR Section 3.8.4.3.2 and WGII SAR Sections 15.3.3 and 22.4.1.4]

7.3.2. *Potential Impacts of Increased Use of Biomass Energy*

The potential mitigation and socio-economic benefits of modern bioenergy technologies are large, but without appropriate site selection and management practices biodiversity could be threatened. Biomass energy from plantations and use of residues and thinning of existing forests could reduce CO_2 emissions by displacing the use of fossil fuels. Positive environmental impacts can include reduced emission of atmospheric pollutants, reclamation of degraded land, and potentially a reduction of pressure on forests to the extent that fuelwood derived from such sources is replaced by other energy sources. However, there is concern over short- and long-term environmental and socio-economic effects of large-scale biofuel production, including degradation of soil and water quality, poor resilience of monoculture plantations, and implications of biofuels for biodiversity, sustainability, and amenity. Large-scale bioenergy plantations that generate high yields with production systems that resemble intensive agriculture would have adverse impacts on biodiversity where they replace systems with higher biological diversity. However, small-scale plantations on degraded land or abandoned agricultural sites would have environmental benefits. Plantations with only a small number of species typically achieve the highest yields and the greatest efficiency in management and harvest, but good plantation design could include set-asides for native flora and fauna and blocks with

Box 14. Agricultural Management Activities

Agricultural intensification practices that enhance production and the input of plant-derived residues to soil include crop rotations, reduced bare fallow, use of cover crops, high-yielding varieties, integrated pest management, adequate fertilization, organic amendments, irrigation, water table management, and site-specific management. These have numerous ancillary benefits including an increase in food production, erosion control, water conservation, improved water quality, and reduced siltation of reservoirs and waterways benefiting fisheries and biodiversity. However, soil and water quality is adversely affected by indiscriminate use of chemical inputs and irrigation water, and the increased use of nitrogen fertilizers will increase fossil energy use and may increase N_2O emissions. [LULUCF Fact Sheet 4.1]

Irrigation, which is widely used in many parts of the world with highly variable seasonal rainfall, can enhance biomass production in water-limited agricultural systems, but increases the risk of salinization and often diverts water from rivers and flood flows with significant impacts on the biodiversity of rivers and floodplains. [LULUCF Fact Sheet 4.2]

Conservation tillage denotes a wide range of tillage practices, including chisel-plow, ridge-till, strip-till, mulch-till, and no-till to conserve soil organic carbon. Adoption of conservation tillage has numerous ancillary benefits, including control of water and wind erosion, water conservation, increased water-holding capacity, reduced compaction, increased soil resilience to chemical inputs, increased soil and air quality, enhanced soil biodiversity, reduced energy use, improved water quality, and reduced siltation of reservoirs and waterways with associated benefits for fisheries and biodiversity. In some areas (e.g., Australia), increased leaching from greater water retention with conservation tillage could cause downslope salinization. [LULUCF Fact Sheet 4.3]

Erosion control practices—which include water conservation structures, vegetative strips used as filter strips for riparian zone management, and shelterbelts for wind erosion control—can reduce the global quantity of soil organic carbon displaced by soil erosion, which has been estimated to be in the range of 0.5 Gt C yr^{-1}. There are numerous ancillary benefits and associated impacts, including increased productivity, improved water quality, reduced use of fertilizers (especially nitrates), decreased siltation of waterways, reduced CH_4 emissions, associated reductions in risks of flooding, and increased biodiversity in aquatic systems, shelter belts, and riparian zones. [LULUCF Fact Sheet 4.4]

Rice management strategies—which include irrigation, fertilization, and crop residue management—affect CH_4 emissions and carbon stocks. There is limited information on the impacts of greenhouse gas mitigation rice management activities on biodiversity. [LULUCF Fact Sheet 4.5]

different clones and/or species. An option is to produce biofuels as an integrated part of forest management with timber and pulpwood production. Harvest residues from different parts of harvest operations like thinning and clear-felling play an important role in the production of biofuels. The impact on biodiversity depends on how these management practices are performed. The variety of species in biofuels plantations falls between that for natural forest and annual row crops. Research on multi-species plantations and management strategies and thoughtful land-use planning to protect reserves, natural forest patches, and migration corridors can help address biodiversity issues. Concerns regarding food supply and access to land for local communities could be addressed through community-scale plantations. Such plantations could feed small-scale conversion technologies, meet local fuel and timber needs, and provide employment, electricity, and liquid fuel products in rural areas. Barriers to community-scale biofuel systems include a lack of institutional and human capital to ensure biofuel projects that meet local needs rather than foreign investors' carbon credit priorities. The on-site impacts of biomass energy include local environmental and socio-economic benefits of the forestry and energy-generation components of a bioenergy project. [WGIII TAR Section 4.3.2.1, WGIII TAR Table 3.31, LULUCF Sections 4.5.3, 4.5.5, and 5.5.3, and WGII SAR Section 25.5]

7.3.3. Potential Impacts of Hydropower

Large-scale hydropower development can have high environmental and social costs such as loss of biodiversity and land, generation of CH_4 from flooded vegetation, and displacement of local communities. Hydropower could make a substantial contribution to reducing the greenhouse gas intensity of energy production. Currently, ~19% of the world's electricity is produced from hydropower. While a large proportion of hydropower potential in Europe and North America is already tapped, a smaller proportion of the larger potential in developing countries has been tapped. Greenhouse gas emissions from most hydropower projects are relatively low, with the one important major exception possibly being large shallow lakes in heavily vegetated tropical areas where emissions from decaying vegetation can be substantial. Evaluation of the social and environmental implications of hydropower developments on a case-by-case basis can minimize unwanted effects. For example, dam reservoirs result in loss of land, which may

Box 15. Grazing Land Management Activities

Grazing management is the management of the intensity, frequency, and seasonality of grazing and animal distribution. Since overgrazing is the single greatest cause of degradation in grasslands, improved grazing management can increase carbon pools, reduce soil erosion, and reduce CH_4 emissions by reducing animal numbers and improving intake quality. In some grasslands, grazing can result in changes in species composition toward those with large root systems, increasing carbon storage in the surface soil layers. Where such species are already dominant, heavy grazing will reduce soil carbon levels. Heavy grazing can increase opportunities for the establishment of unpalatable woody shrubs, resulting in increased biomass carbon but lower grazing utility. [LULUCF Fact Sheet 4.6]

Protected grasslands and set-asides created by changing land use from cropping or transforming degraded land to perennial grasslands can increase above- and below-ground biomass. Associated impacts can include reduced crop production, increased animal production if the land is grazed, increased biodiversity of native grass ecosystems if they are reestablished, increased wildlife habitat, reduced erosion, etc. [LULUCF Fact Sheet 4.7]

Grassland productivity improvement includes the introduction of nitrogen-fixing legumes and high-productivity grasses and/or addition of fertilizers, leading to increases in biomass production and soil carbon pools. This has particular potential in the tropics and arid zones, which are often nitrogen- and other nutrient-limited. While increased agricultural productivity is likely, so is some loss of biodiversity from native grassland ecosystems. Increased legume components are likely to increase acidification rates in tropical and temperate pastures, through increased leaching of nitrate and increased productivity, and may result in more N_2O emissions than from native grass pastures. Optimization of fertilizer application rates can reduce these risks and reduce off-site impacts from nutrient leaching and pollution of waterways and groundwater. [LULUCF Fact Sheet 4.8]

Fire management in grasslands entails changing burning regimes to alter the carbon pool in the landscape. Reduced fire frequency or fire prevention tends to increase mean soil biomass and litter carbon levels, and increases density of woody species in many landscapes. In many ecosystems, fauna and flora species are fire-dependent, thus fire reduction through fire management practices may result in local extinction or decline of species. [LULUCF Fact Sheet 4.9]

result in loss of local terrestrial biodiversity, and dams may prevent fish migration (which is an essential part of life cycle of some fish species) and stop water flow, as well as reduce aquatic and terrestrial biodiversity as a result of changing the timing, flow, flood pulse, and oxygen and sediment content of water. Disturbing aquatic ecosystems in tropical areas can induce indirect environmental effects; for example, increased pathogens and their intermediate hosts may lead to an increase in human diseases such as malaria, *Schistosomiasis*, *Filariasis,* and yellow fever. Well-designed installations (e.g., using modern technologies that cascade the water through a number of smaller dams and power plants) may reduce the adverse environmental impacts of the system. Small- and micro-scale hydroelectric schemes normally have low environmental impacts. [WGIII TAR Section 3.8.4.3.1 and WGII SAR Section 19.2.5.1]

7.3.4. Potential Impacts of Windpower

Windpower has mitigation potential and, if appropriately sited, has limited impact on wildlife. Public acceptability of windpower is influenced by noise, the visual impact on the landscape, and the disturbance to wildlife (birds). The limited evidence of the impact of turbines on wildlife suggests it is generally low and species-dependent; however, a case-by-case analysis may be desirable. [WGII SAR Section 19.2.5.3]

7.3.5. Potential Impacts of Solar Power

Land use, water consumption, compatibility with desert species, and aesthetics are the principle environmental considerations for solar thermal-electric technologies. Because large plants will be best located in desert regions, water consumption is likely to be the most serious environmental consideration. [WGII SAR Section 19.2.5.4.2]

7.3.6. Potential Impacts of Carbon Storage

The technology to capture CO_2 from flue gases or from the fuel gas is available, and CO_2 can then be stored in exhausted oil and gas wells, saline aquifers, or the deep ocean. The key environmental issues associated with saline aquifers include CO_2 escape, dissolution of host rock, sterilization of mineral resources, and effects on groundwater. Not much is known about the environmental effects of storing CO_2 in the oceans (e.g., the effects on marine life). Preliminary studies indicate that ecological perturbations would be confined to the release area. [WGIII TAR Section 3.8.4.4 and WGII SAR Section 19.2.3.3]

7.4. Potential Impacts of Enhanced Biological Uptake in Oceans

Marine ecosystems may offer mitigation opportunities for removing CO_2 from the atmosphere, but the potential and implications for biodiversity are not well understood. Experimental additions of iron to nutrient-rich but iron-poor (e.g., Southern Ocean) regions of the ocean have produced phytoplankton blooms and increased oceanic uptake of CO_2 into surface waters for a period of about a week. The consequences of larger, longer term introductions of iron remain uncertain. Concerns associated with these efforts are the differential impact on different algal species, the impact on concentrations of dimethyl sulfide in surface waters, and the potential for creating anoxic regions at depth—all of which are likely to affect biological diversity negatively. [WGIII TAR Section 4.7]

8. Adaptation Activities and Biodiversity

Climate change is occurring and it has been observed to affect ecosystems and their biodiversity. This means mitigation options (see Section 7) alone are not adequate to avoid impacts of climate change. Thus, adaptation activities (projects and policies) specifically designed to reduce the impact of climate change have to be considered along with mitigation options. Adaptation options can be applied to both intensively and non-intensively managed ecosystems. Adaptation activities can have adverse or beneficial impacts on biodiversity.

Irrespective of climate change, conservation and sustainable use plans for ecosystems and biodiversity (including those outside formal reserves) are implemented in many parts of the world. These plans may not have considered the current and projected climate change and might need to consider doing so.

It is also possible that the current effort to conserve biodiversity and sustainably use ecosystems can affect the rate and magnitude of projected climate change.

8.1. Potential Adaptation Options to Alleviate Climate Change Impacts on Ecosystems and Biodiversity

Many of the adaptation activities that are listed in IPCC reports are very generic, as reflected in this section. Unfortunately, impacts of listed adaptation options are rarely considered. There are limited adaptation options for some ecosystems (e.g., coral reefs and high-latitude and/or high-altitude areas) because of their sensitivity and/or exposure to climate change. For some of these systems (e.g., coral reefs), adaptation options may include limiting other pressures (e.g., pollution and sediment runoff). Conservation of biodiversity is strongly targeted at protected areas. Yet, adaptation options can also be effective outside these areas. Appropriate monitoring systems will help detect potential trends in changes in biodiversity and help to plan adaptive management. [WGII TAR Section 14.2.1.5]

In conservation planning, it may be necessary to realize that certain genotypes, species, and ecosystems could no longer be conserved in a particular area or region due to the impacts of climate change, thus efforts should be directed towards actions to increase the resiliency of biodiversity for future climate change, including:

- ***Networks of reserves with connecting corridors provide dispersal and migration routes for plants and animals.*** The placement and management of reserves (including marine and coastal reserves) and protected areas will need to take into account potential climate change if the reserve system is to continue to achieve its full potential. Options include corridors, or habitat matrices, that link currently fragmented reserves and landscapes by providing potential for migration. [WGII TAR Section 5.4.4]
- ***There are several other design opportunities to increase the resilience of nature reserves.*** These measures include maintaining intact natural vegetation along environmental gradients (e.g., latitude and altitude gradients, soil moisture gradients), providing buffer zones around reserves, minimizing habitat fragmentation and road-building, and conserving genetic diversity within and among populations of native species. Protection of major biodiversity "hot spots" could halt much of the current and projected mass extinction, but this is threatened by climate change. Ecotones serve as repository regions for genetic diversity. Additional conservation of biodiversity in these regions is therefore an adaptation measure. [WGII TAR Section 19.3]
- ***Captive breeding for animals, ex situ conservation for plants, and translocation programs can be used to augment or reestablish some threatened or sensitive species.*** Captive breeding and translocation, when combined with habitat restoration, may be successful in preventing the extinction of small numbers of key selected taxa under small to moderate climate change. Captive breeding for reintroduction and translocation is likely to be less successful if climate change is more dramatic as such change could result in large-scale modifications of environmental conditions, including the loss or significant alteration of existing habitat over some or all of a species' range. Further, it is technically difficult, often expensive, and unlikely to be successful in the absence of knowledge about the species' basic biology and behavior. [WGII TAR Section 5.4.4]
- ***Some natural pest control, pollination, and seed dispersal services provided by wildlife can be replaced, but the alternatives may be costly.*** There are many examples of species introduced to provide ecosystem services such as soil stabilization, pollination, or pest control. Loss of natural biological control species could also be compensated by the use of pesticides and herbicides. While replacing these services may sometimes be technically possible, it

could also be costly and lead to other problems. For example, introduction of a pollinator or a pest control may itself result in a pest, and use of pesticides may cause soil and water pollution. In other cases, such as biogeochemical cycling, such services would be very difficult to replace. [WGII TAR Sections 5.4.4 and 5.7, and WGII SAR Section 25.4]

8.2. Consequences of Adaptation Activities on Ecosystems and Biodiversity

Some adaptation activities for climate change could have both beneficial and adverse impacts on biodiversity, varying in different regions. There are a number of potential adaptation activities that can be effective but can affect conservation and sustainable use of biological diversity. Adaptation activities can also threaten biodiversity either directly (e.g., through the destruction of habitats) or indirectly (e.g., through the introduction of new species or changed management practices). Integrated land and water management can provide many of the adaptation activities. Some examples of adaptation activities and their potential impact on biodiversity follow:

- ***Integrated land and water management (or landscape management)*** options include removing policy distortions that result in loss and or unsustainable use of biodiversity; developing and establishing a methodology that would allow examination of tradeoffs between meeting the human needs and conservation and sustainable use goals; establishing extensive land management programs; planting to overcome land and water degradation; controlling invasive species; cultivating some wild food and medicinal species that would also capture some of the endemic species genetic variability; and monitoring programs involving the local community to check that disease, pest, and invasive species have not migrated, that the ecosystem functions and process have not been lost or detrimentally affected, and that the animals have appropriate migration routes in response to the changing climatic zones. [WGII TAR Sections 4.4.2, 4.6.2, 5.4.4, 5.5.4, 5.6.4, 6.5.1, 10.2.1.5, 11.3, 12.4.8, 12.5.10, 12.8, 14.1.3.1, 14.2.1.5, 15.3, 16.3.2, and 17.3, WGII TAR Figure 5-1, and SYR Q7.8 and Q8.4]
- ***Integrated approach to coastal fisheries management, including the introduction of aqua- and mariculture, could reduce the pressures on some coastal fisheries.*** Development of mariculture and aquaculture as a response to the impacts on coastal fisheries is a possible adaptation option. Aqua- and mariculture would reduce the impact on the remaining coastal systems, but may be best implemented when considered as part of integrated approach to coastal management under climate change; however, there are examples of aqua- and mariculture having had negative impacts on local biodiversity in shallow marine waters, lakes, and rivers and human societies that depend on them. [WGII TAR Section 6.6.4 and WGII SAR Section 16.1]
- ***Integrated approaches aimed at enhancing sustainable agriculture and rural development simultaneously could enhance resilience of biodiversity to climate change.*** Specific land-use activities to achieve sustainable agriculture include appropriate management of agricultural production systems; improved shifting cultivation with sufficient fallow periods, diversification of cropping systems, maintaining continuous ground cover, and nutrient restoration; and agroforestry systems that involve various combinations of woody and herbaceous vegetation with agricultural crops. Such activities could result in multiple agronomic, environmental, and socio-economic benefits, reduce greenhouse gas emissions, and conserve biodiversity. [WGIII TAR SPM, LULUCF Section 2.5, and LULUCF Fact Sheet 4.11]
- ***Moving species to adapt to the changing climate zones is fraught with scientific uncertainties.*** Special attention may be given to poor dispersers, specialists, species with small populations, endemic species with a restricted range, peripheral populations, those that are genetically impoverished, or those that have important ecosystem functions. These species may be assisted for a time by providing natural migration corridors (e.g., by erecting reserves of a north-south orientation), but many may eventually require assisted migration to keep up with the speed with which their suitable habitats move with climate change. The consequences of invasive organisms cannot be predicted; many surprises would be expected. In aquatic systems, the case has been made that managing with non-natives increases the instability of the fish community, creates fish management problems, and includes many unexpected consequences. Introducing a new biota on top of a regional biota that is having increasing problems itself from warming climates will likely be a controversial adaptation. [WGII TAR Section 5.7.4 and WGII SAR Section 1.3.7]
- ***Greater use of pesticides and herbicides in response to new pest species may lead to damage to existing plant and animal communities, to water quality, and to human health.*** Climate change could affect many of these systems by decoupling predators from their prey and parasites from their hosts. Studies in North America project reductions in the extent of distribution and size of some of the species feeding on pests in forest, grassland, and agricultural ecosystems. Human responses to climate change may also contribute synergistically to existing pressures; for example, if new pest outbreaks are countered with increased pesticide use, non-target species might have to endure both climate- and contaminant-linked stressors. In addition, non-target species could include natural predators of other pests thus creating more problems. [WGII TAR Sections 5.4.2, 5.4.3.3, and 5.4.4]

- ***Increased demand for water use due to projected changes in socio-economic conditions and warmer temperatures—and exacerbated by decreased precipitation in some regions—is likely to increase the opportunity cost of water and possibly reduce water availability for wildlife and non-intensively managed ecosystems.*** However, in many regions, one adaptation strategy to climate-induced changes in water demand is to increase water-use efficiency, although it may be hard to implement. [WGII TAR Section 5.3.4]
- ***Physical barriers built as adaptation measures to cope with present climate variability (e.g., storm surges, floods) may lead to local loss of biodiversity and may result in maladaptations for future climate change.*** In some cases, small islands may be destroyed to obtain construction material for coastal protection. There are other potential options available that include enhancement and preservation of natural protection (e.g., replanting of mangroves and protection of coral reefs), use of softer options such as artificial beach nourishment, and raising the height of the ground of coastal villages. A specific form of this enhanced protection could include the strategic placement of artificial wetlands. Other options include the application of "precautionary" approaches—such as the enforcement of building setbacks, land-use regulations, building codes, and insurance coverage—and traditional, appropriate responses (e.g., building on stilts and the use of expandable, readily available indigenous building materials), which have proven to be effective responses in many regions in the past. [WGII TAR Sections 17.2.3 and 17.2.8]

8.3. Synergies between Conservation and Sustainable Use of Biodiversity and Climate Change

Actions taken to conserve and sustainably use biodiversity for reasons other than climate change could predominantly in a positive way affect the amount or rate of climate change and affect the ability of humans to adapt to climate change. Specific examples include:

- ***Areas allocated to conserve biodiversity represent long-term stores of carbon.*** Normally, relatively mature ecosystems are preferred for conservation purposes, and they are usually managed to reduce the likelihood of disturbance, thus minimizing human activities that could release stored carbon. As such, conservation reserves represent a form of avoided deforestation or devegetation. [LULUCF Sections 2.3.1 and 2.5.1]
- ***Maintenance of biodiversity leads to the protection of a larger gene pool from which new genotypes of both domesticated and wild species adapted to changed climatic and environmental conditions can arise.*** Conservation reserves can contribute to the maintenance of a diverse gene pool, but there are also significant contributions from native species growing among agricultural land or in pastures. [WGII TAR Sections 5.3.3, 6.3.7, 14.2.1, and 19.3.3]
- ***The maintenance of biodiversity requires natural disturbance regimes while management for maximal carbon storage tends to avoid disturbance.*** Conservation of the broadest possible range of ecosystems requires that natural ecosystem dynamics continue. Some ecosystems with high carbon content are therefore allowed to be disturbed, resulting in carbon released to the atmosphere. Also ecosystems with low carbon content should be conserved. On the other hand, optimal carbon sequestration could require planting with fast-growing species or eliminating disturbance such as fires. Thus, conservation and sustainable use of biodiversity is not often consistent with high carbon storage goals simultaneously on the same piece of land. [LULUCF Section 2.5.1]

9. Approaches that can be Used to Assess the Impacts of Climate Change Adaptation and Mitigation Activities on Biodiversity and Other Aspects of Sustainable Development

There are potential synergies and tradeoffs between climate change adaptation and mitigation activities (projects and policies) and the conservation and sustainable use objectives of UNCBD, as well as other aspects of sustainable development. Some critical factors affecting sustainable development contributions of activities to mitigate and adapt to climate change include institutional and technical capacity to develop and implement guidelines and procedures; extent and effectiveness of local community participation in development, implementation, and distribution of benefits; and transfer and adoption of technology. Existing project-, sectoral-, and regional-level environmental and social impact assessments, as applied in many countries, can be adapted and used to assess the impacts of mitigation and adaptation activities on biodiversity and other aspects of sustainable development. [WGIII TAR SPM, LULUCF SPM para90, and LULUCF Sections 2.5 and 5.6.4]

The environmental and socio-economic impacts of climate change adaptation and mitigation activities can be assessed through project- and strategic-level (sectoral and regional) environmental and social impact assessments. Best-practice environmental and social impact assessments, which incorporate participatory processes, provide options for decisionmakers about the potential environmental and societal risks and impact of a project or policy change, as well as examining alternatives and mitigative measures. Existing assessment methodologies, which may need to be adapted to assess the full range of climate mitigation and adaptation activities, can include biodiversity concerns and other aspects of sustainable development, including employment, human health, poverty, and equity. [LULUCF Section 2.5]

A wide range of decision analytic frameworks can be used to evaluate climate change adaptation and mitigation activities,

but are rarely used. The diverse set of decision analytical frameworks includes decision analysis, cost-benefit analysis, cost-effectiveness analysis, and the policy exercise approach. There are certain features (e.g., sequential decisionmaking and hedging), specific versions (e.g., multi-criteria analysis), distinctive applications (e.g., risk assessment), or basic components (multi-attribute utility theory) of decision analysis that are all rooted in the same theoretical framework. Decision analysis, which may prove particularly attractive for sectoral and regional adaptation assessments, can be performed with single or multiple criteria, with multi-attribute utility theory providing the conceptual underpinnings for the latter. Decision analysis—adapted to managing technological, social, or environmental hazards—constitutes part of risk assessment. [WGII TAR Section 1.1 and WGIII TAR Section 2.5]

Criteria and indicators consistent with national sustainable development objectives could be developed and used for assessing and comparing the impacts of adaptation and mitigation activities on biodiversity and other aspects of sustainable development. An ideal set of indicators would feature many of the same general characteristics as an ideal accounting system: transparency, consistency, comparability, completeness, and accuracy. While no comprehensive set of indicators with these characteristics currently exists for the suite of policies and measures that could be used to adapt to or mitigate climate change, several approaches are being developed for related purposes that nations might adapt to gauge the implications of adaptation and mitigation activities on biodiversity and other aspects of sustainable development [LULUCF Section 2.5], for example:

- ***Compatibility with internationally recognized principles and indicators of sustainable development and consistency with nationally defined sustainable development and/or national development goals and objectives***—Governments may wish to ensure that climate change adaptation and mitigation activities are consistent with, and supportive of, national sustainability goals. The broad set of national-level indicators being developed under the coordination of the United Nations Commission on Sustainable Development (UNCSD) may be useful to governments seeking to develop indicators with which to assess such consistency. The UNCSD developed social, economic, and environmental indicators within a “Driving Force-State-Response” framework—each with a methodology for use at the national level on the understanding that countries would chose from among the indicators those that are relevant to their national priorities, goals, and targets for a series of program areas including those of particular relevance to LULUCF policies and measures and biodiversity (e.g., combating deforestation), managing fragile ecosystems, combating desertification and drought, and the conservation of biological diversity. The Organisation for Economic Cooperation and Development (OECD) has developed a core set of environmental performance indicators—based on their policy relevance, analytical soundness, and measurability—for a number of issues, such as forest resources, soil degradation, and biological diversity, using a similar “pressure-state-response” model. The European Union (EU) also is developing a set of indicators for human activities that affect the environment for areas including climate change, loss of biodiversity, and resource depletion. A key question is the degree to which the UNCSD, OECD, or EU sets of national- and sectoral-level indicators can be adapted and implemented to assess the implications of adaptation and mitigation activities.
- ***Consistency with internationally recognized criteria and indicators for sustainable forest management and agriculture***—Several intergovernmental efforts have been initiated to develop criteria and indicators for sustainable forestry (e.g., the Helsinki, Montreal, Tarapota, and International Tropical Timber Organization Processes) and agriculture (e.g., Food and Agriculture Organisation). These criteria and indicators need to be adapted and further developed in order to provide better guidance at the local level and with regard to agricultural and forestry management practices in different regions. These criteria and indicators are generally moving beyond a narrowly defined focus on the productivity of timber, other commercial forest products, food, and fodder to incorporate ecological and social dimensions of sustainability such as: (i) conservation of biological diversity, (ii) maintenance of forest ecosystem health and vitality, (iii) maintenance of forests, pastures, and agricultural land contribution to global carbon cycles, (iv) shifting cultivation and agro-pastoral systems, (v) integrated soil and water management, and (vi) maintenance and enhancement of long-term multiple socio-economic benefits from forest and agricultural lands to meet societal needs.

The capacity of countries to implement adaptation and mitigation activities can be enhanced when climate policies are integrated with national development policies that include economic, social, and environmental dimensions. The linkages among local, regional, and global environmental issues (including conservation and sustainable use of biodiversity) and their relationship to meeting human needs offer opportunities to capture synergies in developing response options and reducing vulnerability to climate change, although tradeoffs between issues may exist. The successful implementation of greenhouse gas mitigation and adaptation options would need to overcome technical, economic, political, cultural, social, behavioral, and/or institutional barriers. [SYR SPM and SYR Q7 and Q8]

10. Identified Information and Assessment Gaps

These categories are in the context of impacts, adaptation, and mitigation options for climate change on biodiversity and the feedbacks for changes in biodiversity on climate change.

To answer — What is the impact of climate change on biodiversity and the effect of changes in biodiversity on climate change:

- Improvement of regional-scale climate models coupled with transient ecosystem models that deal with multiple pressures with appropriate spatial and temporal resolution and that include spatial interactions between ecosystems within landscapes.
- Development of monitoring systems, using multiple taxa, to assist in the detection of changes in ecosystems and biodiversity within them, and attribution of such changes to climate change (monitoring within protected areas—where the influence of non-climatic pressures are negligible—may be particularly important).
- Enhanced understanding of the relationship between biodiversity, ecosystem structure and function, and dispersal and/or migration through fragmented landscapes.
- Assessment of all the relevant literature to deal with climate change and biodiversity as well as the other pressures.
- Development and use of detailed and reliable regional scenarios of climate change in vulnerability analysis.

To answer — What is the impact of mitigation and adaptation activities for climate change on biodiversity:

- Evaluation of case studies (to gain experience) that deal with mitigation (including those in marine environments and carbon sequestration projects) and adaptation projects on biodiversity.
- Assessment of the impact of conservation and sustainable use of biodiversity on climate change.
- Development of basic understanding of and policies for the potential impacts of conservation and sustainable use activities on climate change (local, regional, and possibly global).

To answer — The potential for the conservation and sustainable use of biological diversity to contribute to climate change adaptation measures:

- Identification of biodiversity conservation and sustainable use activities and policies that would beneficially affect climate change adaptation and mitigation options.

To develop tools, indicators, and approaches:

- Adaptation of project-, sector-, and regional-level environmental, socio-economic assessment tools, and further development of a set of criteria and indicators to assess (quantitatively and qualitatively) the synergies and tradeoffs between climate change adaptation and mitigation options and sustainable development.

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Appendix A

LIST OF RELEVANT LITERATURE RELATED TO BIODIVERSITY AND CLIMATE CHANGE PUBLISHED SINCE 1999–2000

The 1999–2000 literature is only included if it has not already been assessed in the TAR. Some regional literature is also included. Some pre-1999 references have been added in response to government/expert review comments.

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Appendix B

Glossary of Terms

This Glossary contains terms used throughout the Technical Paper and the definitions are normally taken from the Synthesis Report, the Working Group I, II, and III contributions to the Third Assessment Report, and the Special Report on Land Use, Land-Use Change, and Forestry. Terms that are independent entries in this glossary are in *italics*.

Activity
A *practice* or ensemble of practices that take place on a delineated area and over a given period of time.

Adaptation
Adjustment in natural or *human systems* to a new or changing environment. Adaptation to *climate change* refers to adjustment in natural or human systems in response to actual or expected climatic *stimuli* or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptive capacity
The ability of a system to adjust to *climate change* (including *climate variability* and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Aerosols
A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 μm that reside in the *atmosphere* for at least several hours. Aerosols may be of either natural or *anthropogenic* origin. Aerosols may influence *climate* in two ways: directly through scattering and absorbing radiation, and indirectly through acting as condensation nuclei for cloud formation or modifying the optical properties and lifetime of clouds.

Afforestation
Planting of new *forests* on lands that historically have not contained forests.

Agroforestry
Planting of trees and crops on the same piece of land.

Albedo
The fraction of *solar radiation* reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo; the albedo of soils ranges from high to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's albedo varies mainly through varying cloudiness, snow, ice, leaf area, and land cover changes.

Alpine
The biogeographic zone made up of slopes above timberline and characterized by the presence of rosette-forming herbaceous plants and low shrubby slow-growing woody plants.

Ancillary benefits
The ancillary, or side effects, of policies aimed exclusively at *climate change mitigation*. Such policies have an impact not only on *greenhouse gas emissions*, but also on resource use efficiency, like reduction in emissions of local and regional air pollutants associated with *fossil-fuel* use, and on issues such as transportation, agriculture, *land-use* practices, employment, and fuel security. Sometimes these benefits are referred to as "ancillary impacts" to reflect that in some cases the benefits may be negative. From the perspective of policies directed at abating local air pollution, greenhouse gas mitigation may also be considered an ancillary benefit, but these relationships are not considered in this assessment. See also *co-benefits*.

Anthropogenic
Resulting from or produced by human beings.

Aquaculture
Breeding and rearing fish, shellfish, etc., or growing plants for food in special ponds.

Aquifer
A stratum of permeable rock that bears water. An unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, and the rate of recharge will be influenced by the permeability of the overlying rocks and soils. A confined aquifer is characterized by an overlying bed that is impermeable and the local rainfall does not influence the aquifer.

Arid regions
Ecosystems with less than 250 mm precipitation per year.

Atmosphere
The gaseous envelop surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium, and radiatively active *greenhouse gases* such as *carbon dioxide* (0.035% volume mixing ratio). In addition, the atmosphere contains water vapor, whose amount is highly variable but typically 1% volume mixing ratio. The atmosphere also contains clouds and *aerosols*.

Basin
The drainage area of a stream, river, or lake.

Biodiversity
The numbers and relative abundances of different genes (genetic diversity), species, and *ecosystems* (*communities*) in a particular area. This is consistent with the *United Nations Convention on Biodiversity* definition of "biodiversity" that is given in Section 2.1 of this paper.

Biofuel
A fuel produced from dry organic matter or combustible oils produced by plants. Examples of biofuel include alcohol (from fermented sugar), black liquor from the paper manufacturing process, wood, and soybean oil.

Biological pump
Marine biological processes that sequester CO_2 and remove carbon from surface waters to the ocean interior through the settling of organic particles, and as ocean currents transport dissolved organic matter, thus reducing the total carbon content of the surface layers and increasing it at depth.

Biomass
The total mass of living organisms in a given area or volume; recently dead plant material is often included as dead biomass.

Biome
A grouping of similar plant and animal communities into broad landscape units that occur under similar environmental conditions.

Biosphere (terrestrial and marine)
The part of the Earth system comprising all *ecosystems* and living organisms in the *atmosphere*, on land (terrestrial biosphere), or in the oceans (marine biosphere), including derived dead organic matter such as litter, soil organic matter, and oceanic detritus.

Biota
All living organisms of an area; the flora and fauna considered as a unit.

Bog
A poorly drained area rich in accumulated plant material, frequently surrounding a body of open water and having a characteristic flora (such as sedges, heaths, and sphagnum).

Boreal forest
Forests of pine, spruce, fir, and larch stretching from the east coast of Canada westward to Alaska and continuing from Siberia westward across the entire extent of Russia to the European Plain.

C_3 plants
Plants that produce a three-carbon compound during photosynthesis, including most trees and agricultural crops such as rice, wheat, soybeans, potatoes, and vegetables.

C_4 plants
Plants that produce a four-carbon compound during photosynthesis (mainly of tropical origin), including grasses and the agriculturally important crops maize, sugar cane, millet, and sorghum.

Capacity building
In the context of *climate change*, capacity building is a process of developing the technical skills and institutional capability in developing countries and *economies in transition* to enable them to participate in all aspects of *adaptation* to, *mitigation* of, and research on climate change.

Carbon cycle
The term used to describe the flow of carbon (in various forms such as *carbon dioxide*) through the *atmosphere*, ocean, terrestrial *biosphere*, and *lithosphere*.

Carbon dioxide (CO_2)
A naturally occurring gas, and also a by-product of burning *fossil fuels* and *biomass*, as well as *land-use changes* and industrial processes. It is the principal *anthropogenic greenhouse gas* that affects the Earth's *radiative balance*.

Carbon dioxide (CO_2) fertilization
The enhancement of the growth of plants as a result of increased atmospheric *carbon dioxide* concentration. Depending on their mechanism of *photosynthesis*, certain types of plants are more sensitive to changes in atmospheric carbon dioxide concentration than others.

Catchment
An area that collects and drains rainwater.

Climate
Climate in a narrow sense is usually defined as the "average weather" or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the *climate system*.

Climate change
Climate change refers to a statistically significant variation in either the mean state of the *climate* or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or *external forcings*, or to persistent *anthropogenic* changes in the composition of the *atmosphere* or in *land use*. Note that the *United Nations Framework Convention on Climate Change* (UNFCCC), in its Article 1, defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between "climate change" attributable to human

activities altering the atmospheric composition, and "climate variability" attributable to natural causes. See also *climate variability*.

Climate feedback
An interaction mechanism between processes in the *climate system* is called a climate feedback, when the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.

Climate model (hierarchy)
A numerical representation of the *climate system* based on the physical, chemical, and biological properties of its components, their interactions and *feedback* processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity—that is, for any one component or combination of components a "hierarchy" of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parametrizations are involved. Coupled atmosphere/ocean/sea-ice general circulation models (AOGCMs) provide a comprehensive representation of the climate system. There is an evolution towards more complex models with active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but also for operational purposes, including monthly, seasonal, and interannual *climate predictions*.

Climate prediction
A climate prediction or climate forecast is the result of an attempt to produce a most likely description or estimate of the actual evolution of the *climate* in the future (e.g., at seasonal, interannual, or long-term *time scales*). See also *climate projection* and *climate scenario*.

Climate projection
A *projection* of the response of the *climate system* to *emission* or concentration *scenarios* of *greenhouse gases* and *aerosols*, or *radiative forcing scenarios*, often based upon simulations by *climate models*. Climate projections are distinguished from *climate predictions* in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions, concerning, for example, future socio-economic and technological developments that may or may not be realized, and are therefore subject to substantial *uncertainty*.

Climate scenario
A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of *anthropogenic climate change*, often serving as input to impact models. *Climate projections* often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A "climate change scenario" is the difference between a climate scenario and the current climate.

Climate sensitivity
In IPCC assessments, "equilibrium climate sensitivity" refers to the equilibrium change in global mean surface temperature following a doubling of the atmospheric (equivalent) CO_2 concentration. More generally, equilibrium climate sensitivity refers to the equilibrium change in surface air temperature following a unit change in *radiative forcing* ($°C/Wm^{-2}$). In practice, the evaluation of the equilibrium climate sensitivity requires very long simulations with coupled *general circulation models*. The "effective climate sensitivity" is a related measure that circumvents this requirement. It is evaluated from model output for evolving non-equilibrium conditions. It is a measure of the strengths of the *feedbacks* at a particular time and may vary with forcing history and climate state. See *climate model*.

Climate system
The climate system is the highly complex system consisting of five major components: the *atmosphere*, the *hydrosphere*, the *cryosphere*, the land surface and the *biosphere*, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and human-induced forcings such as the changing composition of the atmosphere and *land-use change*.

Climate variability
Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the *climate* on all *spatial and temporal scales* beyond that of individual weather events. Variability may be due to natural internal processes within the *climate system* (internal variability), or to variations in natural or *anthropogenic external forcing* (external variability). See also *climate change*.

Co-benefits
The benefits of policies that are implemented for various reasons at the same time—including *climate change mitigation*—acknowledging that most policies designed to address *greenhouse gas mitigation* also have other, often at least equally important, rationales (e.g., related to objectives of development, sustainability, and equity). The term co-impact is also used in a more generic sense to cover both the positive and negative sides of the benefits. See also *ancillary benefits*.

Community
The species (or populations of those species) that occur together in space and time, although this cannot be separated from *ecosystems*.

Coral bleaching
The paling in color of corals resulting from a loss of symbiotic algae. Bleaching occurs in response to physiological shock in response to abrupt changes in temperature, salinity, and turbidity.

Cost-effective
A criterion that specifies that a *technology* or measure delivers a good or service at equal or lower cost than current practice, or the least-cost alternative for the achievement of a given target.

Cryosphere
The component of the *climate system* consisting of all snow, ice, and *permafrost* on and beneath the surface of the earth and ocean. See also *glacier* and *ice sheet*.

Deforestation
Conversion of *forest* to non-forest.

Dengue fever
An infectious viral disease spread by mosquitoes often called breakbone fever because it is characterized by severe pain in joints and back. Subsequent infections of the virus may lead to dengue haemorrhagic fever (DHF) and dengue shock syndrome (DSS), which may be fatal.

Desert
An *ecosystem* with less than 100 mm precipitation per year.

Desertification
Land degradation in *arid*, *semi-arid*, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Further, the United Nations Convention to Combat Desertification defines land degradation as a reduction or loss in arid, semi-arid, and dry sub-humid areas of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, *forest*, and woodlands resulting from *land uses* or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil *erosion* caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation.

Disturbance regime
Frequency, intensity, and types of disturbances, such as fires, inspect or pest outbreaks, floods, and *droughts*.

Diurnal temperature range
The difference between the maximum and minimum temperature during a day.

Drought
The phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.

Economic potential
Economic potential is the portion of *technological potential* for *greenhouse gas emissions* reductions or *energy efficiency* improvements that could be achieved *cost-effectively* through the creation of markets, reduction of market failures, or increased financial and technological transfers. The achievement of economic potential requires additional *policies and measures* to break down *market barriers*. See also *market potential* and *socio-economic potential*.

Economies in transition (EITs)
Countries with national economies in the process of changing from a planned economic system to a market economy.

Ecosystem
A system of dynamic and interacting living organisms (plant, animal, fungal, and micro-organism) together with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small *spatial scales* to, ultimately, the entire Earth.

Ecosystem services
Ecological processes or functions that have *value* to individual humans or societies.

El Niño Southern Oscillation (ENSO)
El Niño, in its original sense, is a warm water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as El Niño Southern Oscillation, or ENSO. During an El Niño event, the prevailing trade winds weaken and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru current. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña.

Emissions
In the *climate change* context, emissions refer to the release of *greenhouse gases* and/or their *precursors* and *aerosols* into the *atmosphere* over a specified area and period of time.

Emissions scenario
A plausible representation of the future development of *emissions* of substances that are potentially radiatively active (e.g., *greenhouse gases*, *aerosols*), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change) and their key relationships. Concentration scenarios, derived from emissions scenarios, are used as input into a *climate model* to compute *climate projections*.

Endemic
Restricted to a locality or region. With regard to human health, endemic can refer to a disease or agent present or usually prevalent in a population or geographical area at all times.

Energy balance
Averaged over the globe and over longer time periods, the energy budget of the *climate system* must be in balance. Because the climate system derives all its energy from the Sun, this balance implies that, globally, the amount of incoming *solar radiation* must on average be equal to the sum of the outgoing reflected solar radiation and the outgoing *infrared radiation* emitted by the climate system. A perturbation of this global radiation balance, be it human-induced or natural, is called *radiative forcing*.

Energy efficiency
Ratio of energy output of a conversion process or of a system to its energy input.

Equilibrium and transient climate experiment
An "equilibrium climate experiment" is an experiment in which a *climate model* is allowed to fully adjust to a change in *radiative forcing*. Such experiments provide information on the difference between the initial and final states of the model, but not on the time-dependent response. If the forcing is allowed to evolve gradually according to a prescribed *emission scenario*, the time-dependent response of a climate model may be analyzed. Such an experiment is called a "transient climate experiment."

Erosion
The process of removal and transport of soil and rock by weathering, mass wasting, and the action of streams, *glaciers*, waves, winds, and underground water.

Eutrophication
The process by which a body of water (often shallow) becomes (either naturally or by pollution) rich in dissolved nutrients, especially nitrogen, phosphates,with a seasonal deficiency in dissolved oxygen.

Evaporation
The process by which a liquid becomes a gas.

Evapotranspiration
The combined process of *evaporation* from the Earth's surface and *transpiration* from vegetation.

External forcing
See *climate system*.

Extinction
The complete disappearance of an entire species.

Extreme weather event
An extreme weather event is an event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called extreme weather may vary from place to place. An extreme *climate* event is an average of a number of weather events over a certain period of time, an average which is itself extreme (e.g., rainfall over a season).

Feedback
An interaction mechanism between processes in the system is called a feedback, when the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it. See *climate feedback*.

Fiber
Wood, fuelwood (either woody or non-woody).

Final energy
Energy supplied that is available to the consumer to be converted into usable energy (e.g., electricity at the wall outlet).

Forb
Non-woody plant (e.g., herb, grass).

Forest
A vegetation type dominated by trees. Many definitions of the term forest are in use throughout the world, reflecting wide differences in bio-geophysical conditions, social structure, and economics.

Fossil fuels
Carbon-based fuels from fossil carbon deposits, including coal, oil, and natural gas.

Fragmentation
Breaking an area, landscape, or *habitat* into discrete and separate pieces often as a result of land-use change.

General circulation
The large scale motions of the *atmosphere* and the ocean as a consequence of differential heating on a rotating Earth, aiming to restore the *energy balance* of the system through transport of heat and momentum.

General Circulation Model (GCM)
See *climate model*.

Geo-engineering
Efforts to stabilize the climate system by directly managing the energy balance of the Earth, thereby overcoming the enhanced *greenhouse effect*.

Glacier
A mass of land ice flowing downhill (by internal deformation and sliding at the base) and constrained by the surrounding topography (e.g., the sides of a valley or surrounding peaks); the bedrock topography is the major influence on the dynamics and surface slope of a glacier. A glacier is maintained by accumulation of snow at high altitudes, balanced by melting at low altitudes or discharge into the sea.

Global mean surface temperature
The global mean surface temperature is the area-weighted global average of (i) the sea surface temperature over the oceans (i.e., the sub-surface bulk temperature in the first few

meters of the ocean), and (ii) the surface air temperature over land at 1.5 m above the ground.

Greenhouse effect
Greenhouse gases effectively absorb *infrared radiation*, emitted by the Earth's surface, by the *atmosphere* itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the "natural greenhouse effect." Atmospheric radiation is strongly coupled to the temperature of the level at which it is emitted. In the *troposphere,* the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average, -19°C, in balance with the net incoming *solar radiation*, whereas the Earth's surface is kept at a much higher temperature of, on average, +14°C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a *radiative forcing*, an imbalance that can only be compensated for by an increase of the temperature of the surface-troposphere system. This is the "enhanced greenhouse effect."

Greenhouse gas
Greenhouse gases are those gaseous constituents of the *atmosphere*, both natural and *anthropogenic*, that absorb and emit radiation at specific wavelengths within the spectrum of *infrared radiation* emitted by the Earth's surface, the atmosphere, and clouds. This property causes the *greenhouse effect*. Water vapor (H_2O), *carbon dioxide* (CO_2), *nitrous oxide* (N_2O), *methane* (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover there are a number of entirely human-made greenhouse gases in the atmosphere, such as halocarbons and other chlorine- and bromine-containing substances.

Gross Primary Production (GPP)
The amount of carbon fixed from the *atmosphere* through *photosynthesis* over a certain time period (normally 1 year).

Habitat
The particular environment or place where an organism or species tend to live; a more locally circumscribed portion of the total environment.

Heat index
A combination of temperature and humidity that measures effects on human comfort.

Hedging
In the context of climate change mitigation, hedging is defined as balancing the risks of acting too slowly against acting too quickly, and it depends on society's attitude towards risks.

Heterotrophic respiration
The conversion of organic matter to CO_2 by organisms other than plants.

Human system
Any system in which human organizations play a major role. Often, but not always, the term is synonymous with "society" or "social system" (e.g., agricultural system, political system, technological system, economic system).

Hydrosphere
The component of the *climate system* composed of liquid surface and subterranean water, such as oceans, seas, rivers, freshwater lakes, underground water, etc.

Ice cap
A dome shaped ice mass covering a highland area that is considerably smaller in extent than an *ice sheet*.

Ice sheet
A mass of land ice that is sufficiently deep to cover most of the underlying bedrock topography, so that its shape is mainly determined by its internal dynamics (the flow of the ice as it deforms internally and slides at its base). An ice sheet flows outward from a high central plateau with a small average surface slope. The margins slope steeply, and the ice is discharged through fast-flowing ice streams or outlet *glaciers*, in some cases into the sea or into *ice shelves* floating on the sea. There are only two large ice sheets in the modern world, on Greenland and Antarctica, the Antarctic ice sheet being divided into East and West by the Transantarctic Mountains; during glacial periods there were others.

Ice shelf
A floating *ice sheet* of considerable thickness attached to a coast (usually of great horizontal extent with a level or gently undulating surface); often a seaward extension of ice sheets.

(Climate) Impact assessment
The practice of identifying and evaluating the detrimental and beneficial consequences of *climate change* on natural and *human systems*.

(Climate) Impacts
Consequences of *climate change* on natural and *human systems*. Depending on the consideration of *adaptation*, one can distinguish between potential impacts and residual impacts.

- Potential impacts: All impacts that may occur given a projected change in *climate*, without considering adaptation.
- Residual impacts: The impacts of climate change that would occur after adaptation.

Implementation
Implementation refers to the actions (legislation or regulations, judicial decrees, or other actions) that governments take to translate international accords into domestic law and policy. It includes those events and activities that occur after the issuing of authoritative public policy directives, which include the effort to administer and the substantive impacts on people and events. It is important to distinguish between the legal implementation of international commitments (in national law) and the effective

implementation (measures that induce changes in the behavior of target groups). Compliance is a matter of whether and to what extent countries do adhere to the provisions of the accord. Compliance focuses on not only whether implementing measures are in effect, but also on whether there is compliance with the implementing actions. Compliance measures the degree to which the actors whose behavior is targeted by the agreement, whether they are local government units, corporations, organizations, or individuals, conform to the implementing measures and obligations.

Indigenous peoples
People whose ancestors inhabited a place or a country when persons from another culture or ethnic background arrived on the scene and dominated them through conquest, settlement, or other means and who today live more in conformity with their own social, economic, and cultural customs and traditions than those of the country of which they now form a part (also referred to as "native," "aboriginal," or "tribal" peoples).

Industrial Revolution
A period of rapid industrial growth with far-reaching social and economic consequences, beginning in England during the second half of the 18th century and spreading to Europe and later to other countries including the United States. The invention of the steam engine was an important trigger of this development. The Industrial Revolution marks the beginning of a strong increase in the use of *fossil fuels* and emission of, in particular, fossil *carbon dioxide*. In this report, the terms "pre-industrial" and "industrial" refer, somewhat arbitrarily, to the periods before and after the year 1750, respectively.

Infectious diseases
Any disease that can be transmitted from one person to another. This may occur by direct physical contact, by common handling of an object that has picked up infective organisms, through a disease carrier, or by spread of infected droplets coughed or exhaled into the air.

Infrared radiation
Radiation emitted by the Earth's surface, the *atmosphere*, and clouds. It is also known as terrestrial or long-wave radiation. Infrared radiation has a distinctive range of wavelengths ("spectrum") longer than the wavelength of the red color in the visible part of the spectrum. The spectrum of infrared radiation is practically distinct from that of solar or short-wave radiation because of the difference in temperature between the Sun and the Earth-atmosphere system.

Infrastructure
The basic equipment, utilities, productive enterprises, installations, institutions, and services essential for the development, operation, and growth of an organization, city, or nation. For example, roads; schools; electric, gas, and water utilities; transportation; communication; and legal systems would be all considered as infrastructure.

Internal variability
See *climate variability*.

Invasive species
A native or (locally) *non-native species* that invades natural *habitats*.

Kyoto Protocol
The Kyoto Protocol to the *United Nations Framework Convention on Climate Change* (UNFCCC) was adopted at the Third Session of the Conference of the Parties to the UNFCCC in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol (most countries in the Organisation for Economic Cooperation and Development, and countries with *economies in transition*) agreed to reduce their *anthropogenic greenhouse gas emissions* (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) on average by about 5.2% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol has not entered into force as of April 2002.

La Niña
See *El Niño Southern Oscillation*.

Land cover
The observed physical and biological cover of the Earth's land as vegetation or man-made features.

Landscape
Groups of ecosystems (e.g., forests, rivers, lakes, etc.) that form a visible entity to humans.

Landslide
A mass of material that has slipped downhill by gravity, often assisted by water when the material is saturated; rapid movement of a mass of soil, rock, or debris down a slope.

Land use
The total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation).

Land-use change
A change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land-use change may have an impact on the *albedo*, *evapotranspiration*, *sources* and *sinks* of *greenhouse gases*, or other properties of the *climate system*, and may thus have an impact on *climate*, locally or globally.

Lithosphere
The upper layer of the solid Earth, both continental and oceanic, which is composed of all crustal rocks and the cold, mainly elastic, part of the uppermost mantle. Volcanic activity, although part of the lithosphere, is not considered as part of the *climate system*, but acts as an *external forcing* factor.

Level of scientific understanding
This is an index on a 4-step scale (High, Medium, Low, and

Very Low) designed to characterize the degree of scientific understanding of the *radiative forcing* agents that affect *climate change*. For each agent, the index represents a subjective judgement about the reliability of the estimate of its forcing, involving such factors as the assumptions necessary to evaluate the forcing, the degree of knowledge of the physical/chemical mechanisms determining the forcing, and the uncertainties surrounding the quantitative estimate.

Local peoples
People who practice traditional lifestyles (typically rural) whether or not *indigenous* to region.

Malaria
Endemic or epidemic parasitic disease caused by species of the genus Plasmodium (protozoa) and transmitted by mosquitoes of the genus Anopheles; produces high fever attacks and systemic disorders, and kills approximately 2 million people every year.

Market barriers
In the context of *mitigation* of *climate change*, conditions that prevent or impede the diffusion of *cost-effective* technologies or practices that would mitigate *greenhouse gas emissions*.

Market potential
The portion of the *economic potential* for *greenhouse gas emissions* reductions or *energy-efficiency* improvements that could be achieved under forecast market conditions, assuming no new *policies and measures*. See also *socio-economic potential* and *technological potential*.

Mean sea level (MSL)
Mean sea level is normally defined as the average *relative sea level* over a period, such as a month or a year, long enough to average out transients such as waves. See also *sea-level rise*.

Methane (CH_4)
A hydrocarbon that is a *greenhouse gas* produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and oil, coal production, and incomplete fossil-fuel combustion. Methane is one of the six *greenhouse gases* to be mitigated under the *Kyoto Protocol*.

Mitigation
An *anthropogenic* intervention to reduce the *sources* or enhance the *sinks* of *greenhouse gases*.

Monitoring
A system of observations of relevant physical, chemical, biological, and socio-economic variables.

Monsoon
Wind in the general atmospheric circulation typified by a seasonal persistent wind direction and by a nearly reversed direction from one season to the next (winter to summer).

Montane
The biogeographic zone made up of relatively moist, cool upland slopes below timberline and characterized by the presence of large evergreen trees as a dominant life form.

Mortality
Rate of occurrence of death within a population within a specified time period; calculation of mortality takes account of age-specific death rates, and can thus yield measures of life expectancy and the extent of premature death.

Net biome production (NBP)
Net gain or loss of carbon from a region. NBP is equal to the *net ecosystem production* minus the carbon lost due to a disturbance (e.g., a *forest* fire or a forest harvest) over a certain time period (normally 1 year).

Net ecosystem production (NEP)
Net gain or loss of carbon from an *ecosystem*. NEP is equal to the *net primary production* minus the carbon lost through heterotrophic *respiration* over a certain time period (normally 1 year).

Net primary production (NPP)
The increase in plant *biomass* or carbon of a unit of area (terrestrial, aquatic, or marine). NPP is equal to the *gross primary production* minus carbon lost through autotrophic *respiration* over a certain time period (normally 1 year).

Nitrogen oxides (NO_x)
Any of several oxides of nitrogen.

Nitrous oxide (N_2O)
A powerful greenhouse gas emitted through soil cultivation practices, especially the use of commercial and organic fertilizers, fossil-fuel combustion, nitric acid production, and biomass burning. One of the six *greenhouse gases* to be mitigated under the *Kyoto Protocol*.

Non-native species
A species occurring in an area outside its historically known natural range as a result of accidental dispersal or deliberate introduction by humans (also referred to as “exotic species” or “alien species” or “introduced species”).

North Atlantic Oscillation (NAO)
The North Atlantic Oscillation consists of opposing variations of barometric pressure near Iceland and near the Azores. On average, a westerly current, between the Icelandic low pressure area and the Azores high pressure area, carries cyclones with their associated frontal systems towards Europe. However, the pressure difference between Iceland and the Azores fluctuates on *time scales* of days to decades, and can be reversed at times. It is the dominant mode of winter *climate variability* in the North Atlantic region, ranging from central North America to Europe.

Opportunity
An opportunity is a situation or circumstance to decrease the

gap between the *market potential* of any *technology* or practice and the *economic potential*, *socio-economic potential*, or *technological potential*.

Opportunity costs
The cost of an economic activity forgone by the choice of another activity.

Permafrost
Perennially frozen ground that occurs wherever the temperature remains below 0°C for several years.

Phenology
The study of natural phenomena that recur periodically (e.g., blooming, migrating) and their relation to climate and seasonal changes.

Photosynthesis
The process by which plants take *carbon dioxide* (CO_2) from the air (or bicarbonate in water) to build carbohydrates, releasing oxygen (O_2) in the process. There are several pathways of photosynthesis with different responses to atmospheric CO_2 concentrations. See also *carbon dioxide fertilization*.

Phytoplankton
The plant forms of *plankton* (e.g., diatoms). *Phytoplankton* are the dominant plants in the sea, and are the bast of the entire marine food web. These single-celled organisms are the principal agents for photosynthetic carbon fixation in the ocean.

Plankton
Aquatic organisms that drift or swim weakly. See also *zooplankton* and *phytoplankton*.

Policies and measures
In *United Nations Framework Convention on Climate Change* parlance, "policies" are actions that can be taken and/or mandated by a government—often in conjunction with business and industry within its own country, as well as with other countries—to accelerate the application and use of measures to curb *greenhouse gas emissions*. "Measures" are technologies, processes, and practices used to implement policies, which, if employed, would reduce greenhouse gas emissions below anticipated future levels. Examples might include carbon or other energy taxes, standardized fuel-efficiency *standards* for automobiles, etc. "Common and coordinated" or "harmonized" policies refer to those adopted jointly by Parties.

Pool
See *reservoir*.

Population
A group of individuals of the same species which occur in an arbitrarily defined space/time and are much more likely to mate with one another than with individuals from another such group.

Practice
An action or set of actions that affect the land, the *stocks* of *pools* associated with it, or otherwise affect the exchange of *greenhouse gases* with the *atmosphere*. These specifically include projects and policies.

Precursors
Atmospheric compounds which themselves are not *greenhouse gases* or *aerosols*, but which have an effect on greenhouse gas or aerosol concentrations by taking part in physical or chemical processes regulating their production or destruction rates.

Pre-industrial
See *Industrial Revolution*.

Projection (generic)
A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from "predictions" in order to emphasize that projections involve assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized, and are therefore subject to substantial *uncertainty*. See also *climate projection* and *climate prediction*.

Radiative balance
See *energy balance*.

Radiative forcing
A measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and an index of the importance of the factor as a potential climate change mechanism. It is expressed in Watts per square meter (Wm^{-2}).

Radiative forcing scenario
A plausible representation of the future development of *radiative forcing* associated, for example, with changes in atmospheric composition or *land-use* change, or with external factors such as variations in solar activity. Radiative forcing scenarios can be used as input into simplified *climate models* to compute *climate projections*.

Rangeland
Unimproved grasslands, shrublands, savannahs, and tundra.

Rapid climate change
The non-linearity of the *climate system* may lead to rapid *climate change*, sometimes called abrupt events or even surprises. Some such abrupt events may be imaginable, such as a dramatic reorganization of the thermohaline circulation, rapid deglaciation, or massive melting of *permafrost* leading to fast changes in the *carbon cycle*. Others may be truly unexpected, as a consequence of a strong, rapidly changing, forcing of a non-linear system.

Reforestation
Planting of *forests* on lands that have previously contained forests but that have been converted to some other use.

Regeneration
The renewal of a stand of trees through either natural means (seeded onsite or adjacent stands or deposited by wind, birds, or animals) or artificial means (by planting seedlings or direct seeding).

Relative sea level
Sea level measured by a *tide gauge* with respect to the land upon which it is situated. See also *mean sea level*.

Reservoir
A component of the *climate system*, other than the *atmosphere*, which has the capacity to store, accumulate, or release a substance of concern (e.g., carbon, a *greenhouse gas*, or a *precursor*). Oceans, soils, and *forests* are examples of reservoirs of carbon. *Pool* is an equivalent term (note that the definition of pool often includes the atmosphere). The absolute quantity of substance of concerns, held within a reservoir at a specified time, is called the stock. The term also means an artificial or natural storage place for water, such as a lake, pond, or *aquifer*, from which the water may be withdrawn for such purposes as irrigation, water supply, or irrigation.

Resilience
Amount of change a system can undergo without changing state.

Resources
Resources are those occurrences with less certain geological and/or economic characteristics, but which are considered potentially recoverable with foreseeable technological and economic developments.

Respiration
The process whereby living organisms converts organic matter to *carbon dioxide*, releasing energy and consuming oxygen.

Runoff
That part of precipitation that does not evaporate. In some countries, runoff implies *surface runoff* only.

Salinization
The accumulation of salts in soils.

Saltwater intrusion/encroachment
Displacement of fresh surfacewater or groundwater by the advance of saltwater due to its greater density, usually in coastal and estuarine areas.

Scenario (generic)
A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of *technology* change, prices) and relationships. Scenarios are neither predictions nor forecasts and sometimes may be based on a "narrative storyline." Scenarios may be derived from *projections*, but are often based on additional information from other sources. See also *SRES scenarios*, *climate scenario*, and *emissions scenarios*.

Sea-level rise
An increase in the mean level of the ocean. Eustatic sea-level rise is a change in global average sea level brought about by an alteration to the volume of the world ocean. *Relative sea-level* rise occurs where there is a net increase in the level of the ocean relative to local land movements. Climate modelers largely concentrate on estimating eustatic sea-level change. *Impacts* researchers focus on relative sea-level change.

Semi-arid regions
Ecosystems that have more than 250 mm precipitation per year but are not highly productive; usually classified as *rangelands*.

Sensitivity
Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related *stimuli*. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to *sea-level rise*). See also *climate sensitivity*.

Sequential decisionmaking
Stepwise decisionmaking aiming to identify short-term strategies in the face of long-term uncertainties, by incorporating additional information over time and making mid-course corrections.

Sequestration
The process of increasing the carbon content of a carbon *reservoir* other than the *atmosphere*. Biological approaches to sequestration include direct removal of *carbon dioxide* from the atmosphere through *land-use change*, *afforestation*, *reforestation*, and practices that enhance soil carbon in agriculture. Physical approaches include separation and disposal of carbon dioxide from flue gases or from processing *fossil fuels* to produce hydrogen- and carbon dioxide-rich fractions and long-term storage in underground in depleted oil and gas reservoirs, coal seams, and saline *aquifers*. See also *uptake*.

Set-aside
An area or land mass that is reserved for a specified purpose, often conservation or carbon sequestration projects.

Silt
Unconsolidated or loose sedimentary material whose constituent rock particles are finer than grains of sand and larger than clay particles.

Sink
Any process, activity or mechanism that removes a *greenhouse gas*, an *aerosol*, or a *precursor* of a greenhouse gas or aerosol from the *atmosphere*.

Social cost
The social cost of an activity includes the *value* of all the *resources* used in its provision. Some of these are priced and others are not. Non-priced resources are referred to as externalities. It is the sum of the costs of these externalities and the priced resources that makes up the social cost.

Soil moisture
Water stored in or at the land surface and available for evaporation.

Solar radiation
Radiation emitted by the Sun. It is also referred to as short-wave radiation. Solar radiation has a distinctive range of wavelengths (spectrum) determined by the temperature of the Sun. See also *infrared radiation*.

Source
Any process, activity, or mechanism that releases a *greenhouse gas*, an *aerosol*, or a *precursor* of a greenhouse gas or aerosol into the *atmosphere*.

Spatial and temporal scales
Climate may vary on a large range of spatial and temporal scales. Spatial scales may range from local (less than 100,000 km^2), through regional (100,000 to 10 million km^2) to continental (10 to 100 million km^2). Temporal scales may range from seasonal to geological (up to hundreds of millions of years).

Special Report on Emissions Scenarios (SRES)
SRES scenarios are *emissions scenarios* used, among others, as a basis for the *climate projections* in the IPCC WGI contribution to the Third Assessment Report. The following terms are relevant for a better understanding of the structure and use of the set of SRES scenarios:

- ***(Scenario) Family***: Scenarios that have a similar demographic, societal, economic, and technical change *storyline*. Four scenario families comprise the SRES scenario set: A1, A2, B1, and B2.
- ***(Scenario) Group***: Scenarios within a family that reflect a consistent variation of the storyline. The A1 scenario family includes four groups designated as A1T, A1C, A1G, and A1B that explore alternative structures of future energy systems. In the SRES Summary for Policymakers, the A1C and A1G groups have been combined into one "Fossil-Intensive" A1FI scenario group. The other three scenario families consist of one group each. The SRES scenario set thus consists of six distinct *scenario groups*, all of which are equally sound and together capture the range of uncertainties associated with driving forces and emissions.
- ***Illustrative Scenario***: A scenario that is illustrative for each of the six *scenario groups* reflected in the Summary for Policymakers. They include four revised *scenario markers* for the *scenario groups* A1B, A2, B1, B2, and two additional scenarios for the A1FI and A1T groups. All *scenario groups* are equally sound.
- ***(Scenario) Marker***: A scenario that was originally posted in draft form on the SRES website to represent a given *scenario family*. The choice of markers was based on which of the initial quantifications best reflected the storyline, and the features of specific models. Markers are no more likely than other scenarios, but are considered by the SRES writing team as illustrative of a particular storyline. These scenarios have received the closest scrutiny of the entire writing team and via the SRES open process. Scenarios have also been selected to illustrate the other two *scenario groups*.
- ***(Scenario) Storyline***: A narrative description of a scenario (or family of scenarios) highlighting the main scenario characteristics, relationships between key driving forces, and the dynamics of their evolution.

Stakeholders
Person or entity holding grants, concessions, or any other type of *value* that would be affected by a particular action or policy.

Standards
Set of rules or codes mandating or defining product performance (e.g., grades, dimensions, characteristics, test methods, and rules for use). International product and/or *technology* or performance standards establish minimum requirements for affected products and/or technologies in countries where they are adopted. The standards reduce *greenhouse gas emissions* associated with the manufacture or use of the products and/or application of the technology.

Stimuli (climate-related)
All the elements of *climate change*, including mean *climate* characteristics, *climate variability*, and the frequency and magnitude of extremes.

Stock
See *reservoir*.

Storm surge
The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

Storyline
See *SRES scenarios*.

Stratosphere
The highly stratified region of the *atmosphere* above the *troposphere* extending from about 10 km (ranging from 9 km in high latitudes to 16 km in the tropics on average) to about 50 km. It is the layer where most of the ozone layer filters out ultraviolet-B (UV-B) radiation.

Streamflow
Water within a river channel, usually expressed in $m^3\ sec^{-1}$.

Submergence
A rise in the water level in relation to the land, so that areas of formerly dry land become inundated; it results either from a sinking of the land or from a rise of the water level.

Subsidence
The sudden sinking or gradual downward settling of the Earth's surface with little or no horizontal motion.

Surface runoff
The water that travels over the soil surface to the nearest surface stream; runoff of a drainage *basin* that has not passed beneath the surface since precipitation.

Sustainable development
Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Technological potential
The amount by which it is possible to reduce *greenhouse gas emissions* or improve *energy efficiency* by implementing a *technology* or practice that has already been demonstrated. See also *economic potential*, *market potential*, and *socio-economic potential*.

Technology
A piece of equipment or a technique for performing a particular activity.

Technology transfer
The broad set of processes that cover the exchange of knowledge, money, and goods among different *stakeholders* that lead to the spreading of *technology* for adapting to or mitigating *climate change*. As a generic concept, the term is used to encompass both diffusion of technologies and technological cooperation across and within countries.

Thermal expansion
In connection with sea level, this refers to the increase in volume (and decrease in density) that results from warming water. A warming of the ocean leads to an expansion of the ocean volume and hence an increase in sea level.

Thermokarst
Irregular, hummocky topography in frozen ground caused by melting of ice.

Tide gauge
A device at a coastal location (and some deep sea locations) which continuously measures the level of the sea with respect to the adjacent land. Time-averaging of the sea level so recorded gives the observed *relative sea level* secular changes.

Time scale
Characteristic time for a process to be expressed. Since many processes exhibit most of their effects early, and then have a long period during which they gradually approach full expression, for the purpose of this report the time scale is numerically defined as the time required for a perturbation in a process to show at least half of its final effect.

Transient climate response
The globally averaged surface air temperature increase, averaged over a 20-year period, centered at the time of CO_2 doubling (i.e., at year 70 in a 1% per year compound CO_2 increase experiment with a global coupled *climate model*).

Transpiration
The evaporation of water from a plant surface (through a membrane or pores) especially of leaves or other plant parts.

Tropopause
The boundary between the *troposphere* and the *stratosphere*.

Troposphere
The lowest part of the *atmosphere* from the surface to about 10 km in altitude in mid-latitudes (ranging from 9 km in high latitudes to 16 km in the tropics on average) where clouds and "weather" phenomena occur. In the troposphere, temperatures generally decrease with height.

Tundra
A treeless, level, or gently undulating plain characteristic of arctic and subarctic regions.

Uncertainty
An expression of the degree to which a value (e.g., the future state of the *climate system*) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain *projections* of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Unique and threatened systems
Entities that are confined to a relatively narrow geographical range but can affect other, often larger entities beyond their range; narrow geographical range points to *sensitivity* to environmental variables, including *climate*, and therefore attests to potential *vulnerability* to *climate change*.

United Nations
Convention on Biological Diversity (UNCBD)
The Convention was signed at the 1992 Earth Summit in Rio de Janeiro by about 160 countries. The objectives of this Convention, to be pursued in accordance with its relevant provisions, are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising out of the utilization of genetic resources. The Convention entered into force in 1992.

United Nations
Framework Convention on Climate Change (UNFCCC)
The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." It contains commitments for all Parties. Under the Convention, Parties included in Annex I aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year

2000. The Convention entered into force in March 1994. See also *Kyoto Protocol*.

Uptake
The addition of a substance of concern to a *reservoir*. The uptake of carbon-containing substances, in particular *carbon dioxide*, is often called (carbon) *sequestration*.

Upwelling
Transport of deeper water to the surface, usually caused by horizontal movements of surface water.

Urbanization
The conversion of land from a natural state or managed natural state (such as agriculture) to cities; a process driven by net rural-to-urban migration through which an increasing percentage of the population in any nation or region come to live in settlements that are defined as "urban centers."

Values
Worth, desirability, or utility based on individual preferences. The total value of any resource is the sum of the values of the different individuals involved in the use of the resource. The values, which are the foundation of the estimation of costs, are measured in terms of the willingness to pay by individuals to receive the resource or by the willingness of individuals to accept payment to part with the resource.

Vector
An organism, such as an insect, that transmits a pathogen from one host to another. See also *vector-borne diseases*.

Vector-borne diseases
Disease that is transmitted between hosts by a *vector* organism such as a mosquito or tick (e.g., *malaria*, *dengue fever*, and leishmaniasis).

Vulnerability
The degree to which a system is susceptible to, or unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its *sensitivity*, and its *adaptive capacity*.

Water-use efficiency
Carbon gain in *photosynthesis* per unit water lost in *evapotranspiration*. It can be expressed on a short-term basis as the ratio of photosynthetic carbon gain per unit transpirational water loss, or on a seasonal basis as the ratio of *net primary production* or agricultural yield to the amount of available water.

Weedy
Plant species that are easily dispersed, fast growing, readily established, and thus opportunistic in response to increases in frequency of disturbances.

Zooplankton
The animal forms of *plankton*. They consume *phytoplankton* or other zooplankton.

Appendix C

Acronyms and Abbreviations

AOGCM	Atmosphere-ocean general circulation model
CH_4	Methane
CO_2	Carbon dioxide
DHF	Dengue haemorrhagic fever
DSS	Dengue shock syndrome
EIT	Economy in transition
ENSO	El Niño Southern Oscillation
ES	Executive Summary
EU	European Union
GCM	General circulation model
GPP	Gross primary productivity
LULUCF	Special Report on Land Use, Land-Use Change, and Forestry
H_2O	Water
IPCC	Intergovernmental Panel on Climate Change
MSL	Mean sea level
MSX	Multinucleated spore unknown
N_2O	Nitrous oxide
NAO	North Atlantic Oscillation
NBP	Net biome productivity
NEP	Net ecosystem productivity
NO_x	Nitrogen oxides
NPP	Net primary productivity
O_2	Oxygen
O_3	Ozone
OECD	Organisation for Economic Cooperation and Development
Qx.x	Relevant SYR question or paragraph
RICC	Special Report on the Regional Impacts of Climate Change
SAR	Second Assessment Report
SBSTTA	Subsidiary Body for Scientific, Technical, and Technological Advice
SPM	Summary for Policymakers
SRES	Special Report on Emissions Scenarios
SYR	Synthesis Report
TAR	Third Assessment Report
UNCBD	United Nations Convention on Biological Diversity
UNCSD	United Nations Commission on Sustainable Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UV-B	Ultraviolet-B
WGI	Working Group I
WGII	Working Group II
WGIII	Working Group III
WMO	World Meteorological Organization

Appendix D

List of Major IPCC Reports

Climate Change—The IPCC Scientific Assessment
The 1990 Report of the IPCC Scientific Assessment Working Group (also in Chinese, French, Russian, and Spanish)

Climate Change—The IPCC Impacts Assessment
The 1990 Report of the IPCC Impacts Assessment Working Group (also in Chinese, French, Russian, and Spanish)

Climate Change—The IPCC Response Strategies
The 1990 Report of the IPCC Response Strategies Working Group (also in Chinese, French, Russian, and Spanish)

Emissions Scenarios
Prepared for the IPCC Response Strategies Working Group, 1990

Assessment of the Vulnerability of Coastal Areas to Sea Level Rise–A Common Methodology
1991 (also in Arabic and French)

Climate Change 1992—The Supplementary Report to the IPCC Scientific Assessment
The 1992 Report of the IPCC Scientific Assessment Working Group

Climate Change 1992—The Supplementary Report to the IPCC Impacts Assessment
The 1992 Report of the IPCC Impacts Assessment Working Group

Climate Change: The IPCC 1990 and 1992 Assessments
IPCC First Assessment Report Overview and Policymaker Summaries, and 1992 IPCC Supplement

Global Climate Change and the Rising Challenge of the Sea
Coastal Zone Management Subgroup of the IPCC Response Strategies Working Group, 1992

Report of the IPCC Country Studies Workshop
1992

Preliminary Guidelines for Assessing Impacts of Climate Change
1992

IPCC Guidelines for National Greenhouse Gas Inventories
Three volumes, 1994 (also in French, Russian, and Spanish)

IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations
1995 (also in Arabic, Chinese, French, Russian, and Spanish)

Climate Change 1994—Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios
1995

Climate Change 1995—The Science of Climate Change – Contribution of Working Group I to the IPCC Second Assessment Report
1996

Climate Change 1995—Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses – Contribution of Working Group II to the IPCC Second Assessment Report
1996

Climate Change 1995—Economic and Social Dimensions of Climate Change – Contribution of Working Group III to the IPCC Second Assessment Report
1996

Climate Change 1995—IPCC Second Assessment Synthesis of Scientific-Technical Information Relevant to Interpreting Article 2 of the UN Framework Convention on Climate Change
1996 (also in Arabic, Chinese, French, Russian, and Spanish)

Technologies, Policies, and Measures for Mitigating Climate Change – IPCC Technical Paper I
1996 (also in French and Spanish)

An Introduction to Simple Climate Models used in the IPCC Second Assessment Report – IPCC Technical Paper II
1997 (also in French and Spanish)

Stabilization of Atmospheric Greenhouse Gases: Physical, Biological and Socio-economic Implications – IPCC Technical Paper III
1997 (also in French and Spanish)

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