IPCC Technical Paper on Climate Change and Biodiversity

Requested by UN Convention on Biological Diversity

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Executive Summary

Human activities have and are causing a loss in biodiversity through land cover change, diversion of water to intensively managed ecosystems and urban systems, soil and water degradation, habitat fragmentation, selective exploitation or destruction of species and the introduction of exotic species.

Changes in climate exert an additional pressure and have already affected biodiversity. The atmospheric concentrations of greenhouse gases have increased during the 20th century due to human activities, primarily the combustion of fossil fuels and land-use and land-cover changes. This has contributed to changes in the Earth’s climate; land and ocean surface temperatures have warmed, the spatial and temporal patterns of precipitation have changed, sea level has risen, and during the last 20 years, the frequency and intensity of El Nino events has increased. These changes, particularly the warmer temperatures, have affected the timing of reproduction or migration events (phenology), the length of the growing season, species distributions and population sizes, and the frequency of pest and disease outbreaks, with some coastal, high latitude/altitude ecosystems being the most sensitive to changes in climatic factors.

Climate change is projected to affect all aspects of biodiversity but the projections have to take all human activities (past, present and future) into account. The Earth’s mean surface temperature is projected to warm 1.4 to 5.8°C during the 21st century, with land areas warming more than the oceans, and the high latitudes warming more than the tropics. The associated increase in sea level is projected to be 0.09 to 0.88m. In general, precipitation is projected to increase in high latitude and equatorial areas and decrease in subtropics, with an increase in heavy precipitation events. Climate change is projected to affect individuals, populations, species distributions and ecosystem composition and function both directly (for example through increases in temperature, changes in precipitation and in the case of marine systems changes in sea level etc) and indirectly (for example 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 reconnection in the case of freshwater bodies) and the introduction of exotic species. No realistic projection of the future state of the earth's ecosystems can be made without taking into account human land-use patterns; past, present and future, which will greatly affect the ability of organisms to adapt to climate change via migration.

The general response of species to climate change is that the habitats of many species will move further poleward or higher than their current location. Thus the composition of most current ecosystems is likely to change as species that make up an ecosystem are unlikely to shift together. 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.

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, and limited climatic ranges. Ecosystems that may be most threatened by climate change include coral reefs, mangroves and other coastal wetlands, remnant ecosystems, some ecosystems with restricted distribution and high latitude/high altitude ecosystems.

Loss of biodiversity does not necessarily imply loss of productivity, however, greater loss may pose serious threats to the function of ecosystems including carbon storage.

Large-scale changes in vegetation as a response to climate change could further affect global and regional climate through changes in the uptake and release of greenhouse gases and changes in albedo**.**

Climate mitigation options can either benefit or have adverse impact on biodiversity. Land-use, land-use change and forestry projects (afforestation, deforestation, avoided deforestation, and improved forest, cropland and grazing land management practices) and enhanced use of renewable energy technologies (hydropower, windpower and biofuels) could have potential positive or negative impacts on biodiversity. The environmental and social impacts of such projects could be assessed, and the risks of negative impacts can be reduced, through the application of sound environmental and social impact assessment methodologies, selection criteria, appropriate management and the involvement of local communities. Avoided deforestation projects in threatened/vulnerable forests that contain assemblages of species that are unusually rich, globally rare, or unique to that region can provide greatest biodiversity co-benefits with the avoidance of carbon emissions.

There are a series of climate change adaptation options that can beneficially affect the conservation and sustainable use of biodiversity and there are activities to promote the conservation and sustainable use of biodiversity that reduce the impact of changes in climate on biodiversity. These include the establishment of a mosaic of inter-connected terrestrial and marine multiple-use reserves and protected areas, designed to take into account projected changes in climate, and integrated land and water management activities that reduce non-climate pressures on the biodiversity and hence makes the system less vulnerable to changes in climate.

The effectiveness of adaptation and mitigation options 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, and sustainable development objectives, the objectives of other multilateral environmental agreements (e.g. the Convention on Biological Diversity) and a broad range of issues relating to the conservation, management, and sustainable development of agriculture and forests. A system of criteria and indicators could be developed and adopted on a national or multinational basis to assess and compare sustainable development impacts across alternative adaptation and mitigation activities. Potential tools, such as environmental screens and the application of project-, sector- and regional-level environmental and social impact assessments could be adapted from existing tools and then used to quantitatively assess the synergies and tradeoffs, against a set of criteria and indicators, related to activities under the UNFCCC and its Kyoto Protocol on biodiversity and sustainable development.

Identified information gaps include the need for better and appropriate resolution climate change and ecosystem transient models especially for quantification of the impacts of climate change on biodiversity, adaptation and mitigation options for climate change on biodiversity and the feedbacks for changes in biodiversity on climate change. Evaluation of case studies of adaptation and mitigation projects could help to develop future guidelines, tools and indicators.

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

The Subsidiary Body for Scientific, Technical, and Technological Advice (SBSTTA) of the UN Convention on Biodiversity (CBD) formally requested 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 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 4-6 April 2001) and was approved at the Eighteenth Session (Wembley, UK, 24-29 September 2001).

All of the information contained in this Technical Paper is drawn from approved/adopted/accepted IPCC reports, in particular 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).

This Techincal Paper summarizes the material that is in the IPCC reports of relevance to the UNCBD's request. However, it is recognized that there is limited material available in the IPCC reports to address some of the issues raised by United Nations Convention on Biological Diversity.

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". Climate change directly affect the functions of individual organisms (eg. growth, behavior), modifies populations (eg. size and age structure) and affects ecosystem structure and function (eg. such as decomposition, nutrient cycling, water flows, species composition) and the distribution of ecosystems within landscapes.

2.2. Importance of Biodiversity in Meeting Human Needs

This paper considers biodiversity that occurs in both intensively (agriculture, plantation forestry and aquaculture) and non-intensively (pastoral lands, native forests) managed ecosystems.

Ecosystems provide many goods and services that are crucial to human survival and particularly important for indigenous, pastoral and rural communities as they are directly dependent on many of these goods and services. 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 and recreation. Ecosystems play a critical role in biogeochemical processes that underlie the functioning of the earth's systems.

2.3. Pressures on Biodiversity from Human Activities

The earth is subjected to many human induced and natural pressures, often collectively referred to as global change. These include pressures from increased demand for resources, land-use and land-cover change, the accelerated rate of anthropogenic nitrogen production, air, water and soil pollutants, introduction of exotic species and urbanisation and industrialisation that result in fragmented landscapes. Climate change[1] constitutes an additional pressure on many ecosystems and the goods and services they provide. (TAR WGII, Chapter 5.1)

[FOOTNOTE 1: IPCC defines *climate change* as any change in climate over time, whether due to natural variability or as a result of human activity.]

2.4. IPCC Definitions of Impacts, Adaptation, and Mitigation

The projected changes in climate include increasing mean global temperatures, changes in precipitation, sea level rise and increased frequency and intensity of some extreme climatic events leading to increased climate variability. The impacts 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, pest and diseases). Adaptation measures could reduce some of these impacts. Systems are considered to be vulnerable[2] if they are exposed and/or sensitive to climate change and/or the 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 emission 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.

[FOOTNOTE 2: 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 (TAR WGII SPM-Box1).]

3. Observed Changes in Climate

Observational evidence demonstrates that the composition of the atmosphere (especially greenhouse gases such as carbon dioxide and methane) and the Earth's climate system (i.e., temperature, precipitation, sea level, extreme climatic events including floods, droughts, and storms) is changing. These changes affect biodiversity and are thus summarized below. For example, the concentration of CO_2 in the atmosphere affects the rate and efficiency of photosynthesis and can affect the productivity of plants and thus other ecosystem functions. Climatic factors affect plant and animal productivity as well as ecosystem processes.

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

The atmospheric concentrations of greenhouse gases have generally increased over the 20th century as a result of human activities. Almost all greenhouse gases reached their highest recorded levels in the 1990s and continue to increase. During the period 1750 to 2000, the atmospheric concentration of CO_2 increased by 31±4%, (figure 1) primarily due to the combustion of fossils fuels, agriculture and land-use changes. Over the 19th and for much of the 20th century the terrestrial biosphere has been a net source of atmospheric CO_2, but before the end of the 20th century it had become a net sink. The atmospheric concentration of CH_4 increased by 151±25% from 1750 to 2000, primarily due to emissions from energy use, livestock, rice agriculture, and landfills. [TAR WGI Chapters 3 & 4, & Special Report on Aviation and Global Atmosphere]

[FIGURE 1 CAPTION: Records of past changes in atmospheric composition over the last millennium demonstrate the rapid rise in carbon dioxide (CO_2) that is attributable primarily to industrial growth since 1750. The panel shows increasing atmospheric concentrations of CO_2 over the past 1,000 years. Early sporadic data taken from air trapped in ice (symbols) matches up with continuous atmospheric observations from recent decades (solid lines). The gas is well mixed in the atmosphere, and its concentration reflects emissions from sources throughout the globe. The estimated positive radiative forcing from this gas is indicated on the righthand scale.] [SYR Figure 2-1 & WGI TAR Figures SPM-2, 3-2b, 4-1a, 4-1b, 4-2, & 5.4a]

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 (figure 2), and it is likely[3] 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* 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 night-time temperatures have warmed more than day-time temperatures. Since the year 1950, the increase in sea surface temperature is about half that of the 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. [TAR WGI SPM & TAR WGI Chapters 2.2.2.4, 2 and 12]

[FOOTNOTE 3: The following words have been used throughout the text relating to WGI findings: *virtually certain* (greater than 99% chance that a result is true); *very likely* (90–99% chance); *likely* (66–90% chance); *medium likelihood* (33–66% chance); *unlikely* (10–33% chance); *very unlikely* (1–10% chance); and *exceptionally unlikely* (less than 1% chance). An explicit uncertainty range (±) is a *likely* range. Estimates of confidence relating to WGII findings are: *very high* (95% or greater), *high* (67–95%), *medium* (33–67%), *low* (5–33%), and *very low* (5% or less). When these lexicons appear in italics, they are as defined above, otherwise they are used as in normal usage.]

[FIGURE 2 CAPTION: 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 th 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 could be in part 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 such as the North Atlantic and Arctic Oscillations. As described in the text, warming in some regions is linked with observed changes in biological systems on all continents.] [WGI TAR Figures TS-3 & 2.9]

Precipitation has* very likely *increased during the 20th century by 5 to 10% over most mid- and high latitudes of the Northern Hemisphere continents, but in contrast, rainfall has *likely* decreased by 3% on average over much of the subtropical land areas (figure 3). Increasing global mean surface temperature is *very likely* to lead to changes in precipitation and atmospheric moisture because of changes in atmospheric circulation, a more active hydrologic cycle, and increases in the water-holding capacity throughout the atmosphere. There has *likely* been a 2 to 4% increase in the frequency of heavy precipitation 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, but in many regions these changes are dominated by inter-decadal and multi-decadal climate variability with no significant trends evident. [TAR WGI SPM & chapters 2.5, 2.7.2.2, & 2.7.3]

[FIGURE 3 CAPTION: 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 th 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. Over this period, there were relatively small long-term trends in land areas experiencing severe drought or severe wetness, but in many regions these changes are dominated by inter-decadal and multi-decadal climate variability that has no trends evident over the 20th century.] [SYR Figure 2-6a & WGI TAR Figure 2-25]

3.3. 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. [TAR WGI SPM & Chapter 2]

3.4. Observed Changes in Extreme Climatic Events

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

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

Snow cover and ice extent have decreased. It is *very likely* 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* 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 a 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 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. [TAR WGI SPM & Chapter 2]

Sea level has increased: Based on tide gauge records, after correcting for 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 consistent with model simulations and occurs through thermal expansion of seawater and widespread loss of land ice. [TAR WGI SPM, Chapters 2.2.2.5 & 11.2.1]

[Insert Table 1 here] [SYR Table SPM-1]

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 result of human activities). Emissions of greenhouse gases and aerosols due to human activities, which warm and cool the Earths climate respectively, change the composition of the atmosphere. Carbon dioxide 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 and sea level, compared to the global mean change. An increase in climate variability and some extreme events is also projected.

The Working Group I report of the IPCC Third Assessment provided revised global and to some extent, regional climate change projections based on a new series of emission scenarios from the IPCC Special Report of Emissions Scenarios (SRES). The SRES scenarios 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 change, social, economic and broad technological developments (see Box 1). Each of these scenarios results in a set of greenhouse gas emission trajectories. (TAR WGI, SPM & chapter 4.3)

Box 1. The Emission Scenarios of the Special Report on Emission Scenarios (SRES)

A1. The A1 storyline and scenario family describes 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 describes 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 describes a convergent world with the same global population, that 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 describes 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.

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

All emissions scenarios used in the IPCC Third Assessment Report 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 about 280 ppm in the pre-industrial era and about 368 ppm in the year 2000. The different socio-economic assumptions (demographic, social, economic, and technological) result in different levels of future greenhouse gases and aerosols. Further uncertainties, especially regarding the persistence of the present 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). [TAR WGI Chapter 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 2100 in all six illustrative SRES scenarios, where-as 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. [TAR WGI Chapter 9.3.3 & 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* 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 northern regions of 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 (figure 4). [TAR WGI Box 3.7 & Chapter 10.3.2]

[FIGURE 4 CAPTION: Annual mean change of temperature for the SRES scenario A2. The scenario shows the period 2071 to 2100 relative to the period 1961 to 1990, and was performed by AOGCMs. The global mean annual average warming of the models used spans 1.2 to 4.5°C for A2, and therefore a regional 40% amplification represents warming ranges of 1.7 to 6.3°C.] [SYR Figure 3-2a, WGI TAR Figures 9.10d & 9.10e, & WGI TAR Box 10.1 (Figure 1)]

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* 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 (figure 5). Larger year-to-year variations in precipitation are *very likely* over most areas where an increase in mean precipitation is projected. [TAR WGI Chapters 9.3.1 & 10.3.2]

[FIGURE 5 CAPTION: Annual mean change of rainfall for the SRES scenario A2. The scenario shows the period 2071 to 2100 relative to the period 1961 to 1990, and was performed by AOGCMs.] [SYR Figure 3-3 & WGI TAR Box 10.1 (Figure 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. There is projected to be a decrease in diurnal temperature range in many areas, with nighttime lows increasing more than daytime highs. A number of models show a general decrease of daily variability of surface air temperature in winter and increased daily variability in summer in the Northern Hemisphere land areas. 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* 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 pattern such as the North Atlantic Oscillation (NAO). [TAR WGI Chapters 9.3.6 & 9.3.5, & TAR WGII Chapter 14.1.3]

The amplitude and frequency of extreme precipitation events is* very likely *to increase over many areas and the return period 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* to lead to increases in summer droughts and could increase the risk of wild fires. 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* that global warming will lead to an increase in the variability of Asian summer monsoon precipitation. [TAR WGI Chapter 9.3.6, TAR WGII Chapters 4, 9, & 5.3]

More hot days and heat waves and fewer cold and frost days are* very likely *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. A number of models show a generally decreased daily variability of surface air temperature in winter and increased daily variability in summer in Northern Hemisphere land areas. [TAR WGI Chapters 9.3.6 & 10.3.2, & TAR WGII Chapters 5.3, 9.4.2, & 19.5]

High resolution modeling studies suggest that over some areas the peak wind intensity of tropical cyclones is* likely *to increase 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. [TAR WGI 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. [TAR WGI Chapter 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* to gain mass because of greater precipitation, while the Greenland ice sheet is *likely* to lose mass because the increase in runoff will exceed the precipitation increase. [TAR WGI Chapter 11.5.4]

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 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 factors. 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. [TAR WGI Chapters 11.5.1 &11.5.2]

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

Human activities have led to loss of biodiversity in many regions and the degradation of many ecosystems primarily due to soil and water degradation, habitat fragmentation, selective exploitation of species and the introduction of exotic species. Climate and climate change can affect biodiversity, including ecosystems in many ways (see Box 2); climate change has already contributed to observed changes in terrestrial and marine ecosystems in recent decades. [WGII TAR 5.1 & 5.2]

Box 2. Climate Change and Ecosystems

Climate is the major controlling factor of the global patterns of vegetation structure and plant and animal species composition. Many plants can successfully reproduce and grow only within narrow temperature ranges and require specific seasonal precipitation patterns to successfully compete for space within an ecosystem. Animals also have distinct temperature 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. Extreme climatic events and variability are currently a major source of climate-related impacts. For example, the El Niño event of the years 1997–1998 had major impacts on many terrestrial (both intensively and non-intensively managed, eg. agriculture, wetlands, rangelands, forests) and coastal ecosystems (eg. coral reefs) affecting the human populations that rely on them. Extreme events including floods, hail, tropical cyclones, landslides, droughts and wildfire in many continents have affected ecosystems.

Climate variability and extremes can 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 El Nino events, show the importance of the interaction between climate and human actions in determining the structure and composition of tropical forests and land-use patterns.

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

IPCC evaluated the relationship between climate change and biodiversity, by assessing 3000 studies of which 43 met the criteria of being carried over 10 years and more, having temperature as a variable being measured and the authors of the original studies found a statistically significant change in a biological/physical parameter and the measured temperature and a statistically significant correlation between temperature and a change in the biological/physical parameter. Some of these studies investigated different taxa (e.g., bird and insect) in the same paper. Thus, a total of 39 physical processes (in one study only), 117 plants, 65 insects, 63 amphibians and reptiles, 209 birds and 10 mammal species were examined in the 43 studies. Excluding the study on physical processes, approximately 39% showed no change in the biological parameter, while the changes seen in the other 61% included changes in start and end of breeding season, shifts in migration patterns, shifts in animal and plant distributions and changes in body size). Most of these studies have been carried out (due to 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 (eg. high altitude and latitude ecosystems and coral reefs) have already been affected by changes in climate. [TAR WGII Chapter 5.2 & 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 (phenology), the growing season, 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 (e.g., fires, droughts, blowdowns), intensity, and frequency of disturbances that are affected by regional climatic change (anthropogenic or natural) 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. [TAR WGII Figure SPM-2, Chapters 5.4, 5.6.2, 5.6.2.2, 10.1.3.2, 11.2, & 13.1.3.1 & SYR 2.21]

Changes in phenology [timing] have been observed. Such changes have been recorded for many species [TAR WGII Chapter 5.4.3.1, Table 5.3]; for example:

- Warmer conditions during autumn-spring affect the timing of emergence, growth and reproduction of some cold hardy invertebrate species; experimental work on spittlebugs [*Philaenus spumarius*] found that they hatched earlier in winter-warmed (3°C above ambient) grassland plots.
- Two frog species at their northern range limit in the UK spawned 2-3 weeks earlier from the start to end of the study period (1978-1994). 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 UK, 20 of 65 species, on average, including long-distance migrants, advanced their egg-laying dates by 8 days between 1971 and 1995.
- Changes in insect and bird migration with earlier arrival dates of spring migrants in the US, later autumn departure dates in Europe, and changes in migratory patterns in Africa and Australia.
- Mismatch in the timing of breeding of bird species, eg. *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 (eg. across Europe by about 11 days from the years 1959 to 1993).

Many species have undergone changes in morphology, physiology and behavior as a response to changes in climatic factors. For example, painted turtles grew larger in warmer years or warmer starts and during warm sets of years, turtles reached sexual maturity faster; body weight of North American wood rat (*Neotoma spp.)* has declined with a increase in temperature over the last eight years, and Juvenile red deer (*Cervus elaphus*) in Scotland grew faster in warmer springs leading to increases in adult body size. [TAR WGII Chapter 5.4.3.1]

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 each major taxonomic group of animals (ie, insects, amphibian, birds, mammals). 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. 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 dragon flies *(*Odanata*)* and cockroaches, grasshoppers and locusts (Orthoptera*)*. [TAR WG II Chapters 5.43.1.1, 13.2.2.1]
- The spring range of Barnacle Geese [*Branta leucopsis*] has moved north along the Norwegian coast. The elevational range of some birds in the Costa Rican tropical cloud forest may also be shifting. [TAR WG II Chapters 13.2.2.1 & 5.43.1.1]
- The distribution of vectors (eg., malaria and dengue), food-, and water-borne (eg. diarrhoea) infectious diseases and 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 [TAR WGII Chapters 9.5.1 & 9.7.8].

Changes in climatic variables has 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. Examples of pests and disease include spruce budworm in boreal forests. Outbreaks frequently follow droughts and/or dry summers. The pest-host dynamics are affected by the drought increasing the stress of host trees and the number of spruce budworm eggs laid (eg., the number of spruce budworm eggs laid at 25° C is 50% greater than the number laid at 15°C). In some areas drought and higher temperatures have also shifted the timing of reproduction in budworms such that they can no longer be affected by some of their natural parasitoid predators and extreme climatic events. For example, some outbreaks in late spring have increased due to fewer frost days leading to populations of larvae being too high (1 million larvae / ha) for effective control by bird predation. [TAR WGII Chapters 5.6.2 & 5.6.3]

Changes in stream flow, floods, droughts and water quality have been observed to affect biodiversity. Evidence of regional climate change impacts on elements of the hydrological cycle suggests that warmer temperatures lead to intensification of the hydrological cycle. Peak stream flow has shifted back from spring to late winter in large parts of eastern Europe, European Russia, and North America in the last decades. The increasing frequency of droughts and floods in some areas is related to variations in climate—for example, 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 (eg. those in 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 the siltation in rivers. This along with increased use of chemicals affects the river chemistry and has led to eutrophication, with major implications for water quality, ecological community composition and fishery. The changes in stream flows have affected the goods and services (eg. fish production from freshwater fisheries, water flow from wetlands) from the ecosystems. Increases in water temperature have caused an increase in summer anoxia in deep waters of stratified lakes with possible effects on their biodiversity. [TAR WGI SPM, TAR WGII SPM, Chapters 4.3.6, 10.2.1.1, 10.2.1.2, 10.2.5.3, 10.4.1, 14.3, & 19.2.2.1, & Table 4-6]

High-latitude ecosystems in the northern hemisphere have been affected by regional climate change. For example, in the Arctic extensive land areas show a 20th-century warming trend in air temperature of as much as 5 ^{0}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 of about 100 km °C^{-1}. There are altered plant species composition, especially forbs and lichens, on 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 past several decades. [TAR WGII Chapters 1.3.1, 5.2, 5.9, 13.2.2, 13.6.2, 10.2.6, & 14.2.1]

5.2. Observed Changes in Coastal and Marine Systems

Coral reefs have been adversely affected by rising sea surface temperatures. 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 in any one season, and extensive mortality has occurred for a 3°C rise. This typically occurs during El Niño events, eg. widespread bleaching, leading to death of some corals, occurred globally in 1997-98 associated with a major El Nino event when sea surface temperature anomalies (ie the difference between the long-term mean and 1997-1998) were the most extreme in the past 95 years. Bleaching events may have been accelerated by opportunistic infections of the reef system. In addition bleaching events are often associated with other stresses such as pollution. [TAR WGII Chapters 6.4.5, 12.4.7, 17.4.2]

Diseases and toxicity have affected coastal ecosystems. Changes in precipitation frequency and intensity, pH, water temperature, wind, dissolved carbon dioxide, and salinity can all affect water quality in estuarine and marine waters. Some marine-disease organisms and algal species are strongly influenced by one or more of these factors. In the past few decades there has been an increase in reports of diseases affecting coral reefs and seagrasses, particularly in the Caribbean and temperate oceans. ENSO cycles and increased water temperatures have been correlated with Dermo disease (caused by the protozoan parasite *Perkinsus marinus*) and MSX (multinucleated spore unknown) disease in oysters along the U.S. Atlantic and Gulf coasts. [TAR WGII Chapters 6.3.8, 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 results of fishing for cod during a period of three hundred years (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, 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. [TAR WGII Chapters 6.3.4, 10.2.2.2, 14.1.3, & 15.2.3.3, Box 6-1 & TAR WGI Chapter 2.6.3]

Large fluctuations in abundance of marine birds and mammals across the north Pacific and western Arctic have been suggested to be related to climate variations and change. 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). Sea birds abundances are dependent on specific species of fish, particularly during breeding season and sensitive to small changes in the ocean environment such as that resulting from climate change. Decline of some sea bird species, and increased abundance of a few common ones and changes in some species ranges have been associated with changes in current systems (eg. 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 populations, 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 Chapter 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 distributions and ecosystem composition and function both directly (for example through increases in temperature, changes in precipitation and in the case of marine systems changes in water temperature and sea level etc) and indirectly (for example 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 reconnection in the case of freshwater bodies) and the introduction of exotic species (invasives). No realistic projection of the future state of the earth's ecosystems can be made without taking into account human land-use patterns; past, present and future. Human land-use will endanger some ecosystems, enhance the survival of others and greatly affect the ability of organisms to adapt to climate change via migration.

Protecting threatened and endangered species requires measures that, in general, reverse the trend towards rarity. Without management, rapid climate change, in conjunction with other pressures is likely to cause most species currently classified as critically endangered to become extinct and the majority of those labelled endangered or vulnerable to become much rarer, and thereby closer to extinction, in the 21st century. [TAR WG II Chapter 5.4.1]

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 wildlife (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 indigenous 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 each species plays in ecosystem services is necessary to understand the risks and possible surprises associated with species loss. Without this information the probability of surprises associated with species loss is high. [TAR WGII Chapter 5.4]

6.1. Modeling Approaches Used for Projecting Impacts of Climate Change on Biodiversity

Most models of ecosystem changes are not well suited to projecting changes in regional biodiversity. A large literature is developing on modelling 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 projecting changes in regional biodiversity. Another field of modelling deals with long-term changes in vegetation distributions under climate change. These models usually deal with higher-level entities such as ecosystems or biomes (the collection of ecosystems within a particular climatic zone with similar structure but differing species, eg 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 and structure. There is only a small, but steadily increasing, literature on modelling changes in biodiversity *per se* usually at regional to global scales [TAR WGII, Chapter 5.2].

There are two basic approaches to modelling the way ecosystems (and thus biomes) will respond to global change. The ecosystem movement approach assumes that ecosystems will migrate relatively intact to new locations that are close analogues 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. [TAR WGII, Chapter 5.2]

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. Palaeo-ecological 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. [TAR WGII, Chapters 5.2; Box 5-2, 5.4.3.1.4]

The problem with the ecological 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. 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 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. [TAR WGII, Chapters 5.2, 5.4]

Models need to deal with the spatial interactions between ecosystems within landscapes to capture the responses of ecosystems to pressures, including climate change. Most vegetation models still treat the patches of vegetation as a matrix of discrete units with little interaction between each unit. However, modelling 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 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. [TAR WGII Chapter 5.2.4.1]

Another challenge is to develop realistic models of plant migration. Palaeoecological, modelling and observational data suggest that dispersal would not be a significant problem for most species in adapting to climate change, providing the matrix of suitable habitats was 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 [TAR WGII Chapter 5.2].

6.2. Projected Impacts on the Biodiversity of Terrestrial Systems

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

In summary, biodiversity is forecast to decrease in the future due to a multitude of pressures, in particular increased land-use intensity and the associated destruction of natural or semi-natural habitats**.** The multitude of pressures on biodiversity are occurring independent of climate change, so the critical question is how much might climate change enhance or inhibit these losses in biodiversity? There is little evidence to suggest processes associated with climate change will slow the present rate of species loss**.** [TAR WGII Chapter 5.2]

6.2.1. Impacts on Individuals, Populations, and Species Level

Changes in phenology are expected to occur in many species. Changes in phenology, such as bud break, leaf fall, hatching date, migration dates 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. Continuation of 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. An example is where a plant responds to signals from both temperature and day length. Similarly, 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 predict. Changes in temperature can also have direct physiological effects on many organisms that may upset their life cycle, for example, the temperature experienced while still within their eggs affects sex determination in reptiles. [TAR WGII Chapters 5.4.3.1, 5.5.3.2 & Table 5.3]

Increased variability in rainfall patterns can have significant threshold effects on populations of many organisms. Unusually early or late opening rains in highly seasonal areas (e.g. the wet-dry tropics) can affect the availability of forage for livestock and other mammals and affect the occurrence and susceptibility of these animals to pests and diseases. For example, the Miombo woodlands, which are sensitive to the arrival of spring rains, might undergo significant changes in plant dominance and animal populations if there is a shift in the rainfall patterns. 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. [TAR WGII Chapter 5.3.3.2]

Many taxa from around the world will show range shifts towards higher latitudes or higher elevations in response to climate change. 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. Most climate change scenarios suggest a possible overall displacement of the climatic zone suitable for boreal forests by 150-550 km northwards over the next century. This shift in climatic conditions would occur more rapidly than most species have ever migrated in the past (20-200 km per century). It is also questionable whether soil structural development could keep pace with the changing climate. The northward 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. The species composition of forests are likely to change, entire forest types may disappear, while new assemblages of species may be established. The turnover of the current tree populations may however be enhanced by changes in management practices and changing disturbance regimes. [TAR WG II 13.2.2.1 & 16.2.7.2]

Species composition and water quality could be affected by changes in water temperatures. Climate change will have its most pronounced effect on wetlands through alterations in hydrological regimes, specifically, the nature and variability of the hydroperiod and the number and severity of extreme events. However, other climatic-related variables may play an important role in determining regional and local impacts. Temperature changes have significant impacts on the rates of biological processes in aquatic systems and thus ultimately species composition. Increased temperatures will alter thermal cycles of lakes and solubility of oxygen and other materials. Reduced oxygen concentration could lead to altered community structure, usually characterized by fewer species, especially if exacerbated by eutrophication related to land use practices. Modelling studies suggest that lakes located in subtropical zones (about 30 to 45º latitude) and in subpolar zones (about 65 to 80º latitude) will be subject to greater relative changes in thermal stratification patterns than mid-latitude or equatorial lakes; deep lakes are likely to be more sensitive than shallow lakes in the subtropical zones. Warmer lake temperatures in cold regions would also result in loss of winter ice cover**.** In high latitude lakes ice cover duration and ice break-up dates are among the determinants of species composition, particularly that of diatom species. Changes in sediment transport due to altered hydrology could affect stream fauna biodiversity by habitat alteration, such as the conversion of riffle fauna to interstitial sandy bottom river communities. [TAR WG II Chapters 4.3.7, 4.3.10, 5.6]

More persistent thermal stratification of lakes with warming could reduce secondary productivity and affect species composition. Greater anoxia in the hypolimnion may eliminate a refuge from predation or from thermal stress. Warmer epilimnetic temperatures could decrease the nutritional quality of edible phytoplankton or shift the species composition of the phytoplankton community toward less-preferable cyanobacteria and green algae. Higher 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. [TAR WGII Chapters 4.4, 4.5.2, 4.3.10 & SAR SPM 3.1]

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. Thermal optima for many cold-water taxa from the mid- and high latitudes are less than 20°C***;*** summer temperatures could exceed thermal tolerances and reduce production as well as affect changes in species composition as listed above. In streams, ecological effects could be strongest in humid regions where stream flows are less variable and biological interactions control organism abundance. [TAR WGII Chapters 4.4 & SAR Chapter 10.6.1.1].

6.2.2. Ecosystem Responses and Biodiversity Maintenance

The previous section outlined some examples of how individuals, populations and species will 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/communities. 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 exotic species and further disruption. Thus, the impacts of climate change, and their effects on biodiversity, must 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 disturbance and extreme events.

In summary, increased disturbances along with the shift in habitats and the more restrictive conditions needed for establishment of species could lead to abrupt breakdown of terrestrial and marine ecosystems, which could result in new plant and animal assemblages. [TAR WGII Chapter 5.2 &SYR 4.18]

Species composition will be affected by climate change directly and via interactions with other factors. Ecosystem models suggest that on a broad scale, and subject to suitable edaphic conditions, there will be northward expansion of the boreal forest into the tundra region. In Northern Europe, vegetation change is likely to be complicated due to the influence of geometrid moths, which can cause large-scale defoliation of the boreal forests when winter temperatures are above +3.6°C; empirical models suggest that by 2050, only one-third of the boreal forests of Northern Europe will be protected by low winter temperatures. The northward movement of forest may also lag behind changes in temperature by decades to centuries. Increases of large fires, and changes caused by thawing of permafrost will also affect ecosystem functioning. The species composition of forests are likely to change, entire forest types may disappear, while new assemblages of species may be established. 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 is likely to lead to an increase in geographic distribution of C_3 (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, number of frost days. The rate and duration of this change is likely to be affected by the human activity where a high grazing pressure may mean more establishment sites for the C_4 grasses. [TAR WGII Chapters 5.5, 5.6, 13.2, 15.2 &16.2.7]

Most soil biota have relatively wide temperature optima and 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 litter supply and the distribution of fine roots in soils. The distribution of individual species of soil biota will be affected by climate change where species are associated with specific vegetation and are unable to adapt at the rate of land cover change. [TAR WGII 13.2.1.2].

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 reorganisation. This will disrupt established ecosystems and create new assemblages of species that may be less diverse and include more “weedy” species [TAR WGII Chapters 5.2, 10.2.3.1, 19.1].

Ecosystems dominated by long-lived species (e.g. long-lived trees) will often be slow to show evidence of change. 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 will be slow and often the new habitats will have been occupied by weedy species that were able to disperse and establish quickly. [WGII TAR Chapters 5.2, 5.6.2, SYR 5.8].

Changes in climatic variables are projected to lead to increased frequency and intensity of disturbances, such as fires, and outbreaks of pests. Warmer summer temperatures are likely to contribute to more frequent or intense fires in many regions. 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. This could be accompanied by range shifts poleward or to higher altitudes of the pests/disease organisms. [TAR WGII Chapter 5.5.3, 5.6.4]

Changes in disturbance regimes associated with climate change may lead to rapid changes in vegetation composition and structure and will tend to reduce productivity and carbon stocks. 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. The pest-host dynamics are affected by the drought leading to increased stress of host trees and increasing the number of spruce budworm eggs laid. In some areas drought and higher temperatures also shifts the timing of reproduction in budworms such that they may no longer be affected by some of their natural parasitoid predators and extreme climatic events; budworm larvae feed on the trees' new growth in spring but are often deprived of food by spring frosts that kill the young leaves. Warmer weather will lead to fewer spring frosts and fewer checks on the build up of the budworm. The control of some populations of eastern spruce budworm may be strongly aided by bird predators, especially some of the wood warblers, but once populations exceed a threshold, bird predation is unable to substantially affect budworm populations. 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. A changing climate might also decouple some budworm populations from those of their parasitoid and avian predators. Distributions 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. [WGII TAR Chapters 5.6.2 & 5.6.3]

Changing disturbance regimes can interact with climate change to affect biodiversity often via rapid, discontinuous ecosystem "switches". Ecosystem switches are accompanied by drastic species shifts and even species extinction. For example, changes in the grazing and fire regime during the past century are thought to have increased the woody-plant density over large parts of Australia and southern Africa. Large scale ecosystem switches (e.g. savanna to grassland, forest to savanna, shrubland to grassland) clearly occurred in the past (e.g. during the climatic amelioration dating from the last glacial maximum 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 switches in some areas. The shifts in geographical range required to conserve biodiversity into the future will be strongly constrained by habitat fragmentation, and cannot realistically be accommodated by the nature reserve network evident in some regions. [TAR WGII 5.4, 5.5, 10.2.3, 11.2.1, 12.4.3 & 14.2.1]

The theory required to predict the extent and nature of future ecosystem switches and species geographical shifts is lacking, and there are few case studies. The response of major vegetation types to changes such as rising atmospheric CO_2 are mostly unstudied. However, existing evidence indicates the complexity of the responses. 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. The final outcome depends on the precise balance between opposing pressures and is likely to vary both spatially and through time as that balance shifts. [TAR WGII Chapters 5.5, 5.6]

Models of changes in the global distribution of organisms 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 the GCM are being developed and used for assessments of the overall carbon storage potential of the land 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 interannual variability in precipitation and thus water availability. Other challenges are to simulate the loss of vegetation due to disturbances such as fire, blowdown 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 migration. Modification of the IMAGE2 model to include unlimited migration, limited migration and no migration results in significantly different patterns of vegetation change especially in high latitude regions. [TAR WGII Chapters 5.2.2, 5.2.4.1, 10.2.3.2]

Overall, biodiversity is forecast to decrease in the future independent of climate change, due to a multitude of pressures, in particular increased land-use intensity and the associated destruction of natural or semi-natural habitats. The most significant processes are habitat loss and fragmentation (or reconnection in the case of freshwater bodies), the introduction of exotic species (invasives), 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 species thus allowing them to capitalize upon global change. The doubling of nitrogen input into the terrestrial nitrogen cycle due to human activities appears to be leading to the accelerated losses of biological diversity among plants adapted to efficient use of nitrogen and the animals and micro-organisms that depend on them. In a few cases there might be an increase in local biodiversity but this is usually as a result of species introductions and the longer-term consequences of these changes are hard to foresee. [TAR WGII Chapter 5.2 & 5.7]

How much might climate change enhance or inhibit these losses in biodiversity? **There is little evidence to suggest processes associated with climate change will slow species losses**. Palaeoecology data suggest that the global biota should produce an average of three new species per year but with large variation about that mean between geological eras. Pulses of speciation sometimes appear to be associated with climate change, although moderate oscillations of climate do not necessarily promote speciation despite forcing changes in species' geographical ranges. [TAR WGII Chapter 5.2.3]

6.2.3. Biodiversity and Changes in Productivity

Changes in biodiversity and the changes in ecosystem functioning associated with them may affect biological productivity (see Box 3). These changes may affect critical goods and services upon which human societies rely (e.g. food and fibre). 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.

Box 3. Productivity and Associated Terms

Productivity can be measured in several ways, including net primary productivity and net ecosystem and net biome productivity. 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 (eg fires) and chemical oxidation. The Gross Primary Productivity (GPP) is the total uptake through photosynthesis whereas Net Primary Productivity (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 called the Net Ecosystem Production (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 called Net Biome Productivity (NBP). Mitigation responses based on the long-term sequestration of carbon rely on increasing the NBP. [TAR WGI Chapter 3.2.2, WGII 5.2]

At the global level, net biome production appears to be increasing. Modelling studies 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 increased CO_2 concentrations, to climate warming at high latitudes and to nitrogen deposition. A significant contribution also comes from significant areas of reforestation, especially in temperate regions where former farming land has been set aside or abandoned. [LULUCF Chapter 1.2]

The loss of biodiversity from an ecosystem due to climate change does not necessarily translate into a decrease in productivity. The global distribution of biodiversity is determined largely by global temperature and precipitation patterns. 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 in biodiversity. 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 by another species (sometimes an invasive species). Where significant ecosystem disruption occurs (e.g. loss of dominant species or losses of a high proportion of species and, thus, much of the redundancy) there may be significant losses in net ecosystem productivity during the breakdown. [SAR WGII Chapter 1.2, TAR WGII Chapters 5.2, 10.2.3.1 & SYR 3.18]

The role of biodiversity in maintaining ecosystem structure, functioning and productivity is poorly understood. However, it is an area of active theoretical and experimental research and rapid advances in understanding can be expected [TAR WGII Chapter 13.2.2]

6.3. Projected Impacts on Biodiversity of Coastal and Marine Systems

Marine and coastal systems are affected by many human activities (eg. coastal development, tourism, land clearance, pollution and over exploitation of some species) leading particularly to the degradation of coral reefs, mangroves, and sea grass and beach ecosystems. Global warming and sea level rise will add to these stresses. Projected changes suggest that climate change and sea-level rise will cause shifts in biotic composition and adversely affect competition among some species. Rising atmospheric CO_2 concentrations are projected to increase the productivity of some communities and alter competition of others by eliminating some species and introducing new species to take their place [WGII TAR 17.2.5].

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. Coral bleaching is likely to become widespread by 2100 (see section 5.2 for observed impacts on coral reefs) as sea surface temperatures is projected to increase by at least 1-2°C. The frequency and intensity of the bleaching events is likely to be highest in the Caribbean and slowest in the central Pacific. 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. [TAR WGII Chapters 6.4.5, 17.2.4]

Up to about a fifth of coastal wetlands could be lost by 2080 as a consequence of sea level rise. The proportion of the coastal wetlands lost could vary considerably, but sea level rise along with other human activities could affect mangroves, salt marshes and some sub-tidal seagrasses detrimentally. [TAR WGII Chapter 6.4.4]

Mangroves may not be able to migrate as sea level rises. Mangroves occupy a transition zone between sea and land that is set by a balance between the erosional processes from the sea and siltation/depositional processes from land. The erosional processes from the sea might be expected to increase with sea-level rise and the siltation processes through climate change and other human activities (e.g., coastal development). Thus, the impact on the mangrove forests will be determined by the balance between these two processes, which will determine whether mangrove systems migrate landward or seaward. In some protected coastal settings, inundation of low-lying may promote progressive expansion of mangroves as sea level rises thus accommodating high rates of sea-level; those with low sediment supply may not keep up with sea-level rise. This may depend on stand composition and status and other factors, such as tidal range and sediment supply from both depositional and erosional processes. In contrast, the complete collapse of a mangrove wetland in Jamaica is projected under rapid sea-level rise; with a 1 m increase in sea level in Cuba some 300,000 ha of mangrove, 3% of the total, would be at risk. [TAR WGII SPM, Chapters 6.4.4, 14.2.3, 14.3 &17.2.4].

In some areas the current rate of marsh elevation gain is insufficient to offset relative sea-level rise. Maintenance of productive marshes in settings with sufficient sediment influx could result in the wetland expanding toward the estuary, while also expanding landward if the backshore slope is sufficiently low and not backed by fixed infrastructure. However, if sediment supply is low, marsh front erosion may occur with a potential for significant loss of coastal wetlands, such as those around the Great Lakes of Canada-USA. [TAR WGII Chapter 6.4.4]

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 sea-grass beds. Further, it could undermine the economic foundation for many small islands that often rely on "stable" coastal environments to sustain themselves.

Deltas that are presently deteriorating, as a result of low sediment supply, subsidence and other stresses, will be particularly susceptible to accelerated inundation, shoreline recession, wetland deterioration and interior land loss. Deltas are particularly at risk from climate change, partly due to natural processes, and partly due to human-induced stresses. Deltas are prone to sea-level rise which will exacerbate current low sediment supply, such as that in the Rhone, Ebro, Indus and Nile deltas. Ground water extraction will also result in relative sea level rise and possibly land subsidence 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 6.4.3]

Sea level rise 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 salt water habitats due to the combined actions of sea level rise, more intense monsoonal rains, and larger tidal/storm surges. Saltwater intrusion into freshwater aquifers is also potentially a major problem. [TAR WGII, Chapters 6.4, 17.4]

Currently eroding beaches, barriers and coastal cliffs are expected to erode further as the climate changes and sea level rises. Coastal erosion, which is already a problem in many islands, 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% (1030 ha) of the land mass of Tongatapu island, Tonga, and 80% (60 ha) of that on Majuro Atoll, Marshall Islands with consequent changes in the overall biodiversity, such as endemic plant species in Cuba, endangered and breeding bird species in Hawaii and other islands, and in Samoa the loss of important pollinators such as flying foxes (*Pteropus sp)*. Along the Pacific coast of North and South America, the more frequent occurrence of El Nino-like events could result in increased cliff erosion and thus changes in biodiversity. [TAR WGII Chapters 6.4.2, 14.2.1.5 &17.2.3]

6.3.2. Projected Impacts on Marine Ecosystems

Climate change will have major positive and negative impacts on the abundance and distribution of marine fish. 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. 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. Continued 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. While 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, a reduction in equator-to-pole temperature gradients could weaken winds, and consequently reduce open-ocean upwelling and lead to changes in species distributions in surface waters. [TAR WGII Chapter 6.3.4]

Climate change could affect food chains, particularly those including marine mammals. For example, extended ice-free seasons in the Arctic could prolong the fasting of polar bears with possible implications for 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 (see also Section 5.2 for observed impacts). Reductions in sea ice could alter the seasonal distributions, geographic ranges, migration patterns, nutritional status, reproductive success and ultimately the abundance of Arctic marine mammals. [TAR WGII Chapter 6.3.7]

Survival of seabirds and their distributions could change as climates shift. Small changes in the ocean environment resulting from climate changes could affect seabird reproductive success (see Section 5.2 for observed impacts). It has been argued that long life-spans, and the genetic variation within populations, enable seabirds to survive adverse short-term environmental events. There are however, very few decadal-scale studies of seabirds that are available to assess the impacts of long-term variations in climate. [TAR WGII Chapter 6.3.7]

Inundation and flooding of low-lying forested islands will lead to the loss of some endemic bird species. On islands, 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/or changes and/or loss in habitat caused by changes in disturbance regimes, such as fires. Some vulnerable species include the endangered New Caledonian lorikeet (*Charmosyna diadema*) and critically endangered New Caledonian rail *(Gallirallus lafresnayanus)*, the Samoan white-eye (*Zosterops samoensis*) and critically endangered Samoan moorhen (*Gallinula pacifica*) and the Santo Mountain starling (*Aplonis santovestris*) and the Manus fantail (*Rhipidura semirubra*). [TAR WGII Chapter 17.2.3]

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

Some taxa are likely to be more susceptible to climate change than others. For example, amphibians could be especially susceptible because they have moist permeable skin and eggs, and often use more than one habitat type and food type in different stages of their life. Many amphibian species appear to be declining, although the exact causes are difficult to determine. [TAR WGII Chapter 5.4.3.1 & Table 5.3]

Species with restricted habitat requirements are typically the most vulnerable to extinction, including many endemic species that could be lost with loss of their habitat. Many mountainous areas have endemic species with narrow habitat requirements that could be lost if they cannot move up in elevation. Biota restricted to islands (eg. forest birds) or peninsulas (eg. fynbos) face similar problems. [TAR WGII Chapters 5.4.1, 17.2.3]

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 occur on low-lying island. Many animal species and populations are already threatened and are expected to be placed at greater risk by the synergy between climate change rendering portions of current habitat unsuitable and land-use change fragmenting habitats and raising obstacles to species migration. Without management, these pressures would cause most species currently classified as "critically endangered" to become extinct and the majority of those labelled "endangered or vulnerable" to become much rarer, and thereby closer to extinction, in the 21st century. [WG II TAR Chapters 5.4.3, 17.2.3]

Ecosystems that may be most threatened by climate change include coral reefs, mangrove forests and other coastal wetlands, montane ecosystems that are restricted to upper 200 to 300 meters of mountainous areas, prairie wetlands, remnant native grasslands, cold water and some cool water fish habitat, ecosystems overlying permafrost, and ice edge ecosystems. Low-elevation coral atolls and reef islands, low-lying deltaic, coastal plain and barrier coasts, and their associated wetland habitats (ie beaches, estuaries, lagoons, salt marshes, mangroves) are considered to be vulnerable to climate change. The current exploitation and destruction of mangrove forests is reducing their resilience to accommodate accelerated sea level rise, storm waves and surges. A study based on expert assessment concluded that by year 2100, ecosystems in mediterranean climates and grassland ecosystems are likely to experience the greatest proportional change in biodiversity because of the substantial influence of all drivers of biodiversity change. They concluded that the dominant factors determining biodiversity decline will be climate change in polar regions and land-use change in tropics. Northern temperate ecosystems are estimated to experience the least biodiversity change because major land-use changes have already occurred [TAR WGII Chapters 3.3.3.3, 5.2.3.1, 6.4, 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, which may necessitate larger areas being conserved or well designed networks of reserves. Even with these efforts, some species may not be conserved because they are presently as far poleward [e.g., fynbos region at the southern tip of South Africa], or as high in altitude [e.g., cloud forests in Costa Rica] as they can be, or confined to small islands. [TAR WGII Box 5.7, Chapter 13.2.2.4].

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

Large-scale changes in vegetation as a response to climate change could further affect global and regional climate. Current deforestation and land clearance activities contribute about a fifth of the greenhouse gas emissions (1.7±0.8 GtC/yr with most being from deforestation of tropical regions). Wetlands and rice fields are among the largest sources of methane to the atmosphere, primarily due to the anoxic (reducing) conditions in their flooded soils and their high primary productivity; about one quarter of the carbon sequestered by wetlands is subsequently emitted to the atmosphere as methane. Tropical wetlands appear to be larger contributors of methane to the atmosphere than northern (north of 45°) wetlands with approximately one third of global wetland methane emissions being derived from rice paddies. There is a potential for release of large quantities of greenhouse gases from northern wetlands, tundra under warmer climatic conditions, which may provide a powerful feedback to climate system. 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. In areas without surface water (typically semi-arid or arid), evapotranspiration and albedo affect the local hydrologic cycle, thus a reduction in vegetative cover could lead to reduced precipitation at the local/regional scale and change the frequency and persistence of droughts. [LULUCF Chapter 1.2, TAR WGI Chapter 3.4.2, TAR WGII Chapters 1.3.1, Chapters 5.7, 13.2.2, 13.6.2, 10.2.6.3, & 14.2.1.1]

6.6. Projected Impacts on Traditional and Indigenous Peoples

The livelihood of indigenous peoples will be adversely affected if climate and land-use change lead to losses in biodiversity, including losses of habitats. Indigenous and traditional peoples depend directly on biodiversity and ecosystems for many goods and services (for example from food and medicines from forests, coastal wetlands and rangelands) that are projected to be adversely affected by climate change and are already under stress from many current human activities. Climate change impacts, such as reductions in wildlife populations, may have the greatest impact on the lowest income groups - those having the least ability to adapt if hunting opportunities decline. 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 indigenous and traditional people, especially those in the arctic. Reef ecosystems provide many products for many people and changes in these due to climate change will thus affect them. In some terrestrial ecosystems, adaptation options (such as efficient small-scale or garden irrigation, more effective rainfed 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. [TAR WGII Chapters 5.5.4.3, 5.6.4.1, 6.3.7 & 17.2.4, WGII SAR Chapter 7.5]

Shifts in the timing or the ranges of wildlife species 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. In Boran (Kenya) ceremonies, the selection of tribal leaders involves rituals requiring Ostrich feathers. Birds are also used for tribal cosmology, meteorology, religion and cultural ceremonies. Wildlife plays similar roles in cultures elsewhere in the world. [TAR WGII Chapter 5.4.3.3]

Sea level rise and climate change, coupled with other environmental changes, will affect some very important and unique cultural and spiritual sites and thus the people in coastal areas. The coastal sites are considered to be of vital importance in some Small Island States. Many coastal environments in Southern 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 [TAR WGII Chapter 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 (see Boxes 4 to 11). The major impacts on biodiversity in each region are summarized in the Boxes 4 to 11. Emphasis is placed on region specific issues of impacts of climate change on biodiversity in the Boxes. Since biodiversity underlies many of the goods and services that humans depend on, the consequences of the impacts on biodiversity on human livelihood is also examined, including the impacts on the traditional, pastoral and indigenous peoples.

A limitation of the material is that there are few region specific and country specific studies in some regions and thus the impacts listed in section 6.2 and 6.3 are just as valid. In addition the conclusions are often similar to similar ecosystems elsewhere, eg., the impacts on coral reefs and rangelands are very similar in many parts of the world. Adaptation options could minimize the impacts of climate change and these are examined in Section 8.1.

Box 4. Biodiversity and Impacts of Climate Change in Africa
(from TAR WGII, Chapter 10.2.3.2 & RICC Chapter 2.3)

Africa occupies about one fifth of the global land surface and 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 centres 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 7300 plant species, of which 68% occur nowhere else in the world. The adjacent Succulent Karoo on the west coast of southern Africa contains 4000 species, of which 2500 are endemic. Other major centres 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 about 2000 m. Many systems, but particularly tropical forests and rangelands are under threat from population pressures and systems of land use and have led to loss of biodiversity and degradation of land and aquatic ecosystems.

The rich 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 about 4% (varies between 0 to 17%) of the continental land surface is in formally declared conservation areas. A very large fraction of African biodiversity (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.

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

Projected impacts of climate change include:

- Many thousands of plants are potentially impacted 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 (for instance, 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 centres of biodiversity eg. 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 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 decrease in Mediterranean and southern countries of Africa which would affect their biodiversity. There is possible projected decrease of plankton-eating pelagic freshwater fisheries.
- There are several globally important wetland areas in Africa (e.g., Okovanga Delta. Decreases in runoff could lead to the losses 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. Species most at risk are those with limited distribution ranges and/or poor dispersal abilities especially in fragmented landscapes, habitat specialists (soil specialists in the case of plants), occur on islands and mountain tops and those requiring specific disturbance regimes, especially for regeneration or establishment.
- Ecosystems that are particularly vulnerable to climate change include: Fynbos, some rangelands (including the karoo), cloud/montane forests and wetlands (especially riparian) in arid/semiarid 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 5. Biodiversity and Impacts of Climate Change in Asia
(TAR WGII, section 11.1.4, 11.2.1, RICC Chapter 7.3, 10.2, 11.2, 11.3)

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

Temperate forests in Asia are a globally important resource because of their high degree of endemism and biological diversity. Tropical Asian region is ecologically rich in biodiversity including that of the present varieties of crops and the past ancestors and tropical forest species. 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 Himalayas. Some of the high altitude areas are also centres of origin for many crop and fruit-tree species; as such, they are important sources of genes for the wild relatives. Biodiversity is being lost or endangered in these high altitude areas because of land degradation and the overuse of resources; for example, in 1995, about 10% of the known species in Himalayas were listed as "threatened". The Hindukush Himalayan ranges are the source of some of the major rivers in Asia.

Freshwater aquatic ecosystems in Asia have high flora and fauna diversity. The major freshwater ecosystems have been stressed by land use and land cover change and recreational activities and major rivers have been affected by hydro-electric and industrial development projects affected the flows 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 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/grassland. Much of that land is used as low productive pastures. 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. Some countries are centres of origin for many crop and fruit-tree species; as such, they are important sources of genes for the wild relatives.

Impacts of Climate Change 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 (150-400 km) in the next 100 years.
- Grassland and temperate forest productivity is expected to decrease. There may be a decline of conifer forests in northeast China and broad-leaved forests in east China may shift northward by around 3 degrees of latitude. 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 ecosystem in China could be detrimentally affected due to 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 increase in temperature and decrease in precipitation, water quality might deteriorate and eutrophication might be exacerbated, for example in some lakes in Japan.
- Mangroves (eg. those in Sunderbans) and coral reefs are vulnerable due to climate change. Boreal forests are particularly vulnerable due to the projected changes in disturbance regimes.
- Humans and their livestock depend heavily on the rangelands of the region; almost two-thirds of the domestic livestock are supported on rangelands. With the projected decrease in productivity (of 40 to 90%), climate change is likely to represent an additional stress on these rangelands and affect many people's livelihood. Both climate change and human activities, for example, may influence the levels of the Caspian and Aral Seas with implications for biodiversity and the people.

Box 6. Biodiversity and Impacts of Climate Change in Australia and New Zealand
(RICC, Chapter 4.3, TAR WGII, Chapter 12.1.4)

Australasia's isolated evolutionary history has led to a very high level of endemism, for example, 77% of mammals, 41% of birds, and 93% of plant species are endemic. There are also areas, eg. those in Western Australia and north Queensland, that have high level of endemism. Australia is one of the 12 recognized “mega-diversity” countries. 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 exotic plants and animals. Owing to millions of years of isolation, its ecosystems are extremely vulnerable to introduced pests, diseases, and weeds. These activities have led to a loss of biodiversity in many ecosystems, and of some ecosystems as a whole, the increase in weedy species, fragmentation of ecosystems, and to secondary salinisation.

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, from inappropriate management, These stresses have led to problems of land degradation, salinisation and woody weed invasion. Alpine systems despite covering a small area they are important for many plant and animal species, many of which are listed as threatened.

Wetlands continue to be under threat, despite being listed as Ramsar sites and World Heritage sites; large numbers are already destroyed due to water storage; hydro-electric and irrigation schemes; dams, weirs and river management works; de-snagging and channelisation; 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.

Australia has one of the biggest reef systems (the Great Barrier Reef) in the world. These are facing over-exploitation, increasing pollution and turbidity of coastal waters by sediment loading, fertilizers, pesticides and herbicides but less than many other corals reefs in the world.

Many terrestrial, coastal and marine ecosystems have particular importance to the region’s indigenous peoples, both for use as traditional sources of food and materials and for their cultural and spiritual significance.

Impacts of Climate Change 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.
- 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.
- Changes in forest composition due to climate change which is most likely to occur where fragmentation of the forest 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 Australian alpine systems.
- In both countries, the indigenous peoples (Aborigines and Torres Straits Islanders of Australia, the Maori of New Zealand, and Pacific islanders) are amongst the most disadvantaged members of the population and likely to be adversely impacted by climate change; 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 and more heavily dependent on the ecosystems and species that will be affected by climate change.

Box 7. Biodiversity and Impacts of Climate Change in Europe
(RICC, chapter 5.1.2, TAR WGII, section 13.1.4)

Although much of Europe—particularly the west—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 and central European Russia has the forest cover been relatively unaffected by human activity. A considerable amount of the continent, however, is covered by forest/woodland that has been planted or regenerated on previously cleared land. The largest vegetation zone in Europe—cutting across the middle portion of the continent from the Atlantic to the Urals—is a belt of mixed deciduous and coniferous forest. The Arctic coastal regions of northern Europe and the upper slopes of its highest mountains are characterized by mostly lichens, mosses, herbs, and shrubs. The milder but still cool temperatures of the inland parts of northern Europe have coniferous trees. 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 regions are covered by vegetation that has adapted to generally dry and warm conditions; natural vegetation tends to be more sparse in the southern and eastern reaches of the Mediterranean basin.

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 or have been greatly reduced in number. Native mountain animals have survived human encroachment on their habitats (to some extent); chamois and ibex are found in the higher elevations of the Pyrenees and Alps. Europe still has many smaller mammals and contains many native bird species.

Europe at present is predominantly a region of fragmented natural or semi-natural habitats in a highly urbanized, agricultural landscape. A significant proportion of non-intensively managed ecosystems of high conservation value are 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. The forests in many parts of Europe are affected by high deposition rates of nitrogen.

Impacts of Climate Change 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; 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 displacement of the climatic zone that is suitable for boreal forests by 150-550 km over the 21st century.
- 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 area 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 population.
- 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. This will impact aquatic ecosystems.

- Where ranges of species are already fragmented they may become even more fragmented, with regional disappearances, if they cannot persist, adapt, or migrate.
- 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. With climate change, valued communities within reserves may dissociate, leaving species with nowhere to go. Sites that lie near the current maximum temperature limits of particular species could expect that if climate warms beyond these limits, species would become extinct at that site. Thus, biological diversity in nature reserves is under threat from rapid climate change.

Box 8. Biodiversity and Impacts of Climate Change in Latin America

(TAR WGII, section 14.2.1, RICC chapter 6)

Latin America possesses a large variety of ecosystems, ranging from the Amazonian tropical rain forest, Andean (Paramos), rangelands, shrublands, deserts, grassland and wetlands. Latin America is known as home to some of Earth's greatest concentrations of biodiversity, including 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.

The tropical Andes has exceptional numbers of endemic plants and endemic vertebrates, the highest in the world.

Forests occupy approximately 22% of the region and represent about 27% of global forest cover.

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.

Many ecosystems are already at risk due to human activities and climatic change will be an additional stress.

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. Rangelands cover about one-third of the land area of Latin America.

Coastal and inland wetlands have very high biodiversity and also contribute to the region's genetic diversity. The second largest coral reef system in the world dominates the offshore area of the western Caribbean Sea. Coastal forests, mainly mangroves, are lost approximately 1 % per yr leading to a decline in nurseries and refuge for fish and shellfish species. Many local communities depend on the coastal wetlands for subsistence livelihood and cultural values.

Impacts of Climate Change and Vulnerable Ecosystems in Latin America

Projected impacts of climate change include:

- Increase in the rate of biodiversity loss, especially that already being lost due deforestation in the Amazon.
- Adverse impacts on cloud forests, tropical seasonally dry(-deciduous) forests and shrublands, low-lying habitats.
- 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 many systems 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 negatively affected by sea level rise at a rate of 1 to 1.7% per year and 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 the indigenous people.

Box 9. Biodiversity and Impacts of Climate Change in North America
(TAR WGII, section 15.2, RICC chapter 8.3)

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), polar ecosystems (tundra and taiga), rangelands (grasslands, deserts, and savannas), and improved pastures. 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 about 17% of the world's forests. There is strong evidence that there has been significant warming at high latitudes and that this warming has increased boreal forest productivity.

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 U.S. 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 exotic species. High-latitude wetlands have had much lower levels of human disturbance.

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 suggests that 42 mammal, 56 bird, 28 reptile, and 25 amphibian species are at least considered vulnerable to extinction. Recent studies suggest climate-linked changes in butterflies and some desert species, timing of bird migrations, bird and emergence on hibernating mammals.

Impacts of Climate Change and Vulnerable Ecosystems in North America

Projected impacts of climate change include:

- Productivity in forests would benefit from modest warming, but there will be strong regional effects, including declines in Canada's Prairies and the U.S. Great Plains with consequent effects on some ecosystems
- Snowmelt dominated watersheds in western North America will experience earlier spring peak flows and possible reductions in summer flows and impact aquatic ecosystems.
- Geographic ranges of forest species are expected to shift northward and upward in altitude, but forests cannot move across the land surface as rapidly as climate is projected to change. The faster the rate of climate change, the greater the probability of ecosystem disruption and species extinction.
- Sea level rise would result in enhanced coastal erosion, coastal flooding, loss of coastal wetlands, and increased risk from storm surges, particularly in Florida and much of the US Atlantic coast.
- Ecosystems such as prairie wetlands, alpine tundra, and cold water ecosystems will be vulnerable.

Box 10. Biodiversity and Impacts of Climate Change in the Polar Regions
(RICC Chapter 3.2, TAR WGII, Chapters 16.2 ,16.3.1 and 16.3.2)

The Arctic and Antarctic contain about 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 the Antarctic is a frozen continent surrounded by ocean and in the IPCC reports include the sub-Antarctic islands. 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. The Antarctic is the driest and the coldest continent and is devoid of tress. The Arctic includes the boreal forests, tussock grasslands and shrublands. Polar bears, various caribou species, musk-oxen are characteristic terrestrial animals in the Arctic and the penguin species in the Antarctic. The terrestrial ecosystems in the Antarctica is comparatively simple, constrained by an exposed land area that is very cold. Only 2% of the Antarctic surface is not covered by ice. They have 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 such as grass. Some species of invertebrates survive in the harsh environment by super-cooling or anhydrobiosis mechanisms. The

Dry Valley's are one of the world's most extreme desert regions. Both Arctic and the Antarctic are very important for marine mammals, including seals, walruses and whales and for many migratory bird species.

Impacts of Climate Change and Vulnerable Ecosystems in Polar Regions

Projected impacts of climate change include:

- Climate change in polar regions 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 in the 21st century. Tundra could shrink by 2/3, boreal forest advance further to the north, some of the northern wetlands and peatlands could dry, whilst others may appear as a result of changing hydrology and draining 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 the 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 population. 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 mixing, and lead to lower oxygen concentrations and increased stress on cold-water 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 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.
- Less sea ice will reduce ice edges, which are prime habitats for marine organisms in the Polar regions.
- The decrease in the extent and thickness of Arctic sea ice may lead to changes in the distribution, age structure, and size of populations of marine mammals. Seal species that use ice for resting, and polar bears that feed on seals, are particularly at risk.
- Polar regions are highly vulnerable to climate change and have low adaptive capacity; indigenous communities, in which traditional life-styles are followed, have little capacity and few options for adaptation.

Box 11. Biodiversity and Impacts of Climate Change in Small Island States
(TAR WGII, Chapter 17.2, RICC Chapter 9.3)

Coral reefs, mangroves and seas grasses are important ecosystems in many Small Island Sates and are significant contributors to the economic resource base of many Small Island States.

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, approximately 23% of island species are threatened, compared with only 11% of the global bird population.

Although significant land clearance has been a feature of many Small Island States over decades of settlement, extensive areas of some islands (eg. 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 socioeconomic importance as sources of timber, fuel, and many nonwood products.

Impacts of Climate Change 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
- Mangrove, sea grass 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
- Forests are an issue on some islands in the South Pacific. Increases in typhoon/hurricane frequency or wind speed could negatively impact some habitats
- 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 lens loss and increased storm surges will stress freshwater plants and increase vulnerability to drought

7. Mitigation Options for Climate Change and their Potential Impacts on Biodiversity

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 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 generating environmental and socio-economic, including biodiversity, benefits. [TAR WGIII Glossary & SYR SPM Q6, Q7]

In this section, biodiversity and other environmental and social implications of climate change mitigation options are addressed (sustainable development implications are discussed in Section 9). These options include carbon sequestration and emission avoidance from land management activities including those addressed in Articles 3.3 and 3.4 of the Kyoto Protocol; increased use of low-carbon or carbon free energy systems, including biomass energy, wind, and hydro power; and geo-engineering, ie., biological uptake in the oceans. The IPCC Special Report on Land Use, Land Use Change and Forestry (LULUCF), which focused on issues related to land use and the Kyoto Protocol, is a primary source of information for this section. There is less information on other mitigation options and biodiversity in the IPCC literature.

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, rangeland and forest management. The estimated global potential of biological mitigation options is in the order of 100 GtC (cumulative) by the year 2050, equivalent to about 10 – 20 % of projected fossil fuel emissions during that period, with the largest biological potential being in subtropical and tropical regions. [TAR WGIII Glossary, & SYR SPM Q6, Q7]

The production of greenhouse gas offsets should be placed in the context of many goods and services that lands produce. There are important links between pressures on biodiversity and demands for goods and services. GHG offsets can compete or complement other land uses and land conservation. [TAR WGIII ES Chapter 4]

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

Afforestation, reforestation and avoided deforestation projects with appropriate management, selection criteria and involvement of local communities can enhance conservation and sustainable use of biodiversity. Synergy between carbon sequestration and biodiversity conservation in afforestation, reforestation and avoided deforestation projects can be achieved by improved management practices, project selection criteria and the involvement of local communities. There are management options to address the trade-offs between biomass production and biodiversity, such as adopting longer rotation times, altering felling unit sizes, altering edge lengths, creating a multi-aged patchwork of stands, minimising chemical inputs, reducing or eliminating measures to clear understorey vegetation, or using mixed species planting including native species. [LULUCF Chapter 2.5.1.1.1]

Afforestation and reforestation projects could have potentially positive or negative impacts on the biodiversity of forests, woodlands, grasslands and wetlands. The environmental and social impacts of such projects could be assessed, and the risks of negative impacts can be reduced, through the application of sound environmental and social impact assessment methodologies (see Section 9). [LULUCF Chapter 2.5.2.2]

7.1.1. Potential Impacts of Reducing Deforestation on Biodiversity

Projects aimed at slowing deforestation and/or forest degradation would provide substantial biodiversity benefits. Tropical forests, which contain an estimated 50-70% of all terrestrial species, are currently experiencing significant rates of deforestation (averaging 15 Mha annually during the 1980s). Tropical deforestation is a primary cause of global biodiversity loss. It also reduces the availability of habitats and causes local loss of species, population and genetic diversity as well as resulting in emission of carbon dioxide of about 1.7 GtC annually. Hence, halting or slowing the rate of tropical deforestation can have beneficial effects on biodiversity and can reduce carbon emissions. The mitigation potential of slowing rates of tropical deforestation has been estimated to be about 11–21 GtC over the period 1995-2050. [SAR WGII Chapter 24.4.2.2, LULUCF Chapters 1.4.1, 2.5.1.1.1, 3.6.2 & TAR WGIII Chapter 4.3.2]

Projects in threatened/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 greatest biodiversity co-benefits. Projects that protect forests from land conversion or degradation in key watersheds have potential to substantially slow soil erosion, protect water resources for local communities and conserve biodiversity. Projects that are designed to promote reduced impact logging as a carbon offset may produce fewer biodiversity co-benefits than forest protection (i.e., not logging) at the site level, but may provide larger socio-economic benefits to local owners. 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, however, 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. [LULUCF Chapters 5.5.1, 2.5.1.1.1 & TAR WGIII Chapter 4.4]

Pilot LULUCF projects that were designed to avoid emissions by reducing deforestation and forest degradation have produced marked environmental and socio-economic co-benefits, including biodiversity conservation, protection of watersheds, improved forest management and local capacity-building and employment in the local enterprises. [LULUCF Chapter 5.5.1]

7.1.2. Potential Impacts of Afforestation and Reforestation on Biodiversity

In the context of the Kyoto Protocol, both afforestation and reforestation refer to the conversion of land 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 forest 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-forest land to forest 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-forest land. In the first commitment period these changes in land use must have occurred after December 31st 1989. [FCCC/2001/2/Add.3/Rev.1]

Afforestation and reforestation mitigation projects provide potential for carbon sequestration and socio-economic benefits, and also promote biodiversity, if appropriate species choices and silvicultural practices are adopted. The global mitigation potential of post 1990 afforestation, reforestation and slowing deforestation activities is projected to be 60 to 87 GtC on 344 Mha between 1995-2050, with 70% in tropical forests, 25% in temperate forests and 5% in boreal forests. The annual carbon sequestration rate would be 1.1 – 1.6 GtC. [LULUCF Chapter 3.5]

Converting the present non-forest land to forest could increase the biological diversity, except in situations where biologically diverse non-forest ecosystems are replaced by forests that consist of single or a few species. Afforestation and reforestation can increase or benefit biodiversity where it replaces land cover that is species-poor and where it promotes diversification of native plants and animals. However, in some places afforestation and reforestation can threaten valuable non-forest species and habitats, eg. conversion of species rich native-grasslands. 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 Chapters 2.5.1, 3.6.1 & 4.7.2.4]

Afforestration with fast-growing species in water limited lands generally reduces streamflow, which would have a negative impact on riparian biodiversity. Water yield from the catchment is often reduced significantly, as is biodiversity. [TAR WGII 4.7.2.4]

Although plantations usually have lower biodiversity than natural forests, they can reduce pressure on natural forests by 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 or wetland habitats, but plantations of exotic or native species can be designed to enhance biodiversity by encouraging the protection or restoration of natural forests. Studies also show that tree plantations in the tropics/sub-tropics, e.g., *Eucalyptus grandis*, can if appropriately spaced, allow the establishment of diverse native understorey species by providing shade and modifying microclimates. Trade-offs between carbon storage and maintenance of biodiversity can occur when large areas of forest are created using single exotic species. For example, 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 single species are likely to have more limited fauna and flora than native forest stands. [LULUCF Chapters 2.5.1.1.1, 5.5.2 & TAR WGIII Chapter 4.4.1]

7.2. Potential Impacts of Land-Use Change and Land Management on Biodiversity

Land management that promotes the optimum and sustainable use of land and other resources therein is premised on land use planning, allocation and monitoring that preclude inefficiency, misuses and abuses of land and other resources. It ensures that lands are used in a manner that provides the society the best opportunity to realize both environmental and socioeconomic objectives. Land management actions to offset greenhouse gas emissions can have an impact on overall environmental quality including soil quality and soil erosion, water quality, air quality and wildlife habitat, in turn having impacts on terrestrial and aquatic biodiversity.

7.2.1. Potential Impacts of Agroforestry

Agroforestry activities can sequester carbon and have beneficial effects on biodiversity. The carbon sequestration potential of agroforestry activities (planting combinations of woody and herbaceous vegetation with agricultural crops) range from about 10 Mt C per year in 2010 to 20 Mt C per year in 2040 in industrialized countries, and from about 400 Mt C per year in 2010 to 600 Mt C per year in 2040 in developing countries (primarily through the conversion to agroforestry of low productivity croplands and grasslands, degraded/deforested lands in the humid tropics, and recently deforested lands). The associated impacts of agroforestry activities include increased food security, increased farm income, decreasing soil erosion and restoring and maintaining above ground and below ground biodiversity. Where agroforestry replaces native forest, biodiversity is usually lost, however, agroforestry can be used to enhance biodiversity on degraded sites. Agroforestry systems are more biologically diverse than croplands, grasslands and secondary forest fallows. Therefore, the challenge is to avoid deforestation where possible and use local knowledge and local species wherever possible 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

There are a large number of forest management activities that can be used to sequester carbon in above and below ground biomass and soil carbon, that may have positive or negative effects on biodiversity, i.e., regeneration, fertilization, fire management, pest management, harvest scheduling, and low-impact harvesting (see Box 12). The carbon sequestration potential of these activities collectively ranges from about 100 Mt C per year in 2010 to 500 Mt C per year in 2040 in industrialized countries, and from 70 Mt C per year in 2010 to 200 Mt C per year in 2040 in developing countries [LULUCF Table 4.1].

Box 12. Forest Management Activities

Improved natural regeneration is the act of renewing tree cover by establishing young trees naturally or artificially—generally, 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. “Human-assisted natural regeneration” means establishment of a forest age class from natural seeding or sprouting after harvesting through selection cutting, shelter (or seed-tree) harvest, soil preparation, or restricting the size of a clear-cut stand to secure natural regeneration from surrounding trees. “Enrichment planting” means increasing the planting density (i.e., the numbers of plants per hectare) in an already growing forest stand. These activities would result in most cases in increased biodiversity, and recreational/landscape improvements. These effects could also result from increased mixed-species stands and higher tree density in savanna woodlands. Conversely, tree planting and change of tree species could result in decreased biodiversity and reduced recreational benefits, particularly if monoculture stands are emphasized. All activities will produce more jobs and income in the establishment phase, as well as at harvesting and end-use activities, especially in rural areas [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. In some areas it may have several negative environmental impacts, e.g., increased emissions of N_2O and 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 some ecosystems need fires to be sustainable. Restoring near-historical fire regimes may be an important component of sustainable forestry but may also require access (road construction) and other practices that may create other deleterious environmental effects [LULUCF fact sheet 4.14].

Pest management, which is the application of biocides to maintain a pest’s population within tolerable levels may result in reduced biodiversity, contamination of water and other resources, and in some locations, lower landscape and recreational benefits. On the other hand, where pest management prevents large-scale forest die-off, it may dramatically increase landscape, recreational, watershed, and other benefits [LULUCF fact sheet 4.15].

Harvesting scheduling, a procedure by which forest stands are managed by selecting rotation lengths and matching harvesting activities to a range of economic, suitability and conservation goals, could have positive or negative environmental benefits regarding biodiversity, recreation, and landscape management, depending on local circumstances [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, as well as increase the economic value of logged and remaining trees [LULUCF fact sheet 4.17].

7.2.3. Potential Impacts of Agriculture Sector Mitigation Activities

Activities and projects in the agricultural sector to reduce carbon emissions and increase carbon sequestration can promote sustainable agriculture, promote rural development and enhance biodiversity. There are a large number of agricultural management activities that can be used to sequester carbon in soil carbon, that may have positive or negative effects on biodiversity, i.e., intensification, irrigation, conservation tillage, erosion control and rice management (see Box 13). The estimated carbon sequestration potential of additional activities since 1990 collectively ranges from about 75 Mt C per year in 2010 to 130 Mt C per year in 2040 in industrialized countries, and from about 60 Mt C per year in 2010 to 140 Mt C per year in 2040 in developing countries.[4] These activities include adopting farmer-centred participatory approaches and carefully considering indigenous knowledge and technology, promoting cycling and use of organic materials in low-input farming systems and using agro-biodiversity, including use of locally-adapted crop varieties and crop diversification. [LULUCF Chapters 2.5.1.1, 2.5.2.4.2, Table 4.1 & fact sheets 4.1- 4.5]

[FOOTNOTE 4: The TAR (Table 3.27) reports a global sequestration potential for agricultural soils of 450-600 Mt C per year over the next 20-50 years (erosion control: 80-120 Mt C per year; restoration: 20-30 Mt C per year; conservation tillage and crop residue management: 150-170 Mt C per year; reclamation of saline soils: 20-40 Mt C per year; improved cropping: 180-240 Mt C per year). The technological and market potential is, however, significantly lower.]

Box 13. 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. 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 flood plains. [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 (SOC). Conservation tillage is widely practiced in the USA, and is being rapidly adopted in a number of developing countries, including Brazil and Argentina. However, there is significant potential for expansion in Asia, Australia, Africa and Europe. Sequestration of SOC depends on continued use: reversion to conventional methods (high degree of disturbance) can cause loss of sequestered SOC. 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, reduced siltation of reservoirs and waterways, and possible double-cropping. In some areas (e.g., Australia), increased leaching from greater water retention with conservation tillage could cause downslope salinization. In wet years, planting may be delayed in no-till systems, potentially resulting in a yield reduction. [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 SOC displaced by soil erosion, that has been estimated to be in the range of 0.5 Gt per annum. 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 methane emissions; associated reductions in risks of flooding; and increased biodiversity in shelter belts and riparian zones. [LULUCF fact sheet 4.4]

Rice management strategies, which include irrigation, fertilization, and crop residue management, affect methane emissions and carbon stocks. Rice agriculture tends to increase soil carbon stocks in comparison with adjacent areas without rice. Most practices that reduce methane emissions will, however, likely also reduce the rate of carbon storage in rice paddy soils. The impact of management strategies on costs to farmers and on rice yield and sustainability has yet to be assessed. [LULUCF fact sheet 4.5]

7.2.4. Potential Impacts of Grassland Management

Activities and projects in the grasslands sector can increase carbon sequestration and enhance biodiversity. There are a large number of grasslands management activities that can be used to sequester carbon in soils, that may have positive or negative effects on biodiversity. They include grazing management, protected grasslands and set-asides, grassland productivity improvements and fire management (see Box 14). The carbon sequestration potential of these activities collectively ranges from about 70 Mt C per year in 2010 to 140 Mt C per year in 2040 in industrialized countries, and from 170 Mt C per year in 2010 to 340 Mt C per year in 2040 in developing countries [LULUCF Table 4.1].

Box 14. Grassland Management Activities

Grazing management, which requires management of the intensity, frequency, and seasonality of grazing and animal distribution, can reduce soil erosion, and can reduce methane emissions by reducing animal numbers and improving intake quality [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 ground and below ground biomass. Globally, estimates of the cropland area that potentially could be placed into set-asides are on the order of 100 Mha. Associated impacts can include reduced crop production, increased animal production if the land is grazed, increased biodiversity of native grass ecosystems if they are re-established, increased wildlife habitat, reduced erosion etc. However, if the land is grazed, methane and nitrous oxide emissions may more than offset the sink provided by increasing carbon pools [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 nitrous oxide 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 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].

7.3. Potential Impacts of Changing Energy Technologies and Geo-Engineering on Biodiversity

Mitigation options in the energy sector and geo-engineering that may impact biodiversity include: increasing the efficient use of fuelwood and charcoal as energy sources, renewable energy technologies such as biomass energy, wind power, and hydro-power and biological uptake in oceans.

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

Use of fuelwood conservation measures, such as efficient cookstoves and biogas, has the potential to reduce pressure on forests and thus conserve biodiversity in the tropics. Fuelwood in many regions is traditionally the dominant biomass extracted from forests with significant implications for biodiversity. The fuelwood used from forests is largely for subsistence activities such as cooking and can be reduced by 30 to 40% through improved wood-burning stoves. Fuelwood is also used for charcoal making for industrial applications in for example in Brazil. Fuelwood and charcoal consumption in tropical countries is estimated to increase from 1.3 billion cubic metres in 1991 to 3.4 billion cubic metres by 2050, with significant implications for forest resources, including biodiversity. Biogas derived from anaerobic decomposition of crop waste and cattle dung can be a potential substitute for fuelwood at household or at community level. Thus, mitigation activities aimed at reducing fuelwood use for cooking through efficiency improvements (improved stoves and biogas) can significantly reduce pressure on forests and thereby contribute to biodiversity conservation [SAR WGII Chapters 15.3.3 & 22.4.1.4]

7.3.2. Potential Impacts of Increasing 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, for biomass energy, which can be derived from dedicated plantations (energy crops) as well as agricultural and forestry residues, landfill gas and municipal solid wastes, is projected to contribute 200 EJ or more per year by 2050, avoiding CO_2 emissions of 3.5 GtC per year or more, which is about half of the current fossil fuel emissions. The use of agricultural and forest crops to produce biofuels currently reduces the use of fossil fuels by the equivalent of 1 GtC per year and in the future by up to 10 GtC per year. Positive environmental impacts can include reclamation of degraded land, potential promotion of biodiversity provided a part of the plantation area is left for natural regeneration, and reduction of pressure on primary forest 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 in place of natural forest. However, small-scale plantations on degraded land or abandoned agricultural sites would have environmental benefits. Plantations with only a small number of species 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 different clones and or species. 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 that feeds mass scale conversion technologies, meet local fuel and timber needs, provide employment with biofuel powered rural electrification and export liquid fuel products. 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. [LULUCF Chapters 4.5.3, 4.5.5, 5.5.3 & TAR WGIII Table 3.31].

7.3.3. Potential Impacts of Hydropower

Large-scale hydropower plant development can have high environmental and social costs such as loss of fertile land, methane generation from flooded vegetation and displacement of local communities. Hydropower can, in principle, make a major contribution to reducing the greenhouse gas intensity of energy production. Currently about 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 only a small proportion of the larger potential in developing countries has been tapped. Greenhouse gas emissions from most hydropower plants are relatively low, with the one important major exception possibly being large flat lakes in heavily-vegetated tropical areas where emissions from decaying vegetation can be substantial. The social (e.g., relocation of local populations) and environmental implications of hydropower development must be carefully evaluated on a case-by-case basis to minimize unwanted social and environmental effects. For example, dam reservoirs result in loss of land and terrestrial biodiversity, and dams may prevent fish migration (which is an essential part of lifecycle of some fish species) and stop water flow. 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 using modern technology that cascade the water through a number of smaller dams and power plants may reduce the adverse environmental impacts of the system. Small and the micro-scale hydroelectric schemes normally have low environmental impacts. [SAR WGII Chapter 19.2.5.1 & TAR WGIII 3.8.4.3.1]

7.3.4. Potential Impacts of Windpower

Windpower has significant mitigation potential and 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. [SAR Chapter 19.2.5.3].

7.3.5. Potential Impacts of 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. The results of experiments show that weeklong, sustained additions of iron to nutrient-rich but iron-poor (eg. Southern Ocean) regions of the ocean can produce massive phytoplankton blooms and increased oceanic uptake of CO_2 and nutrients. The consequences of larger, longer-term introductions of iron, however, remain uncertain. Concerns associated with these efforts are the differential impact on different algal species, the impact on concentrations of dimethyl sulphide in surface waters, and the potential for creating anoxic regions at depth, all of which are likely to affect biological diversity [TAR WGIII Chapter 4.7].

8. Consequences of Adaptation Options

Adaptation options specifically addressing the impacts of climate change can have adverse or beneficial impacts on biodiversity. It is possible that the current effort to conserve and sustainablly use biodiversity can affect the rate and magnitude of projected climate change. However, it is accepted that climate change is occurring and thus conservation efforts can take this into account during the planning phase.

8.1. Planning for Conservation under Present and Projected Climate Change

Present conservation planning does not necessarily take climate change into account. Actions can be taken to minimize the impact of climate change on biodiversity especially in protected areas

Networks of reserves with connecting corridors are needed to provide migration routes for animals affected by climate change. The placement and management of reserves (including marine and coastal reserves) 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, which link currently fragmented reserves and landscapes by providing potential for migration. Appropriate monitoring systems will help detect potential losses of biodiversity and provide opportunities for adaptive management. [TAR WGII Chapters 5.4.4 &14.2.1.5]

Captive breeding and translocations can be used to augment or re-establish 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. [TAR WGII Chapter 5.4.4]

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 stabilisation, pollination or pest control. Loss of natural biological control species could also be compensated for 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. [TAR WGII Chapter 5.4.4, 5.7]

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, especially in coral reefs and mangroves is a possible adaptation option. The aqua-- and mariculture would reduce the impact on the remaining coastal systems, but may be best implemnted when considered as part of integrated approach to coastal management under climate change. [TAR WGII Chapter 6.6.4]

8.2. Effect of Adaptation Option for Climate Change on Conservation and Sustainable Use of Biological Diversity

There are a number of potential adaptation options that can be effective for climate change but can affect conservation and sustainable use of biological diversity. Some adaptation options for climate change could have beneficial impacts and some adverse on biodiversity and vary in different regions. Adaptation options can also threaten biodiversity either directly (eg through the destruction of habitats) or indirectly (e.g. through the introduction of new species or changed management practices).

Moving species poleward to adapt to the changing climate zones is fraught with scientific uncertainties. The exotic can become a super-abundant, pest species with negative effects on native organisms including their extirpation and extinction. The invasion ecology of organisms is not a predictive science; many surprises would be expected. In aquatic systems the case has been made that managing with exotics increases the instability of the fish community, fish management problems, and includes many unexpected consequences. Introducing a warmer fauna on top of a regional fauna that is having increasing problems itself from warming climates will likely be a controversial adaptation. [TAR WGII Chapter 5.7.4]

Greater use of pesticides and herbicides in response to new pests species may lead to damage to existing plant and animal communities, water quality and human health. Climate change could impact many of these systems by decoupling predators from their prey. Studies in North America project reductions in the extent of distribution 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. [TAR WGII Chapter 5.4.2, 5.4.3.3, 5.4.4]

Increased demand for irrigation projected under many climate change scenarios is likely to increase the opportunity cost of water and possibly reduce water availability for wildlife and natural ecosystems. However, many regions have low irrigation efficiencies and one adaptation strategy to climatically induced changes in demand is to increase irrigation efficiency. [TAR WGII Chapter 5.3.4]

Rising sea levels may lead to the increased use of engineering works for coastal protection (e.g. groynes, seawalls, breakwaters and bulkheads), which will often damage or replace existing coastal ecosystems leading to the local loss of biodiversity. 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. Other options include the application of 'precautionary 'approaches, such as the enforcement of building setbacks, land-use regulations, building codes and insurance coverage and the application of traditional, appropriate responses (e.g. building on stilts and the use of expendable, readily available indigenous building materials), which have proven to be effective responses in many regions in the past. [TAR WGII Chapter 17.2.3]

Competition for different uses of land will remain and the rate of land-use change will accelerate as climate changes. There is significant adaptive capacity in agricultural sectors that could allow practices on current agricultural lands to be modified and agricultural output maintained largely from existing areas. However, this will be achieved only if there is rapid diffusion of information and technology. Without this, greater land-use change is likely to occur as some areas are abandoned, or used less effectively and new areas are converted to agriculture or other intensive uses thereby increasing the vulnerability of natural systems. Scenarios vary in their estimates of how significant this effect will be depending on assumptions about the rates of technological and behavior al change. [TAR WGII Chapter 3.3.3.3, 3.3.4]

8.3. Impacts of Actions to Conserve and Sustainably Use Biological Diversity on Climate Change

Actions taken to conserve and sustainable use biodiversity for reasons other than climate change, could affect the amount or rate of climate change or affect our ability to adapt to climate change (eg decisions to maintain the genetic resources).

Areas set aside to conserve biodiversity represent long-term stores of carbon. Usually relatively mature examples of ecosystems are preferred for conservation purposes and they are usually managed to reduce the likelihood of disturbance or human activities releasing the stored carbon. Thus, conservations reserves represent a form of avoided deforestation or devegetation. [LULUCF Chapter 2.3.1, 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. [TAR WGII Chapters 5.3.3, 6.3.7, 14.2.1 & 19.3.3]

The goals of high biodiversity and high carbon storage often cannot be met simultaneously on the same piece of land. The maintenance of biodiversity requires the protection of all life stages of all ecosystem types. This requires that ecosystems will low carbon content are conserved and that some ecosystems with high carbon content are allowed to be disturbed and some of that carbon released to the atmosphere. [LULUCF Chapter 2.5.1]

9. Approaches, such as Sustainable Development, can be Used to Assess the Impacts of Adaptation and Mitigation Activities on Biodiversity

Different types of adaptation and mitigation activities could have highly variable environmental and socioeconomic impacts depending on the measures and the means by which they are implemented. Hence, there are potential synergies and tradeoffs between climate adaptation and mitigation activities, and sustainable development objectives, the objectives of other multilateral environmental agreements (including the Convention on Biological Diversity, the Convention to Combat Desertification, and the Ramsar Convention on Wetlands), and a broad range of issues relating to the conservation, management, and sustainable development of agriculture and forests. A system of criteria and indicators could be developed and adopted on a national or multinational basis to assess and compare sustainable development impacts across alternative adaptation and mitigation activities. Potential tools, such as environmental screens and the application of project-, sector- and regional-level environmental and social impact assessments could be adapted from existing tools and then used to quantitatively assess the synergies and tradeoffs, against a set of criteria and indicators, related to activities under the UNFCCC and its Kyoto Protocol on biodiversity and sustainable development. [LULUCF Chapter 2.5]

A system of criteria and indicators could be developed for assessing and comparing sustainable development impacts across alternative adaptation and mitigation activities. Regardless of whether the Parties opt for a strictly national or multinational approach to sustainable development, a system of criteria and indicators could be developed for assessing and comparing sustainable development impacts across alternative adaptation and mitigation activities. 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 to climate change, several approaches have been developed for related purposes that the Parties might adapt to gauge the sustainable development contributions of such activities. Criteria and indicators for sustainable agriculture and forest management may be most directly adaptable to specific LULUCF measures at the project and national levels. For example [LULUCF Chapter 2.5]:

- *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 adaptation and mitigation activities and projects 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), as well as those being developed for specific LULUCF sectors, may be useful to governments seeking to develop indicators with which to assess such consistency. The UNCSD developed an "initial" set of 134 specific social, economic, and environmental indicators, within a "Driving Force-State-Response" framework, for a series of program areas that encompass areas of particular relevance to LULUCF policies and measures: (i) integrated approach to the planning and management of land resources; (ii) combating deforestation; (iii) managing fragile ecosystems: combating desertification and drought; (iv) sustainable mountain development; (v) sustainable agriculture and rural development; (vi) conservation of biological diversity; and (vii) protection of the quality and supply of freshwater resources. The OECD has developed a core set of environmental performance indicators, based on their policy relevance, analytical soundness, and measurability, for a number of economic sectors, including LULUCF-related issues such as forest resources, landscape, soil degradation, and biological diversity, using a similar "pressure-state-response" model. The European Union (EU) also is developing a set of about 60 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 sustainable development contributions of adaptation and mitigation measures under the Kyoto Protocol.
- *Consistency with Internationally Recognized Criteria and Indicators for Sustainable Forest Management.* Several intergovernmental efforts have been initiated to develop criteria and indicators for sustainable forest management, including the Helsinki, Montreal, Tarapoto, and International Tropical Timber Organization Processes. National and sub-national levels build on these international approaches and adapt them to national and local forest conditions. These criteria and indicators, some of which could be harmonized and adapted for LULUCF activities under the Kyoto Protocol, are generally moving beyond a narrowly defined focus on the productivity of timber and other commercial forest products to incorporate ecological and social dimensions of sustainability such as: (i) conservation of biological diversity, (ii) maintenance of the productive capacity of forest ecosystems, (iii) maintenance of forest ecosystem health and vitality, (iv) conservation and maintenance of soil and water resources, (v) maintenance of forest contribution to global carbon cycles, (vi) maintenance and enhancement of long-term multiple socioeconomic benefits to meet societal needs, and (vii) an effective legal, institutional, and economic framework for forest conservation and sustainable management. For site-specific projects, governments might find the criteria and indicators that the Center for International Forestry Research (CIFOR) has developed for the management of natural forests particularly valuable, and those being developed for tropical plantations and community-managed forests. These criteria and indicators provide a useful framework for evaluating policy, environmental, social, and production aspects of sustainable forest management and are designed to be readily adaptable to local conditions.
- *Consistency with Internationally Recognized Criteria and Indicators for Sustainable Agriculture*. The major objective of sustainable agriculture and rural development is to increase agricultural production in ways that ensure access by all people to the food they need; help people satisfy their social and cultural aspirations; and protect and conserve the capacity of the natural resource base to continue to provide production, environmental, and cultural services. The FAO is helping countries evaluate the compatibility of their policies with these objectives, advising on incentives, and developing indicators and guidelines for sustainable agricultural practices. In addition, the Committee on Sustainable Agriculture and the Environment in the Humid Tropics of the US National Research Council proposed several specific land-use options to achieve sustainable agriculture in tropical regions, including the following: (i) intensive cropping systems under proper management that do not lead to resource degradation; (ii) shifting cultivation

systems, coupled with the use of local cropping systems, observation of sufficient fallow periods, diversification of cropping systems, maintaining continuous ground cover, and nutrient restoration through mulching; (iii) agro-pastoral systems combining crop and animal production, allowing for enhanced agro-ecosystem productivity and stability through integrated management of soil and water resources and crop and animal diversification; (iv) intensive animal husbandry (ranching), combined with sustainable pasture and rangeland management; (v) agroforestry systems that involve various combinations of woody and herbaceous vegetation with agricultural crops, often practiced for multiple agronomic, environmental, and socioeconomic benefits.

The environmental and socioeconomic impacts of adaptation and mitigation activities can be assessed through project-, sector- and regional-level environmental and social impact assessments. These can be used to evaluate consistency with national and international environmental impacts standards and guidelines. For example, environmental and social impact assessments can be used to quantitatively assess the environmental, social and economic impacts of adaptation and mitigation activities on, *inter-alia:* (i) biodiversity; (ii) the quantity and quality of forests, grazing lands, soils, fisheries and water resources; (iii) the ability to provide food, fiber, fuel and shelter; and (iv) employment, human health, poverty and equity. An EIA is a broad process that informs decision makers about a project's potential environmental and societal risks and impacts, as well as examining alternatives and identifying mitigative measures. During the process of identifying, designing, and implementing projects, effective application of an EIA to climate adaptation and mitigation projects might help ensure that potential positive and negative environmental and societal impacts are effectively addressed in all phases of project development. Currently, more than 100 countries have a national EIA system. One factor that affects their applicability to climate adaptation and mitigation projects is that EIA guidelines and their degree of rigor in application vary widely. One option for governments to address this concern would be to adopt internationally recognized EIA standards and guidelines. For example, the World Bank has published its three volume *Environmental Assessment Sourcebook,* which contains, *inter-alia,* sectoral guidelines for natural forest, livestock, rangeland, and agricultural production management; plantation development/reforestation; and watershed development. For each of these sectors, the *Sourcebook* identifies several potential environmental and social impacts, as well as mitigating measures for negative impacts. The Asian Development Bank (ADB) has a similar manual titled *Environmental Guidelines for Selected Agricultural and Natural Resources Development Projects*. [LULUCF Chapter 2.5]

A wide range of decision-analytic frameworks have been developed to evaluate mitigation and adaptation options, but rarely used. The diverse set of decision analytical frameworks (DAFs) include decision analysis, cost-benefit analysis, cost-effectiveness analysis and the policy exercise approach. There are certain features (sequential decision-making and hedging), specific versions (multi-criteria analysis), distinctive applications (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 later. Decision analysis, adapted to managing technological, social or environmental hazards constitutes part of risk assessment. [TAR WG III Chapter 2.5 & TAR WGII Chapter 1.1]

The capacity of countries to adapt and mitigate can be enhanced when climate policies are integrated with national development policies including economic, social and other environmental dimensions. The linkages among local, regional and global environmental issues and their relationship to meeting human needs offer opportunities to capture synergies in developing response options and reducing vulnerability to climate change, although trade-offs between issues may exist. The successful implementation of greenhouse gas mitigation options would need to overcome technical, economic, political, cultural, social, behavioral and/or institutional barriers that prevent the full exploitation of the technical, economic, social and environmental opportunities of these mitigation options. The involvement of local communities that directly depend on the forest resources is the best way of ensuring the success of community-based mitigation projects. [SYR SPM Q7, 8,, LULUCF SPM para 85 & Chapter 5.6.3]

Current and emerging pathways and mechanisms for technology transfer for LULUCF mitigation projects have several limitations, namely: limited financial resources, inadequate information on costs and potential benefits of projects, limited host country technical capacity, absence of policies and institutions to process and evaluate mitigation projects. Some critical factors affecting sustainable development contributions of LULUCF 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. [LULUCF Chapter 5.6.4, SPM para 90]

10. Identified Information and Assessment Gaps

These 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:

- Improved regional scale climate models coupled with transient ecosystem models that deal with multiple pressures with appropriate spatial and temporal resolution and include spatial interactions between ecosystems within landscapes.
- Developing monitoring systems, including indicators, that would help in assessing the relationship between climate change and biodiversity given all the pressures that exist
- Inclusion of all the relevant literature to deal with climate change and biodiversity as well as the other pressures
- Detailed and reliable regional scenarios of climate change need to be developed and used in rigorous vulnerability analysis

To answer — What is the impact of mitigation options for climate change on biodiversity:

- Evaluation of case studies (to gain experience) that deal with mitigation and adaptation projects, especially to disaggregate the effects of mitigation vs adaptation options
- What is the impact of conservation and sustainable use of biodiversity on climate change
- Developing basic understanding of the potential impacts of conservation and sustainable use activities on climate change (local, regional and possibly global)

To develop tools, indicators and approaches:

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

Appendix 1: 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, where available, is also included.

Adams, G. A. and D. H. Wall 2000. Biodiversity above and below the surface of sails and sediments: Linkages and implications for global change. - *Bioscience*, **50,** 1043-1048.

Aguirre, J., R. Riding, et al. 2000. Diversity of coralline red algae: origination and extinction patterns from the Early Cretaceous to the Pleistocene. - *Paleobiology*, **26,** 651-667.

Ambrogi, A. O. 2001. Transfer of marine organisms: a challenge to the conservation of coastal biocoenoses. *Aquatic Conservation : Marine & Freshwater Ecosystems*, **11,** 243-251.

Andersson, E., C. Nilsson, et al. 2000. Plant dispersal in boreal rivers and its relation to the diversity of riparian flora. - *Journal of Biogeography*, **27,** 1095-1106.

Ayres, M. P. and M. J. Lombardero 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens [Review]. - *Science of the Total Environment*, **262,** 263-286.

Baldwin, V.C., H.E. Burkhart, J.A. Westfall, and K.D. Peterson, 2001: Linking growth and yield and process models to estimate impact of environmental changes on growth of loblolly pine. *Forest Sc*., **47**, 77-82.

Barendse, J. and S. L. Chown 2001. Abundance and seasonality of mid-altitude fellfield arthropods from Marion Island. - *Polar Biology*, **24,** 73-82.

Bawa, K. S. and S. Dayanandan 1998. Global climate change and tropical forest genetic resources. *Climatic Change*, **39,** 473-485.

Bazzaz, F. A. 1998. Tropical forests in a future climate - changes in biological diversity and impact on the global carbon cycle. *Climatic Change*, **39,** 317-336.

Beerling, D. J. 1999. Long-term responses of boreal vegetation to global change: an experimental and modelling investigation. *Global Change Biology*, **5,** 55-74.

Beilman, D. W. 2001. Plant community and diversity change due to localized permafrost dynamics in bogs of western Canada. *Canadian Journal of Botany Revue Canadienne de Botanique*, **79,** 983-993.

Bellett-Travers, J. and D.M. Bellett-Travers, 2000: The predicted effects of climate change on the survival of inner city trees. *Mitt. Biol. Bundesanst. Land- Forstwirtsch*., **370,** 155-161.

Bellwood, D. R. and T. P. Hughes 2001. Regional-scale assembly rules and biodiversity of coral reefs. - *Science*, **292,** 1532-1534.

Bendix, J. and C. R. Hupp 2000. Hydrological and geomorphological impacts on riparian plant communities. - *Hydrological Processes*, **14,** 2977-2990.

Bengtsson, J., S. G. Nilsson, et al. 2000. Biodiversity, disturbances, ecosystem function and management of European forests. - *Forest Ecology & Management*, **132,** 39-50.

Bergengren, J. C., S. L. Thompson, *et al*. 2001. Modeling global climate-vegetation interactions in a doubled CO_2 world. *Climatic Change*, **50,** 31-75.

Bergeron, Y. 1998. Consequences of climate changes on fire frequency and forest composition in the southwestern boreal forest of Quebec [French]. *Geographie Physique et Quaternaire*, **52,** 167-173.

Bergeron, Y. and M. D. Flannigan 1995. Predicting the effects of climate change on fire frequency in the southeastern Canadian boreal forest. *Water, Air, & Soil Pollution*, **82,** 437-444.

Bergeron, Y., S. Gauthier, et al. 2001. Natural fire frequency for the eastern Canadian boreal forest: consequences for sustainable forestry. *Canadian Journal of Forest Research Journal Canadien de la Recherche*.

Betts, R. A. 2000. Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. *Nature*, **408,** 187-190.

Bianchi, C. N. and C. Morri 2000. Marine biodiversity of the Mediterranean Sea: Situation, problems and prospects for future research. - *Marine Pollution Bulletin*, **40,** 367-376.

Blaney, C. S. and P. M. Kotanen 2001. The vascular flora of Akimiski Island, Nunavut Territory, Canada. - *Canadian Field-Naturalist*, **115,** 88-98.

Bonell, M. 1998. Possible impacts of climate variability and change on tropical forest hydrology. *Climatic Change*, **39,** 215-272.

Bonotto, S. 2001. Aspects of pollution on the coastal ecosystems of the Mediterranean Sea. *Aquatic Conservation : Marine & Freshwater Ecosystems*, **11,** 319-323.

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Boone, R. B. and W. B. Krohn 2000. Partitioning sources of variation in vertebrate species richness. - *Journal of Biogeography*, **27,** 457-470.

Bradshaw, R.H.W, B.H. Holmqvist, S.A. Cowling, and M.T. Sykes, 2000: The effects of climate change on the distribution and management of Picea abies in southern Scandinavia. *Can. J. For. Res.* **30,** 1992-1998.

Brenchley, P. J., J. D. Marshall, et al. 2001. Do all mass extinctions represent an ecological crisis? Evidence from the Late Ordovician. - *Geological Journal*, **36,** 329-340.

Brown, J. H., S. K. M. Ernest, et al. 2001. Regulation of diversity: maintenance of species richness in changing environments. *Oecologia*, **126,** 321-332.

Brown, J. H., T. G. Whitham, et al. 2001. Complex species interactions and the dynamics of ecological systems: Long-term experiments [Review]. - *Science*, **293,** 643-650.

Brown, S. 1996. Mitigation potential of carbon dioxide emissions by management of forests in Asia. *Ambio*, **25,** 273-278.

Buckland, S. M., K. Thompson, et al. 2001. Grassland invasions: effects of manipulations of climate and management. - *Journal of Applied Ecology*, **38,** 301-309.

Budd, A. F. 2000. Diversity and extinction in the Cenozoic history of Caribbean reefs [Review]. - *Coral Reefs*, **19,** 25-35.

Bugmann, H., 1999: Anthropogenic climate change, succession and forestry. *Schweiz. Z. Forstwesen*, **150**, 275-287 (in German).

Burger, J. 2000. Landscapes, tourism, and conservation. - *Science of the Total Environment*, **249,** 39-49.

Burke, A. 2001. Determining landscape function and ecosystem dynamics: Contribution to ecological restoration in the southern Namib desert. - *Ambio*, **30,** 29-36.

Burkett, V. and J. Kusler 2000. Climate change: potential impacts and interactions in wetlands of the United States. *Journal of the American Water Resources Association*, **36,** 313-320.

Cairns, M. A. and R. A. Meganck, 1994. Carbon sequestration, biological diversity, and sustainable development - integrated forest management. *Environmental Management*, **18,** 13-22.

Cameron, G. N. and D. Scheel 2001. Getting warmer: Effect of global climate change on distribution of rodents in Texas. - *Journal of Mammalogy*, **82,** 652-680.

Campbell, B. D. and D. M. S. Smith 2000. A synthesis of recent global change research on pasture and rangeland production: reduced uncertainties and their management implications. *Agriculture Ecosystems & Environment*, **82,** 39-55.

Carbone, F. and G. Accordi 2000. The Indian Ocean coast of Somalia. - *Marine Pollution Bulletin*, **41,** 141-159.

Cardinale, B. J., K. Nelson, et al. 2000. Linking species diversity to the functioning of ecosystems: on the importance of environmental context. *Oikos*, **91,** 175-183.

Carpentier, C. L., S. A. Vosti, et al. 2000. Intensified production systems on western Brazilian Amazon settlement farms: could they save the forest? *Agriculture Ecosystems & Environment*, **82,** 73-88.

Carrington, D. P., R. G. Gallimore, *et al*. 2001. Climate sensitivity to wetlands and wetland vegetation in mid-Holocene North Africa. *Climate Dynamics*, **17,** 151-157.

Cassel-Gintz, M. and G. Petschel-Held 2000. GIS-based assessment of the threat to world forests by patterns of non-sustainable civilisation nature interaction. - *Journal of Environmental Management*, **59,** 279-298.

Castro, R., F. Tattenbach, et al. 2000. The Costa Rican experience with market instruments to mitigate climate change and conserve biodiversity. - *Environmental Monitoring & Assessment*, **61,** 75-92.

Chapin, F. S., E. S. Zavaleta, et al. 2000. Consequences of changing biodiversity [Review]. - *Nature*, **405,** 234-242.

Chave, J. 2000. Spatio-temporal dynamics of the tropical rain forest [Review] [French]. - *Annales de Physique*, **25,** 1-.

Chuine, I., G. Cambon, and P .Comtois, 2000: Scaling phenology from the local to the regional level: advances from species-specific phenological models. *Global Change Biology* **6**: 943-952.

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Collatz, G. J., J. A. Berry, *et al*. 1998. Effects of climate and atmospheric CO_2 partial pressure on the global distribution of c-4 grasses - present, past, and future. *Oecologia*, **114,** 441-454.

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Dauer, D. M., J. A. Ranasinghe, et al. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay [Review]. *Estuaries*, **23,** 80-96.

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

Indicator	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*).
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*).
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*).
Hot days / heat index	Increased (*likely*).
Cold / frost days	Decreased for nearly all land areas during the 20th century (*very likely*).
Continental precipitation	Increased by 5-10% over the 20th century in the Northern Hemisphere (*very likely*), 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*).
Frequency and severity of drought	Increased summer drying and associated incidence of drought in a few areas (*likely*). 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*).
Arctic sea-ice extent and thickness	Thinned by 40% in recent decades in late summer to early autumn (*likely*) 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*).
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 (see Figure 2-7). 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 the relevant Working Group.

FIGURE 1

SEE PAGE 6 LINES 1 - 7 FOR FIGURE CAPTION

Color versions can be viewed at <http://www.usgcrp.gov/ipcc/biotp_grev>
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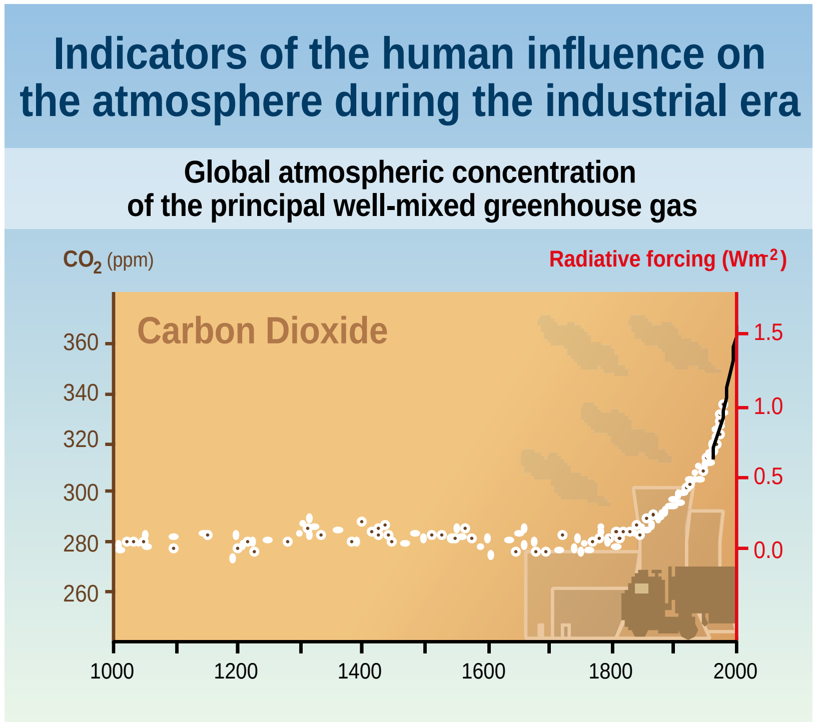

FIGURE 2

SEE PAGE 6 LINES 30 - 77 FOR FIGURE CAPTION

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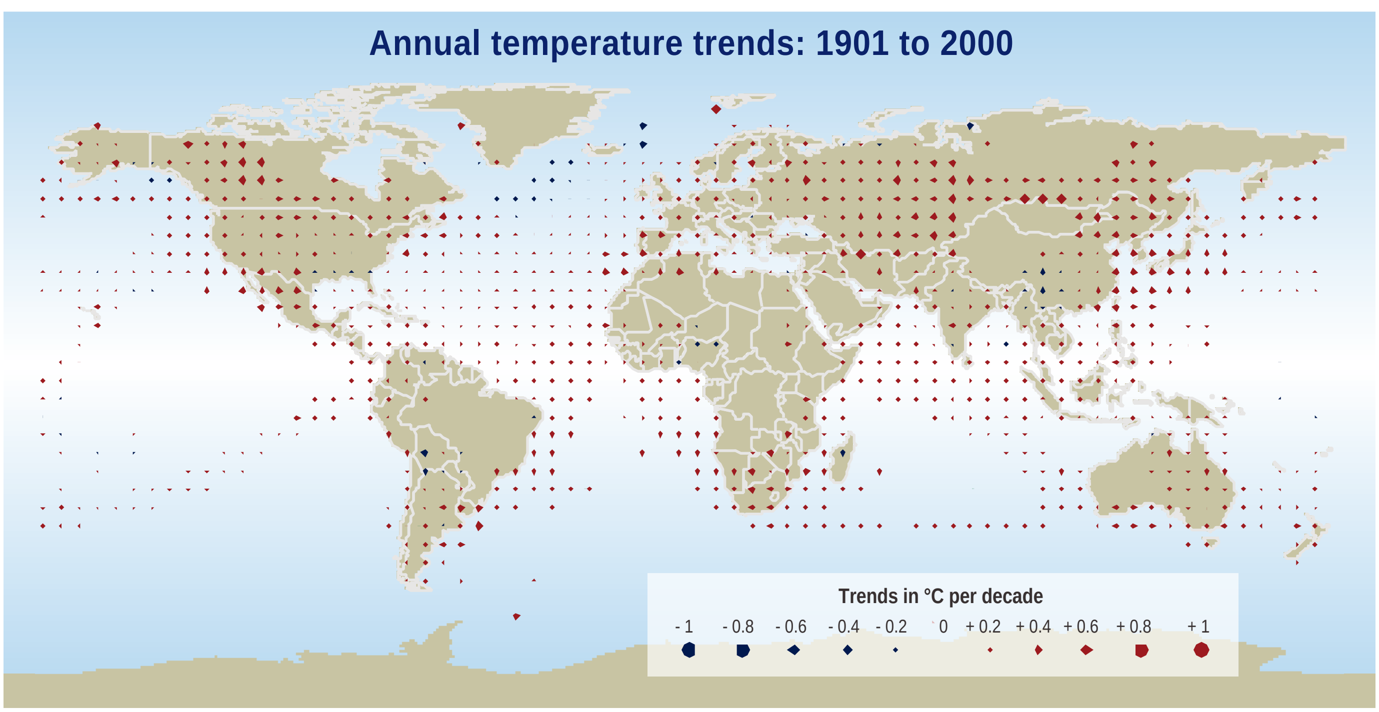

FIGURE 3

SEE PAGE 6 LINE 50 - PAGE 7 LINE 3 FOR FIGURE CAPTION

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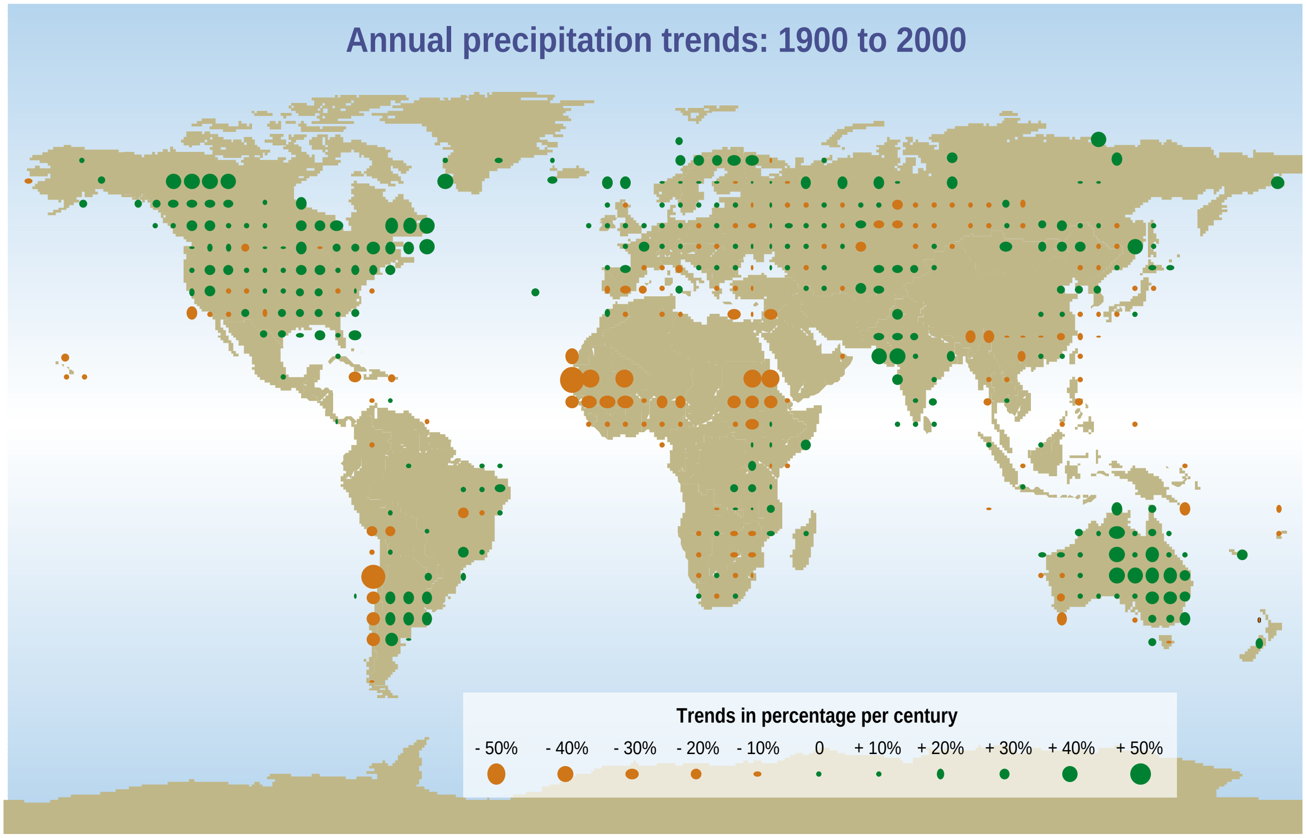

FIGURE 4

SEE PAGE 9 LINES 13 - 17 FOR FIGURE CAPTION

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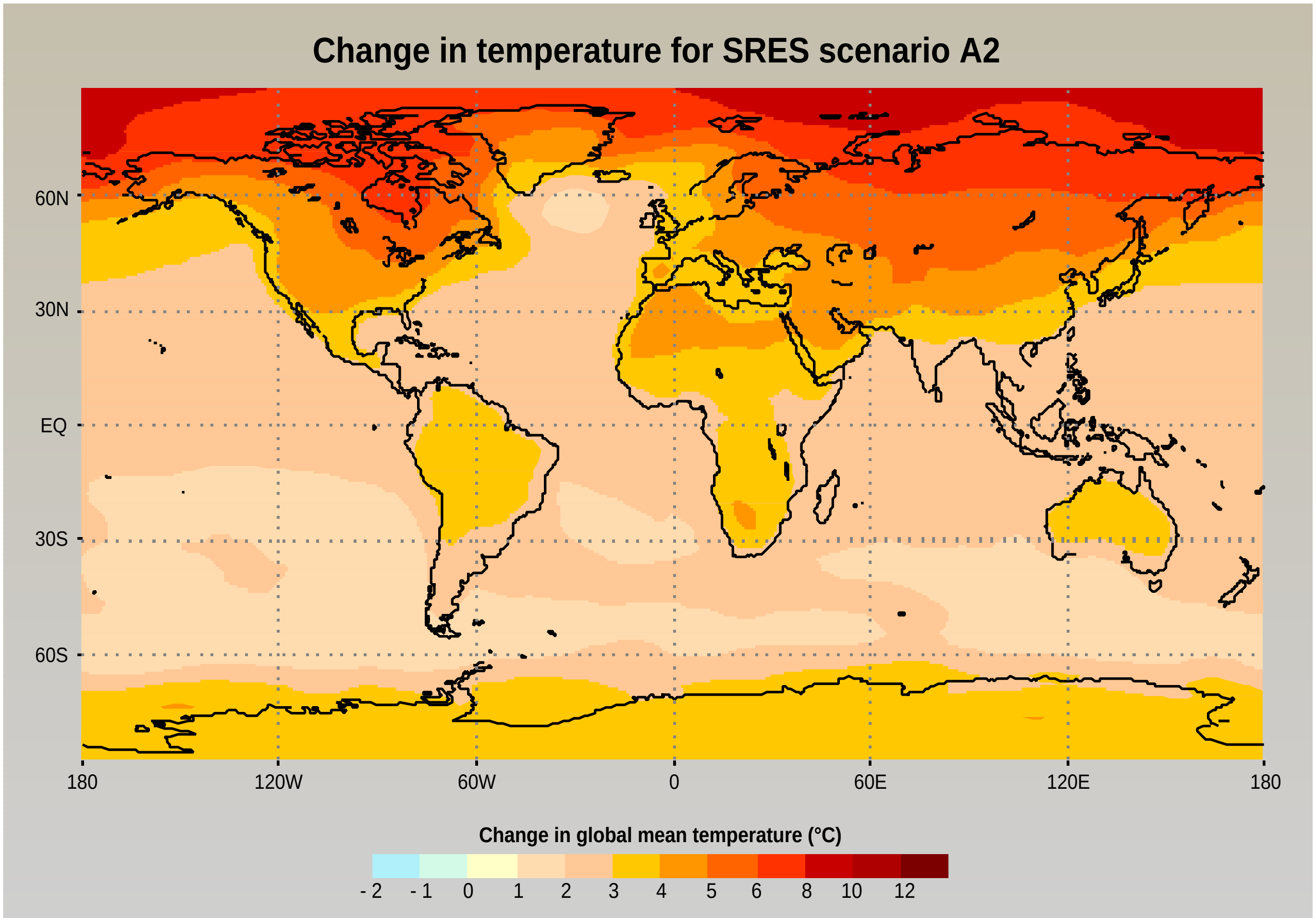

FIGURE 5

SEE PAGE 9 LINES 28 - 30 FOR FIGURE CAPTION

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