3. CLIMATE CHANGE AND BIODIVERSITY: OBSERVED AND PROJECTED IMPACTS

Main authors: *Habiba Gitay, Miguel Lovera, Avelino Suarez, Yoshitaka Tsubaki, Robert Watson.*

Contributing authors: *Muna Faraj, Mirna Marin, Peter Straka, Andreas Volentras, Clive R. Wilkinson.*

INTRODUCTION

The Convention on Biological Diversity (CBD) has organized its work under the following thematic programs: agricultural biodiversity, dry and sub-humid lands biodiversity, forest biodiversity, inland waters biodiversity, mountain biodiversity, and marine and coastal biodiversity. This chapter summarizes the observed and projected changes in the climate system and the impacts of these changes on the above ecosystem types, and the potential impacts of large-scale changes in biodiversity on regional and global climates.

The majority of the material for this chapter is drawn from Intergovernmental Panel on Climate Change (IPCC)[16] reports; in particular, the Technical Paper V on climate change and biodiversity that summarized the material in IPCC reports of relevance to this chapter. Appendix A of the IPCC Technical Paper V provided a set of additional literature of some relevance to this chapter; in addition, a thorough literature search was conducted from 1999 to late 2002. Thus, there have been a number of publications of relevance to this chapter published post-IPCC Third Assessment Report and these have been assessed and are cited. Overall, the additional publications have supported the IPCC findings, often with specific examples of a particular taxa, ecosystem or region.

IPCC in its Working Group II (impacts, adaptation and vulnerability – IPCC 2001, IPCC 2002- section 1) provides definitions of concepts of importance to this chapter. The major concepts are impacts, adaptation, and vulnerability and their accepted definitions are as follows:

(a) The magnitude of the impact is a function of the extent of change in a climatic parameter (e.g., a mean climate characteristic, climate variability and/or the frequency and magnitude of extremes) and the sensitivity of the system to that climate-related stimuli. The impacts of the projected changes in climate include direct changes in many aspects of biodiversity and disturbance regimes (e.g., changes in the frequency and intensity of fires, pests, and diseases).

(b) *Adaptation* measures could reduce some of the impacts. Human and natural systems will to some degree adapt autonomously to climate change. Planned adaptation (see section 4.11) can supplement autonomous adaptation, though options and incentives are greater for adaptation of human systems than for adaptation for natural systems. Natural and human systems are considered to be vulnerable if they are exposed and/or sensitive to climate change and/or adaptation options are limited.

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

(b) *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.

Chapter 2 has discussed the links between climatic factors and biodiversity. In this chapter, drawing on findings of the IPCC, the observed and the projected changes in the climate system

16 IPCC publications are based on extensive assessment of literature, both peer reviewed and some grey literature, from all over the world.

of relevance to biodiversity are summarised in sections 3.1 and 3.2. These include changes in the composition of the atmosphere (e.g., the atmospheric concentrations of CO_2), the Earth's climate (e.g., surface temperature, including day-night and seasonal, intensity and frequency of precipitation, snow cover, sea, river and lake ice, glaciers, sea level, and climate variability) as well as El Niño Southern Oscillation (ENSO) events. ENSO events consistently affect regional variations of precipitation and temperature over much of the tropics, subtropics, and some mid-latitude areas), and in some regions extreme climatic events (e.g., heat waves, heavy precipitation events).

As stated in chapter 2, ecosystems provide many goods and services crucial to human well being, including those for indigenous and local communities. These include food, fibre, fuel, energy, fodder, medicines, clean water, clean air, flood/storm control, pollination, seed dispersal, pest and disease control, soil formation and maintenance, cultural, spiritual, aesthetic and recreational values. Human activities create many pressures on ecosystems such as land use change, soil and water and air pollution. In many cases, climate change is an added stress. Climate and climate change can affect ecosystems and biodiversity in many ways: the impacts of observed and projected changes on terrestrial and inland wetlands (including freshwater systems), marine and coastal systems and the goods and services they provide is summarized in sections 3.3 to 3.5. Climate change is particularly likely to impact traditional and indigenous peoples and the projected impacts are summarised in section 3.6. Some ecosystems are sensitive to climatic factors and have limited adaptation options thus making them vulnerable to climate change; these are summarised in section 3.7. Some changes in terrestrial and marine biodiversity could affect the regional and global climate and these interactions are summarised in section 3.8. The chapter ends with summarising the information gaps and research needs that have to be considered to increase the understanding of the impacts of climate change on ecosystems and to reduce some uncertainties in projecting the impacts.

3.1 OBSERVED CHANGES IN THE 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 change the composition of the atmosphere. Increasing greenhouse gases tend to warm the Earth's climate, while increasing aerosols can either cool or warm the Earth's climate.

The IPCC findings of the observed changes over the 20th century in the composition of the atmosphere (e.g., the increasing atmospheric concentrations of greenhouse gases such as CO_2 and methane (CH_4), the Earth's climate (e.g., temperature, precipitation, sea level, sea ice, and in some regions extreme climatic events including heat waves, heavy precipitation events and droughts) are summarized in this section (IPCC 2001, [questions 2, 4, 5] and the IPCC Working Group 1, SPM).

a) **Concentrations of atmospheric greenhouse gases have generally increased.** During the period 1750 to 2000, the atmospheric concentration of CO2 increased by 31±4%, primarily due to the combustion of fossil fuels, land use, and land-use change (see also chapter 4 on carbon cycle explanation). The atmospheric concentration of CH_4 increased by 151±25% from the years 1750 to 2000, primarily due to emissions from fossil-fuel use, livestock, rice agriculture, and landfills. Stratospheric aerosols from large volcanic eruptions have led to important, but brief-lived, negative forcings, particularly the periods about 1880 to 1920 and 1963 to 1994.
b) **Over the 20th century there has been a con-**

sistent, large-scale warming of both the land and ocean surface. 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 (range of 0.4–0.8°C) over the last 100 years. The warming has been greatest in the mid-high latitudes. Since the year 1950, the increase in sea surface temperature is about half that of the increase in mean land surface air temperature and night-time 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.

c) **Precipitation has *very likely*[17] increased during the 20th century by 5 to 10% over most mid- and high latitudes of the Northern Hemisphere continents, but in contrast precipitation has *likely* decreased by 3% on average over much of the subtropical land areas.** There has *likely* been a 2 to 4% increase in the frequency of heavy precipitation (50 mm in 24 hours) events in the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century. There were relatively small increases over the 20th century in land areas experiencing severe drought or severe wetness: in many regions these changes are dominated by inter-decadal and multi-decadal climate variability with no significant trends evident.

d) **Snow cover and ice extent have decreased.** It is *very likely* that the 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 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 was also widespread retreat of mountain glaciers in non-polar regions during the 20th century. Northern Hemisphere spring and summer sea-ice extent decreased by about 10 to 15% from the 1950s to the year 2000.

e) **The average annual rise in sea level was between 1 and 2 mm during the 20th century.** This is based on the few, very long, tide gauge records from the northern hemisphere and after correcting for vertical land movements. It is *very likely* that the 20th century warming contributed significantly to the observed sea level rise through thermal expansion of seawater and widespread loss of land ice.

f) **Warm episodes of the ENSO phenomenon have been more frequent, persistent, and intense since the mid-1970s,** compared with the previous 100 years.

g) **There have been observed changes in some extreme weather and climate events.** It is *likely* that there have been higher maximum temperatures, more hot days and an increase in heat index, and *very likely* that there have been 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.

3.2 PROJECTED CHANGES IN THE CLIMATE

The Working Group I contribution to the IPCC Third Assessment Report (IPCC 2001) provided revised global and, to some extent, regional climate change projections based on a new series

17 Based on the IPCC Working Group I lexicon use, the following words have been used where appropriate to indicate judgemental estimates of confidence: *very likely* (90–99% chance) and *likely* (66–90% chance). When the words *likely* and *very likely* appear in italics, these definitions are applied; otherwise, they reflect normal usage.

of emission scenarios from the IPCC Special Report on 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, social, economic, and broad technological development assumptions. Each of these scenarios results in a set of atmospheric concentrations of greenhouse gases and aerosols from which the changes in the climate can be projected. CO_2 concentrations, globally averaged surface temperature, and sea level are projected to increase during the 21st century. Substantial differences are projected in regional changes in climate and sea level as compared to the global mean change. An increase in climate variability and some extreme events is also projected. The projected changes, extracted from section 4 of IPCC (2002), and that have relevance to biodiversity--supplemented with any recent literature--are summarized below.

(a) **The concentrations of greenhouse gases are projected to increase in the 21st century and sulphate aerosol are projected to decrease.** The projected concentrations of CO_2, in the year 2100 range from 540 to 970 parts per million (ppm), compared to about 280 ppm in the pre-industrial era and about 368 ppm in the year 2000. Sulfate aerosol concentrations are projected to fall below present levels by 2100 in all six illustrative SRES scenarios, whereas natural aerosols (e.g., sea salt, dust) and emissions leading to sulfate and carbon aerosols (e.g. dimethyl sulphide – DMS – emitted by some species of phytoplankton) are projected to increase as a result of changes in climate.

(b) **The projected global average increases in temperature are about two to ten times larger than the central value of observed warming over the 20th century** and the projected rate of warming of 1.4 to 5.8^{o}C over the period 1990 to 2100 is *very likely* to be without precedent during at least the last 10,000 years. The most notable areas of warming are in the landmasses of northern regions (e.g., North America, and northern and central Asia), which exceed global mean warming in each climate model by more than 40%. In contrast, the warming is less than the global mean change in south and southeast Asia in summer and in southern South America in winter.

(c) **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. 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. Larger year-to-year variations in precipitation are *very likely* to occur over most areas where an increase in mean precipitation is projected.

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

(e) **The amplitude and frequency of extreme precipitation events are** *very likely* to increase over many areas and the return periods for extreme precipitation events are projected to decrease. This would lead to more frequent floods even in areas of decreasing overall precipitation (Christensen and Christensen 2003). 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.

(f) **More hot days and heat waves and fewer cold and frost days are** *very likely* **over nearly all land areas.**

(g) **High-resolution modelling studies suggest that over some areas the peak wind intensity of tropical cyclones is** *likely* **to increase over the 21st century** by 5 to 10% and precipitation rates may increase by 20 to 30%, but none of the studies suggest that the locations of the tropical cyclones will change. There is little consistent modelling evidence for changes in the frequency of tropical cyclones

(h) **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.

(i) **Glaciers and ice caps are projected to continue their widespread retreat during the 21st century.** 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.

(j) **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.** Projected rise in sea-level 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 additional factors (e.g., atmospheric pressure, wind stress and thermocline depth). Confidence in the regional distribution of sea-level change from complex models is low because there is little similarity between model results, although nearly all models project greater than average rise in the Arctic Ocean and less than average rise in the Southern Ocean.

(k) **Most models project a weakening of the ocean thermohaline circulation, which leads to a reduction of the heat transport into high latitudes of Europe.** The current projections do not exhibit a complete shutdown of the thermohaline circulation by 2100. Beyond 2100, there is some evidence to suggest that the thermohaline circulation could completely, and possibly irreversibly, shut down in either hemisphere if the change in radiative forcing is large enough and applied long enough. The impact of this on biodiversity is unknown.

3.3 OBSERVED CHANGES IN TERRESTRIAL AND MARINE ECOSYSTEMS ASSOCIATED WITH CLIMATE CHANGE

IPCC evaluated the effect of climate change on biological systems by assessing 2 500 published studies. Of these, 44 studies, which included about 500 taxa, met the following criteria: 20 or more years of data; measuring temperature as one of the variables; the authors of the study finding a statistically significant change in both a biological/physical parameter and the measured temperature; and a statistically significant correlation between the temperature and the change in the biological/physical parameter. Some of these studies investigated different taxa (e.g., bird and insect) in the same paper. Thus, a total of 59 plants, 47 invertebrates, 29 amphibians and reptiles, 388 birds, and 10 mammal species. Approximately 80% showed change in the biological parameter measured (e.g., start and end of breeding season, shifts in migration patterns, shifts in animal and plant distributions, and changes in body size) in the manner expected with global warming, while 20% showed change in the opposite direction. Most of these studies have been carried out (due to long-term research funding decisions) in the temperate and high-latitude areas and in some high-altitude areas. The main findings of the IPCC are that some ecosystems that are particularly sensitive to changes in regional climate (e.g., high-altitude and high-latitude ecosystems) have already been affected by changes in climate (IPCC 2002– section 5.1, Root et al. 2003, Parmesan and Yohe 2003). Specifically, there has been a discernible impact of regional climate change, particularly increases in temperature, on biological systems in the 20th century. Specific changes highlighted in the IPCC paper, supplemented by recent material, include changes in terrestrial (including freshwater) species distributions, population sizes, community composition and plant productivity: declines in frog and some bird species have been assessed in the IPCC Third assessment Report, but it is not clear that climate change is the causal factor, with pressures from other human activities being implicated. The main findings of the IPCC Third Assessment Report (IPCC 2002) are:

(a) **Changes in the timing of biological events (phenology) have been observed.** These include changes the timing of growth, flowering and reproduction. Such changes have been recorded in some insects, amphibians, reptiles, birds, and plant species.

(b) **Changes in species distribution linked to changes in climatic factors have been observed.** These include extension of range limit of some species polewards, especially in the northern hemisphere. Drought associated shifts in animal's ranges and densities have been observed in many parts of the world.

(c) **Many taxa (birds, insects, plants) have shown changes in morphology, physiology, and behavior** associated with changes in climatic variables.

(d) **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.

(e) **Changes in streamflow, floods, droughts, water temperature, and water quality have been observed** and they have affected biodiversity and the goods and services ecosystems provide.

(f) **In high-latitude ecosystems in the Northern Hemisphere, the warmer climate has lead to increased growing degree-days** for agriculture and forestry. However, the amount of sunlight and perhaps the proportion of direct and diffuse sunlight also influence plant productivity. There has been altered plant species composition, especially forbs and lichens in the tundra, due to thermokarst, some boreal forests in central Alaska have been transformed into extensive wetlands during the last few decades of the

20th century. The area of boreal forest burned annually in western North America has doubled in the last 20 years, in parallel with the warming trend in the region.

(g) **There has been observed decrease in survivorship of adult penguins.** Over the past 50 years, the population of emperor penguins in Terre Adelie has declined by 50% because of a decrease in adult survival during the late 1970s when there was a prolonged abnormally warm period with reduced sea-ice extent (Barbraud and Weimerskirch 2001).

(h) **Extreme climatic events, and variability (e.g., floods, hail, freezing temperatures, tropical cyclones, droughts), and the consequences of some of these (e.g., landslides and wildfire) have affected ecosystems in many continents.** Climatic events such as the El Niño event of the years 1997–1998 had major impacts on many terrestrial ecosystems.

The coastal and marine ecosystems are sensitive to changes in water temperature and extreme climatic events. Specific findings of the IPCC (2002 – section 5.2, IPCC 2001, SYR, Question 2) include:

(a) **Tropical and subtropical coral reefs have been adversely affected** by rising sea surface temperatures, especially during El-Nino events during which the temperatures increase beyond the normal seasonal range. These bleaching events are often associated with other stresses such as, sediment loading and pollution. The repercussions of the 1998 mass bleaching and mortality events will be far-reaching (Reaser et al. 2000).

(b) **Diseases and toxicity have affected coastal ecosystems** related to increased seasonal or annual water temperatures.

(c) **Changes in marine systems, particularly fish populations, have been linked to large-scale climate oscillations.**

(d) **Large fluctuations in the abundance of marine birds and mammals across parts of the Pacific and western Arctic have been detected** and may be related to changing regimes of disturbances, climate variability, and extreme events.

3.4 PROJECTED IMPACTS OF CHANGES IN MEAN CLIMATE AND EXTREME CLIMATIC EVENTS ON TERRESTRIAL (INCLUDING RIVERS, LAKES AND WETLANDS) AND MARINE ECOSYSTEMS

Climate change and elevated atmospheric concentrations of CO_2 is projected to affect individuals, populations, species and ecosystem composition and function both directly (e.g., through increases in temperature and changes in precipitation, changes in extreme climatic events and in the case of aquatic systems changes in water temperature, sea level, etc.) and indirectly (e.g., through climate changing the intensity and frequency of disturbances such as wildfires). The impacts of climate change will depend on other significant anthropogenic pressures. The most significant pressures are increased land-use intensity and the associated destruction of natural or semi-natural habitats, loss and fragmentation (or habitat unification, especially in the case of freshwater bodies), the introduction of invasive species, and direct effects on reproduction, dominance, and survival through chemical and mechanical treatments. No realistic projection of the future state of the Earth's ecosystems can be made without taking into account human land- and water-use patterns—past, present, and future. Human use will endanger some terrestrial and aquatic ecosystems, enhance the survival of others, and greatly affect the ability of organisms to adapt to climate change via migration (chapter 2). Independent of climate change, biodiversity is forecast to decrease in the future due to the multiple pressures from human activities—climate change constitutes an additional pressure. Quantification of the impacts of climate change alone, given the multiple and interactive pressures acting on the

Earth's ecosystems, is difficult and likely to vary regionally. Losses of species can lead to changes in the structure and function of the affected ecosystems, and loss of revenue and aesthetics (IPCC 2002 – section 6 introduction and 6.1).

IPCC (2002 – section 6.1, 6.2) stated that projecting changes in biodiversity in response to climate change presents some significant challenges, especially at the fine scale. Modelling requires projections of climate change at high spatial and temporal resolution and often depends on the balance between variables that are poorly projected by climate models (e.g., local precipitation and evaporative demand). It also requires an understanding of how species interact with each other and how these interactions affect the communities and ecosystems of which they are a part. The data and models needed to project the extent and nature of future ecosystem changes and changes in the geographical distribution of species are incomplete, meaning that these effects can only be partially quantified. Models of changes in the global distribution of vegetation are often most sensitive to variables for which we have only poor projections (e.g., water balance) and inadequate initial data.

Biodiversity is recognized to be an important issue for many regions of the world. It also provides goods and services for human wellbeing (Box 2.1). Different regions have varied amounts of biodiversity with varying levels of endemic species. The projected impacts of climate change at the regional level are summarised in Boxes no. 5 to 15 of the IPCC (2002) and will not be summarised here. It is worth noting that there is a limitation of region- and country-specific studies on the impacts of climate change on biodiversity particularly at the genetic level.

3.4.1 Projected impacts on individuals, populations, species, and ecosystems

Based on IPCC Reports (2001; 2002), and additional material (as listed), some examples of how individuals, populations, and species, ecosystems and some ecological processes that may be affected by climate change (directly or indirectly) include:

(a) **While there is little evidence to suggest that climate change will slow species losses, there is evidence that it may increase species losses.**

(b) **Extinction of wildlife populations may be hastened by increasing temporal variability in precipitation.** Models of checkerspot butterfly (a common species found in North America) populations showed that changes in precipitation amplified population fluctuations, leading to rapid extinctions (McLaughlin et al. 2002). This process will be particularly pronounced when a population is isolated by habitat loss.

(c) **Changes in phenology, such as the date of bud break of plants, hatching, and migration of insects, birds and mammals, have already been observed and are expected to continue.** This can be beneficial or detrimental, e.g., the changes in phenology of plants can lead to higher productivity, but can make the plants more vulnerable to early or late onset of frost and pest/disease outbreak. There could be further interaction between the phenology and changes in extreme climatic events, e.g., the lack of frost in some regions can stop the onset of flowering and thus fruit formation (e.g., in southern Australia- Pittock et al. 2001).

(d) **Ecosystems dominated by long-lived species (e.g., long-lived trees) will often be slow to show evidence of change** and slow to recover from climate-related stresses as the changes in the climate may not be sufficient to cause increased mortality among mature individuals. Changes in climate often also affect vulnerable life stages such as seedling establishment and are expected to continue to do so.

(e) **Plant communities are expected to be disrupted**, as species that make up a community are unlikely to shift together. In lakes and river systems, changes in water quality due to climate change could cause eutrophication and thus change the species composition.

(f) **Most soil biota have relatively wide temperature optima, so are unlikely to be adversely affected directly by changes in temperatures, although there is lack of information on the effect of changes in soil moisture.** Some evidence exists to support changes in the balance between soil functional types (see section 2.3 for discussion on functional types).

(g) **For inland wetlands, changes in rainfall and flooding patterns across large areas of arid land will adversely affect bird species** that rely on a network of wetlands and lakes that are alternately or even episodically wet and fresh and drier and saline (Roshier et al. 2001), or even a small number of wetlands, such as those used by the banded stilt (Cladorhynchus leucocephalus) which breeds opportunistically in Australia's arid interior (Williams 1998). Responses to these climate induced changes may also be affected by fragmentation of habitats or disruption or loss of migration corridors, or even, changes to other biota, such as increased exposure to predators by wading birds (Butler and Vennesland 2000, van Dam et al. 2002).

(h) **The lack of thermal refugia and migratory routes in lakes, streams and rivers, may cause contraction of the distributions of many fish species.** For example, warmer lake water temperature will reduce dissolved oxygen concentration and lower the level of the thermocline, most likely resulting in a loss of habitat for coldwater fish species in areas such as Wisconsin and Minnesota (western Great Lakes). In addition, reduced summer flows and increased temperatures will cause a loss of suitable habitat for cool water fish species in riverine environments in the Rocky Mountain region (British Columbia, western Canada; Gitay et al. 2001)

(i) **Species and ecosystems are projected to be impacted by extreme climatic events,** e.g., higher maximum temperatures, more hot days, and heat waves are projected to increase heat stress in plants and animals and reduce plant productivity; higher minimum temperatures, fewer cold days, frost days and cold waves could result in extended range and activity of some pest and disease vectors, increased productivity in some plant species and ecosystems; more intense precipitation events are projected to result in increased soil erosion, increased flood runoff; increased summer drying over most mid-latitude continental interiors and associated risk of drought are projected to result in decreased plant productivity, increased risk of wild fires and diseases and pest outbreaks; increased Asian summer monsoon precipitation variability and increased intensity of mid-latitude storms could lead to increased frequency and intensity of floods and damage to coastal areas.

(j) **The general impact of climate change is that the habitats of many species will move poleward or upward** from their current locations with most rapid changes being where they are accelerated by changes in natural and anthropogenic disturbance patterns. Weedy (i.e., those that are highly mobile and can establish quickly) and invasive species will have advantage over others.

(k) **Drought and desertification processes will result in movements of habitats of many species towards areas of higher rainfall from their current locations.**

(l) **The climatic zones suitable for temperate and boreal plant species may be displaced by 200–1,200 km poleward** (compared to the 1990s distribution) by the year 2100. The species composition of forests is likely to change and new assemblages of species may replace existing forest types that may be of lower species diversity due to the inability of some species to migrate fast enough and or due to habitat fragmentation. Increased frequency and intensity of fires and changes caused by thawing of permafrost will also affect some of these ecosystems.

(m) **For lakes and streams, the effects of temperature-dependent changes would be least in the tropics, moderate at mid-latitudes, and pronounced in high latitudes** where the largest changes in temperature are projected. Increased temperatures will alter thermal cycles of lakes and solubility of oxygen and other materials, and thus affect ecosystem structure and function. Changes in rainfall frequency and intensity combined with land-use change in watershed areas has led to increased soil erosion and siltation in rivers. This along with increased use of manure, chemical fertilizers, pesticides, and herbicides as well as atmospheric nitrogen deposition affects river chemistry and has led to eutrophication, with major implications for water quality, species composition, and fisheries. The extent and the duration of the ice cover is projected to decrease in some high latitude lakes and thus the biodiversity may be affected by the shorter ice cover season (Christensen and Christensen 2003)

(n) **Climate change will have most pronounced effects on wetlands through altering the hydrological regime** as most inland wetland processes are intricately dependent on the hydrology of the catchments (river basin) or coastal waters. This is expected to affect biodiversity and the phenology of wetland species (van Dam et al. 2002)

(o) **Land degradation arises both from human activities and from adverse climate conditions as to the exact quantitative attribution is difficult and controversial.** Climate-related factors such as increased drought can lead to increased risk of land degradation and desertification (Bullock et al. 1996, Le Houerou 2002, Nicholson 2001).

(p) **Disturbance can both increase the rate of loss of species and create opportunities for the establishment of new (including invasive alien) species.** Changes in the frequency, intensity, extent and locations of disturbances such as fires, outbreaks of pests and diseases, will affect whether and how existing ecosystems reorganize and the rate at which they are replaced by new plant and animal assemblages (see section 2.2.1).

(q) **The effect of interactions between climate change and changes in disturbance regime and their effect on biotic interactions may lead to rapid changes in vegetation composition and structure.** However, the quantitative extent of these changes is hard to project due to the complexity of the interactions.

3.4.2. Projected changes in biodiversity and changes in productivity

IPCC 2002 (section 6.2.2) stated that changes in biodiversity and the changes in ecosystem functioning associated with them might affect biological productivity. These changes may affect critical goods and services (see Chapter 2) and 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. Productivity can be measured as net primary productivity (NPP), net ecosystem productivity (NEP) or net biome productivity (NEB – see Box 4 of IPCC 2002).

3.4.2.1.Effects of elevated atmospheric CO_2 concentrations on vegetation

Climate change may either augment or reduce the direct effects of CO_2 on productivity, depending on the type of vegetation, the region, and the scenario of climate change. In most vegetation systems, increasing CO_2 concentrations would increase net primary productivity (often referred to as CO_2 fertilization effect) and net ecosystem productivity, causing carbon to accumulate in vegetation and soils over time assuming that the temperature increase is about 2-3 °C and there is little or no moisture limitation (Gitay et al. 2001).

The IPCC assessment was that over the 19th and for much of the 20th century the global terrestrial biosphere was a net source of atmospheric CO_2, but before the end of the 20th century it became a net sink, because of a combination of factors, e.g., changes in land-use and land management practices (e.g., reforestation and re-growth on abandoned land), increasing anthropogenic deposition of nitrogen, increased atmospheric concentrations of CO_2, and possibly climate warming (IPCC 2001, SYR, Question 2, IPCC 2001, section 6.2.2 --see also chapter 4).

54. During recent decades, the peak-to-trough amplitude in the seasonal cycle of atmospheric CO_2 concentrations has increased, and the phase has advanced at Arctic and sub-Arctic CO_2 observation stations north of 55° N. This change in carbon dynamics in the atmosphere probably reflects some combination of increased uptake during the first half of the growing season which could explain the observed increase in biomass of some shrubs, increased winter efflux and increased seasonality of carbon exchange associated with disturbance. This "inverse" approach has generally concluded that mid-northern latitudes were a net carbon sink during the 1980s and early 1990s. At high northern latitudes, these models give a wider range of estimates, with some analyses pointing to a net and others to a sink.

Free-air CO_2 enrichment (FACE) experiments suggest that tree growth rates may increase, litterfall and fine root increment may increase, and total net primary production may increase in forested systems, but these effects are expected to saturate because forest stands tend towards maximum carrying capacity, and plants may become acclimated to increased CO_2 levels. Longer-term experiments on tree species grown under elevated CO_2 in open-top chambers under field conditions over several growing seasons show a continued and consistent stimulation of photosynthesis, little evidence of long-term loss of sensitivity to CO_2, the relative effect on aboveground dry mass highly variable and greater than indicated by seedling studies, and the annual increase in wood mass per unit of leaf area. These results contradict some of the FACE experiment results.

On a global scale, terrestrial models project that climate change would reduce the rate of uptake of carbon by terrestrial ecosystems, but that they would continue to be a net, but decreasing, sink for carbon through 2100 (IPCC, 2001, Question 3).

The interaction between atmospheric CO_2 concentrations, air temperature and moisture is particularly noticeable in the context of plant-plant interactions (including shifts in competitiveness of some groups of plants, e.g. C_3 and C_4 species and lianas). 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. However, the impacts are not that simple. In pot experiments, elevated CO_2 is reported to improve water relations and enhance productivity in the C_4 shortgrass Bouteloua gracilis. In modelling and experimental studies, NPP of both C_3 and C_4 grasses increased under elevated CO_2 for a range of temperatures and precipitation but could result in relatively small changes in their geographical distributions. There are additional interactions with soil characteristics and climatic factors. The rate and duration of any 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 (Gitay et al. 2001). Phillips et al. (2002) have found increased competitiveness and dominance of lianas in Brazilian Amazon under higher CO_2 situations. There could be a resultant degradation of forest structure with increased liana biomass pulling down trees.

3.4.2.2. Summary findings of projected changes in biodiversity and changes in productivity

The main findings of IPCC (2002 – section 6.2.2) are:

(a) **Where significant ecosystem disruption occurs (e.g., loss of dominant species or losses of a high proportion of species, thus much of the redundancy), there may be losses in NEP during the transition.**

(b) **The role of biodiversity in maintaining ecosystem structure, functioning, and productivity is still poorly understood** (see also section 2.3).

3.5. PROJECTED IMPACTS ON BIODIVERSITY OF COASTAL AND MARINE ECOSYSTEMS

Climate change will affect the physical, biological, and biogeochemical characteristics of the oceans and their coasts at different time and space scales, modifying their ecosystem structure and functioning. This in turn could exert feedbacks on the climate system (IPCC 2002 - section 6.3).

Human populations dependent on reef and coastal systems face losses of marine biodiversity, fisheries, and shoreline protection. Even those reefs with well-enforced legal protection as marine sanctuaries, or those managed for sustainable use, are threatened by global climate change and thus would have repercussions for the human populations that depend on them for various goods and services (Reaser et al. 2000).

61. Wetlands, including reefs, atolls, mangroves, and those in prairies, tropical and boreal forests and polar and alpine ecosystems, are considered to be amongst those natural systems especially vulnerable to climate change because of their limited adaptive capacity, and are likely to undergo significant and irreversible change (IPCC 2001 – WG2 SPM).

Other wetlands that could be impacted by climate change are those in regions that experience El Niño-like phenomena, which are projected to increase, and/or are located in the continental interiors, and thus are likely to experience changes in the catchment hydrology (van Dam et al. 2002).

3.5.1 Projected impacts on ecosystems in coastal regions

Some of the findings of IPCC (2002- section 6.3.1) and supplemented by recent material include:

(a) **Coral reefs will be impacted detrimentally if sea surface temperatures increase by more than 1°C above the seasonal maximum temperature.** 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 (see also section 3.7).

(b) **In the near-shore marine and coastal systems, many wetlands could be impacted indirectly as a result of climate change due to changes in storm surges.** As a result, there will be saltwater intrusion into the freshwater systems. This may result in large-scale translocation of populations in low lying coral reef countries when tropical storm surges pollute water supplies and agricultural land with saltwater (Wilkinson and Buddemeier 1994). Mangroves and coastal lagoons are expected to undergo rapid change and perhaps be lost as relocation may be impeded by physical factors, including infrastructure and physical geographical features (van Dam et al. 2002). Some examples are the United States of America coastal ecosystems where the increasing rates of sea-level rise and intensity and frequency of coastal storms and hurricanes over the next decades will increase threats to shorelines, wetlands, and coastal development (Scavia et al. 2002, Burkett and Kusler 2000).

(c) **Sea-level rise and changes in other climatic factors (e.g., more intense monsoonal rains, and larger tidal or storm surges) 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. Such changes are likely to result in dislocation if not displacement of many wetland species, both plants and animals. Plants, turtles, some frogs and snakes, a range of invertebrate species, bird and fish populations and species not tolerant to increased salinity or inundation, have and could continue to be eliminated or restricted in their distribution, whilst salt-tolerant mangrove species could expand from nearby coastal habitats.

(d) **The combined pressures of sea level rise and coastal development (resulting in coastal squeeze) could reduce the availability of intertidal areas**, resulting in loss of feeding habitat and leading to population declines in wintering shorebirds (Lindström and Agrell 1999). For a number of trans-African-Arctic migratory bird species, the wintering grounds in Africa and breeding grounds in the Arctic will be threatened by sea level rise, especially due to loss of mudflats (Bayliss et al. 1997, Lindström and Agrell 1999, van Dam et al. 2002). Migratory and resident animals, such as birds and fish, may lose important staging, feeding and breeding grounds (Bayliss et al. 1997, Eliot et al. 1999, Finlayson et al. 1993, Lal et al. 2001, Li et al. 1999, van Dam et al. 2002).

(e) **Currently eroding beaches and barriers are expected to erode further as the climate changes and sea level rises.**

(f) **Globally, about 20% of coastal wetlands could be lost** by the year 2080 due to sea-level rise, with significant regional variations.

(g) **The impact of sea-level rise on coastal ecosystems (e.g., mangroves, marshes, seagrasses) will vary regionally** and will depend on the interactions between erosion processes from the sea depositional processes from land and sea-level rise. The ability of fringing and barrier reefs to reduce impacts of storms and supply sediments can be adversely affected by sea-level rise.

3.5.2 Projected impacts on marine ecosystems

Marine ecosystems include various functionally different seas and oceans. Changes in the physical and chemical characteristics of the ocean and seas (e.g. currents or circulation patterns, nutrient availability, pH, salinity, and the temperature of the ocean waters) will affect marine ecosystems. Climate change impacts on the marine system include sea surface temperature-induced shifts in the geographic distribution of the biota and compositional changes in biodiversity, particularly in high latitudes. The literature in this area is not as extensive as in the terrestrial and coastal ecosystems. In addition, the present knowledge of the impacts of potential changes in entire ecosystems due to climate change is still poor.

Current scenarios of global climate change include projections of increased upwelling and consequent cooling in temperate and subtropical upwelling zones. Ecological evidence, despite being limited, suggests that such cooling could disrupt trophic relationships and favour retrograde community structures in those local areas (Aronson and Blake 2001, Barret 2003).

The response of marine productivity to climate change, using two different ocean biogeochemical schemes and two different atmosphere-ocean coupled general circulation models (GCM), suggest a reduction in marine export production (-6%) although regional changes can be both negative and positive (from -15% zonal average in the tropics to +10% in the Southern Ocean; Bopp et al. 2001).

The main findings of the IPCC (2002- section 6.3.2) supplemented by recent literature include:

(a) **The mean distribution of plankton and marine productivity in the oceans in many regions could change during the 21st century** with projected changes in the sea surface temperature, wind speed, nutrient supply, and sunlight.

(b) **Climate change will have both positive and negative impacts on the abundance and distribution of marine biota**. Recent findings show that warming will cause a northern shift of distribution limits for the cod (*Gadus morhua*) and common eelpout (*Zoarces viviparus*) with a rise in growth performance and fecundity larger than expected in the north and lower growth or even extinction of the species in the south. Such a shift may heavily affect fishing activities in the North Sea (Portner et al. 2001).

(c) **Productivity of commercially important fish species could be affected.** 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 (see also Napp and Hunt 2001).

(d) **There is likely to be a poleward shift of marine production** due mainly to a longer growing season at high latitudes. At low latitudes the effect of reduced upwelling would prevail. Ocean warming is expected to cause poleward shifts in the ranges of many other organisms, including commercial species, and these shifts may have secondary effects on their predators and prey (Bopp et al. 2001).

(e) **Climate change could affect food chains, particularly** those that include marine mammals. Reductions in sea ice in Arctic and Antarctic could alter the seasonal distributions, geographic ranges, migration patterns, nutritional status, reproductive success, and ultimately the abundance of marine mammals.

3.6 PROJECTED IMPACTS ON TRADITIONAL AND INDIGENOUS PEOPLES

Traditional[18] and indigenous peoples depend directly on diverse resources from ecosystems and biodiversity for many goods and services (e.g., food and medicines from forests, coastal wetlands, and rangelands – see also chapter 2). These ecosystems are already under stress from many current human activities and projected to be adversely affected by climate change (IPCC 2002 – section 6.6). The main findings of IPCC (2002 –section 6.6, Box 5-12) supplemented with additional material include:

(a) **The effects of climate change on indigenous and local peoples are likely to be felt earlier than the general impacts.** The livelihood of indigenous peoples will be adversely affected if climate and land-use change lead to losses in biodiversity, especially mammals, birds medicinal plants and plants or animals with restricted distribution (but have importance in terms of food, fibre or other uses for these peoples) and losses of terrestrial, coastal and marine ecosystems that these peoples depend on. In some terrestrial ecosystems, adaptation options (such as efficient small-scale or garden

18. Following IPCC (2002) "Traditional peoples" here refers to local populations who practice traditional lifestyles that are often rural. Traditional people may, or may not, be indigenous to the location.

irrigation, more effective rain-fed farming, changing cropping patterns, intercropping and/or using crops with lower water demand, conservation tillage and coppicing of trees for fuelwood) could reduce some of the impacts and reduce land degradation (see section 4.10).

(b) **Climate change will affect traditional practices of indigenous peoples in the Arctic**, particularly fisheries, hunting, and reindeer husbandry. The on-going interest among indigenous groups relating to the collection of traditional knowledge and their observations of climate change and its impact on their communities could provide future adaptation options.

(c) **Cultural and spiritual sites and practices could be affected by sea level rise and climate change.** Shifts in the timing or the ranges of wildlife species due to climate change could impact the cultural and religious lives of some indigenous peoples. Sea-level rise and climate change, coupled with other environmental changes, will affect some, but not all, unique cultural and spiritual sites in coastal areas and thus the people that reside there.

(d) **The projected climate change impacts on the biodiversity, including disease vectors, at ecosystem and species level could impact human health.** Many indigenous and local peoples live in isolated rural living conditions and are more likely to be exposed to vector- and water-borne diseases and climatic extremes and would therefore be adversely affected by climate change. The loss of staple food and medicinal species could have an indirect impact and can also mean potential loss of future discoveries of pharmacological products and sources of food, fibre and medicinal plants for these peoples (Gitay et al. 2001, McMichael et al. 1996, 2001)

(e) **Loss of food sources and revenues from key sectors such as tourism and fisheries could occur** As summarised in Section 3.5.1, coral reefs will be negatively affected by bleaching; Fishing, although largely artisanal or small-scale commercial, is an important activity on most small islands, and makes a significant contribution to the protein intake of island inhabitants and thus could lead to loss of food source and revenue.

(f) **Change in food production and water flows in mountainous areas could affect the indigenous and local people of those areas.** For indigenous and local people living in mountainous regions, the impacts of climate change are projected to result in altering the already marginal food production, change the seasonality of water flows and thus the habitats of many species that these people depend on.

(g) **The potential expansion of tree monoculture used as "carbon sinks" can compete with traditional land use practices** by indigenous and local communities, e.g., in South Africa (see also chapter 4). However, community involvement and knowledge could help towards win-win situations.

3.7 POPULATIONS, SPECIES AND ECOSYSTEMS VULNERABLE TO CLIMATE CHANGE

Many of the Earth's species are already at risk of extinction due to pressures arising from natural processes and human activities. Climate change will add to these pressures for many threatened and vulnerable species. For a few, climate change may relieve some of the existing pressures (IPCC 2002- section 6.4). Regional variation in the impacts of climate change on biodiversity is expected because of multiple interactions between drivers of biodiversity loss. The main findings of IPCC (2002) are:

(a) **Species with limited climatic ranges and/or restricted habitat requirements are typically the most vulnerable to extinc-**

tion. These include species on mountainous areas (as they cannot move up in elevation), and species restricted to islands or peninsulas (e.g., the Cape Floral Kingdom including the fynbos region at the southern tip of South Africa). Additionally, biota with particular physiological or phenological traits (e.g., biota with temperature-dependent sex determination like sea turtles and crocodiles, amphibians with a permeable skin and eggs) could be especially vulnerable. For some threatened species, habitat availability will increase (e.g., warm-water fish are projected to benefit in shallow lakes in cool temperate regions), possibly reducing vulnerability.

(b) **The risk of extinction will increase for many species, especially those that are already at risk** due to factors such as low population numbers, restricted or patchy habitats, limited climatic ranges, or occurrence on low-lying islands or near the top of mountains.

(c) **Geographically restricted ecosystems, especially in regions where there is added pressure from other human activities, are potentially vulnerable to climate change.** Examples of geographically restricted, vulnerable ecosystems include coral reefs, mangrove forests and other coastal wetlands, high mountain ecosystems (upper 2000 to 3000 m), prairie wetlands, remnant native grasslands, ecosystems overlying permafrost, and ice-edge ecosystems.

(d) **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.**

3.8 IMPACTS OF CHANGES IN TERRESTRIAL AND MARINE BIODIVERSITY ON REGIONAL AND GLOBAL CLIMATE

70. Changes in genetic or species biodiversity can lead to changes in the structure and functioning of ecosystems and their interaction with the water, carbon, nitrogen, and other major biogeochemical cycles and so affect climate. Changes in diversity at ecosystem and landscape scales in response to climate change and other pressures could further affect regional and global climate. Changes in trace gas fluxes are most likely to exert their effect at the global scale due to rapid atmospheric mixing of greenhouse gases, whereas the climate feedbacks from changes in water and energy exchange occur locally and regionally (IPCC 2002 – section 6.5). The IPCC (2002 – section 6.5) findings were as follows:

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

(a) **Human actions leading to the long-term**

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

(b) **Changes in land surface characteristics—such as those created by land-cover change—can modify energy, water, and gas fluxes and affect atmospheric composition creating changes in local, regional, and global climate.** Evapotranspiration and albedo affect the local hydrologic cycle, thus a reduction in vegetative cover may lead to reduced precipitation at local and regional scales and change the frequency and persistence of droughts. For example, in the Amazon basin, at least 50% of precipitation originates from evapotranspiration from within the basin. Deforestation reduces evapotranspiration, which could reduce precipitation by about 20%, producing a seasonal dry period and increasing local surface temperatures by 2°C. This could, in turn, result in a decline in the area of wet tropical rainforests and their permanent replacement by less diverse drought-deciduous or dry tropical forests or woodlands.

(c) **Marine ecosystems can be affected by climate-related factors, and these changes in turn could act as additional feedbacks on the climate system.** Some phytoplankton species cause emission of dimethylsulfide to the atmosphere that has been linked to the formation of cloud condensation nuclei. Changes in the abundance or distribution of such phytoplankton species may cause additional feedbacks on climate change.

3.9 RESEARCH NEEDS AND INFORMATION GAPS

Further research of present and projected climate change impacts on soils and on coastal and marine ecosystems is warranted. There are also some information gaps that affect the ability of making reliable projections of impacts. The main ones relate to development of data and models for:

(a) the geographical distribution of terrestrial, freshwater, coastal and marine species, especially those based on quantitative information and at high resolution Special attention should be given to invertebrates, lower plants and key species in ecosystems.
(b) the inclusion of human land and water use patterns, as they will greatly affect the ability of organisms to respond to climate change via migration, to provide a realistic projection of the future state of the Earth's ecosystems.
(c) enabling the elucidation of the impacts of climate change compared with pressures from other human activities.
(d) projections on changes in biodiversity in response to climate change especially at the regional and local level.
(e) assessing impacts and adaptations to climate change at genetic, population and ecosystem level.

3.10 REFERENCES

Aronson, R.B. and Blake, D.B. (2001). Global climate change and the origin of modern benthic communities in Antarctica. American Zoologist 41: 27 – 39.

Barbraud, C. and H. Weimerskirch. (2001). Emperor penguins and climate change. Nature 411: 183-186.

Barret, P. (2003). Cooling a continent. Nature 421: 221-223.

Bayliss B, Brenman K, Elliot I, Finlayson M, Hall R, House T, Pidgeon B, Walden D and Waterman, P. (1997). Vulnerability Assessment of Predicted Climate Change and Sea Level Rise in the Alligator Rivers Region, Northern Territory Australia. Supervising Scientist Report 123, Supervising Scientist, Canberra, 134 pp.

Bopp, L., P. Monfray, O. Aumont, J.L. Dufresne, H. Le Treut, G. Madec, L. Terray, and J.C. Orr. (2001). Potential impact of climate change on marine export production. Global Biogeochemical Cycles 15: 81-99.

Bullock, P., Le Houreou, H., Hoffmann, M.T., Rousevelle, M., Seghal, J. and Várallyay, G. (1996). Chapter 4. Land Degradation and Desertification. IN Climate Change 1995: Impacts, Adaptations and Mitigations of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the International Panel on Climate Change. Watson, R.T., Zinyowera, M.C. and Moss, R.H. (eds). pp. 170-200. IPCC/Cambridge University Press

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.

Butler, R.W. and Vennesland R.G. (2000). Integrating climate change and predation risk with wading bird conservation research in North America. Waterbirds 23(3): 535-540.

Christensen J.H. and Christensen O.B. (2003). Climate Modelling: Severe summertime flooding in Europe. Nature 421: 805-806.

Eliot I., Waterman P. and Finlayson C.M. (1999). Monitoring and assessment of coastal change in Australia's wet-dry tropics. Wetlands Ecology and Management 7: 63-81.

Finlayson C.M., Volz, J. and Chuikow, Y. (1993). Ecological change in the wetlands of the Lower Volga, Russia. In ME Moser, RC Prentice and J van Vessem (eds) Waterfowl and Wetland Conservation in the 1990s - A Global Perspective, IWRB Special Publication No 26, Slimbridge, UK. pp 61-66.

Gitay, H., Brown, S., Easterling, W., Jallow, B. et al. (2001). Chapter 5. Ecosystems and Their Goods and Services. IN Climate Change 2001: Impacts, Adaptations, and Vulnerability. Contribution of Working Group II to the Thirds Assessment Report of the International Panel on Climate Change. McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (eds). pp. 235-342. IPCC/Cambridge University Press

IPCC. (2001). Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

IPCC. (2002). Climate Change and Biodiversity. A Technical Paper of the IPCC. Edited by Gitay, H. Suarez, A. Watson, R. T and Dokken, D. WMO/IPCC publication.

Lal M., Harasawa, H., Murdiyarso, D (2001). Chapter 11. Asia. In: Climate Change 2001: Impacts, Adaptations, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the International Panel on Climate Change. McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (eds). pp533-590. Cambridge University Press.

Le Houerou, H.N. (2002.) Man-made deserts: Desertization processes and threats. Arid Land Research and Management 16: 1-36.

Li., P., Jun Y, Lejun L and Mingzuo, F. (1999). Vulnerability assessment of the Yellow River Delta to predicted climate change and sea level rise. In Vulnerability assessment of two major wetlands in the Asia-Pacific region to climate change and sea level rise, eds RA van Dam, CM Finlayson and D Watkins. Supervising Scientist Report 149, Supervising Scientist, Darwin, Australia, pp. 7-73.

Lindström, A. and Agrell, J. (1999). Global changes and possible effects on the migration and reproduction of arctic-breeding waders. Ecological Bulletins 47: 145-159.

McLaughlin, J.F., J.J. Hellmann, C.L. Boggs, and P.R. Ehrlich. (2002). Climate change hastens population extinctions. Proceedings of the National Academy of Sciences of the United States of America 99: 6070-6074.

McMichael, A.J. M. Ando, R. Carcavallo, P. Epstein, A. Haines; G. Jendritzky, L. Kalkstein, R. Odongo, J. Patz, W. Piver, et al. (1996). Chapter 18. Human Population Health. IN Climate Change 1995: Impacts, Adaptations and Mitigations of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the International Panel on Climate Change. Watson, R.T., Zinyowera, M.C. and Moss, R.H. (eds). pp. 350-380. IPCC/Cambridge University Press

McMichael, et al. Chapter 9: Human health. (2001). IN Climate Change 2001: Impacts, Adaptations, and Vulnerability. Contribution of Working Group II to the Thirds Assessment Report of the International Panel on Climate Change. McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (eds). IPCC/Cambridge University Press

Napp, J.M. and G.L. Hunt (2001). Anomalous conditions in the south-eastern Bering Sea 1997: linkages among climate, weather, ocean, and Biology. Fisheries Oceanography 10: 61-68.

Nicholson, S.E. (2001.) Climatic and environmental change in Africa during the last two centuries [Review]. Climate Research 17: 123-144.

Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37– 42

Phillips, O.L. et al. (2002). Increasing dominance of large lianas in Amazonian forests. Nature 418: 770–774.

Pittock, B., Wratt, D. (with Basher, R., Bates, B., Finlayson, M., Gitay, H. and Woodward, A.). (2001). Chapter 12. Australia and New Zealand. In: Climate Change 2001: Impacts, Adaptations, and Vulnerability. Contribution of Working Group II to the Thirds Assessment Report of the International Panel on Climate Change. McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (eds). Pp. 591-640. Cambridge University Press.

Portner, H.O., B. Berdal, R. Blust, O. Brix, A. Colosimo, B. De Wachter, A. Giuliani, T. Johansen, T. Fischer, R. Knust, G. Lannig, G. Naevdal, A. Nedenes, G. Nyhammer, F.J. Sartoris, I. Serendero, P. Sirabella, S. Thorkildsen, and M. Zakhartsev. (2001). Climate induced temperature effects on growth performance, fecundity and recruitment in marine fish: developing a hypothesis for cause and effect relationships in Atlantic cod (*Gadus morhua*) and common eelpout (*Zoarces viviparus*) [Review]. Continental Shelf Research 21: 1975-1997.

Reaser, J.K., R. Pomerance, and P.O. Thomas. (2000). Coral bleaching and global climate change: Scientific findings and policy recommendations. Conservation Biology 14: 1500-1511.

Root, T. L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig, and J. A. Pounds. (2003). Fingerprints of global warming on wild animals and plants. Nature 421: 57 - 60

Roshier, D.A., P.H. Whetton, R.J. Allan, and A.I. Robertson (2001). Distribution and persistence of temporary wetland habitats in arid Australia in relation to climate. Austral Ecology 26: 371-384.

Scavia, D., J.C. Field, D.F. Boesch, R.W. Buddemeier, V. Burkett, D.R. Cayan, M. Fogarty, M.A. Harwell, R.W. Howarth, C. Mason, D.J. Reed, T.C. Royer, A.H. Sallenger, and J.G. Titus. (2002). Climate change impacts on US coastal and marine ecosystems [Review]. Estuaries 25: 149-164.

van Dam, R., Gitay, H. and Finlayson, M. (2002). Climate Change and Wetlands: Impacts and Mitigation. Ramsar Draft COP8 paper.

Wilkinson, C.R. and Buddemeier, R.W. (1994). Global Climate Change and Coral Reefs: Implications for People and Reefs. Report of the UNEP-IOC-ASPEI-IUCN Global Task Team on Coral Reefs. IUCN, Gland Switzerland, pp.124

Williams, W.D. (1998). Dryland wetlands. In: McComb, A.J. and Davis, J.A. (eds). Wetlands for the Future. Gleneagles Publishing, Glen Osmond, Australia. pp 33-47.