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INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

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IPCC SPECIAL REPORT
THE REGIONAL IMPACTS OF CLIMATE CHANGE: AN ASSESSMENT OF VULNERABILITY

Summary for Policymakers

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The Regional Impacts of Climate Change:

An Assessment of Vulnerability

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Foreword

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization and the United Nations Environment Programme in 1988 to assess the scientific and technical literature on climate change, the potential impacts of changes in climate, and options for adaption to and mitigation of climate change. Since its inception, the IPCC has produced a series of Assessment Reports, Special Reports, Technical Papers, methodologies and other products which have become standard works of reference, widely used by policymakers, scientists and other experts.

This Special Report, which has been produced by Working Group II of the IPCC, builds on the Working Group's contribution to the Second Assessment Report (SAR), and incorporates more recent information made available since mid-1995. It has been prepared in response to a request from the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UN Framework Convention on Climate Change (UNFCCC). It addresses an important question posed by the Conference of the Parties (COP) to the UNFCCC, namely, the degree to which human conditions and the natural environment are vulnerable to the potential effects of climate change. The report establishes a common base of information regarding the potential costs and benefits of climatic change, including the evaluation of uncertainties, to help the COP determine what adaptation and mitigation measures might be justified. The report consists of vulnerability assessments for 10 regions that comprise the Earth's entire land surface and adjoining coastal seas: Africa, Arid Western Asia (including the Middle East), Australasia, Europe, Latin America, North America, the Polar Regions (The Arctic and the Antarctic), Small Island States, Temperate Asia and Tropical Asia. It also includes several annexes that provide information about climate observations, climate projections, vegetation distribution projections and socioeconomic trends.

As usual in the IPCC, success in producing this report has depended on the enthusiasm and cooperation of numerous scientists and other experts worldwide. These individuals have given generously of their time, often going beyond reasonable demands of duty. We applaud, admire, and are grateful for their commitment to the IPCC process. We are pleased to note the continuing efforts made by the IPCC to ensure participation of scientists and other experts from the developing countries and countries with economies in transition. Given the regional focus of this report, their participation was especially essential to its successful completion. We also express our thanks to the many governments, including those in the developing regions and regions with economies in transition, that supported these scientists and experts in their work.

We take this opportunity to express our gratitude to the following individuals for nurturing another IPCC report through to completion:

- Professor B. Bolin, the Chairman of the IPCC
- The Co-Chairs of Working Group II, Dr. R.T. Watson (USA) and Dr. M.C. Zinyowera (Zimbabwe)
- The Vice-Chairs of the Working Group, Dr. M. Beniston (Switzerland), Dr. O. Canziani (Argentina), Dr. J. Friaa (Tunisia), Ing. (Mrs.) M. Perdomo (Venezuela), Dr. S.K. Sharma (India), Mr. H. Tsukamoto (Japan), and Professor P. Vellinga (The Netherlands)
- Dr. R.H. Moss, Head of the Technical Support Unit (TSU) of Working Group II, Mr. D.J. Dokken, the Project Administrator and the other members of the TSU, including Ms. S. MacCracken, Ms. L. Van Wie McGrory and Ms. F. Ormond
- Dr. N. Sundararaman, the Secretary of the IPCC, and his staff, including Ms. R. Bourgeois, Ms. C. Ettori and Ms. C. Tanikie.

G.O.P. Obasi

Secretary-General
World Meteorological Organization

Ms. E. Dowdeswell

Executive Director
United Nations Environment Programme

Preface

The Intergovernmental Panel on Climate Change (IPCC) has produced a series of Assessment Reports, Special Reports, Technical Papers and methodologies. As an intergovernmental body, the IPCC has procedures governing the production of each of these. This Special Report on the Regional Impacts of Climate Change was first requested by the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) as a Technical Paper, which restricted the authors to using only materials already in IPCC Assessment Reports and Special Reports. In the course of drafting the paper, the authors felt that the inclusion of new literature that had become available since the completion of the IPCC Second Assessment Report (SAR), including work undertaken under the auspices of several "country studies programmes," would make the paper more complete, up-to-date, and broadly representative of trends and vulnerabilities in the regions. Including these materials in the report would not have conformed to the IPCC procedures for Technical Papers; hence, the IPCC decided at its Twelfth Session (Mexico City, 11–13 September 1996) to rewrite the Technical Paper as a Special Report, and SBSTA was informed accordingly.

The Special Report explores the potential consequences of changes in climate for ten continental- or subcontinental-scale regions. Because of the uncertainties associated with regional projections of climate change, the report necessarily takes the approach of assessing sensitivities and vulnerabilities of each region, rather than attempting to provide quantitative predictions of the impacts of climate change. As in the SAR, "vulnerability" is the extent to which climate change may damage or harm a system; it is a function of both sensitivity to climate and the ability to adapt to new conditions.

This assessment confirms the findings of the SAR and underlines the potential for climate change to alter the ability of the Earth's physical and biological systems (land, atmosphere and oceans) to provide goods and services essential for sustainable economic development.

The report represents an important step in the evolution of the impact assessment process for the IPCC. Previous impact assessments have examined the potential effects of climate change primarily at a global scale. This report analyzes impacts at a continental or subcontinental scale that is of more practical interest to decisionmakers. This regional approach reveals wide variation in the vulnerability of different populations and environmental systems. This variation stems from differences in local environmental conditions; economic, social and political conditions; and degrees of dependence on climate-sensitive resources, among other factors. Because of its smaller scale of analysis, the report provides more information regarding the potential for the adaptation of systems activities and infrastructure to climate change than did the SAR. The chapters indicate, however, that far more research and analysis of adaptation options and adjustment processes are necessary if private sector and governmental entities are to make climate-sensitive sectors more resilient to today's climate variability, and to limit damage from—or take advantage of—potential long-term changes in climate.

The report is also an initial step in examining how projected changes in climate could interact with other environmental changes (e.g., biodiversity loss, land degradation, stratospheric ozone depletion and degradation of water resources) and social trends (e.g., population growth, economic development and technological progress). The assessment indicates that additional research into the interlinkages among environmental issues also is needed.

This report will provide a foundation for impacts assessment in the Third Assessment Report (TAR), which is expected to be completed in late 2000. An important early step in the process of preparing the IPCC TAR will be to review and refine the approach—and the regional groupings—used in this assessment. In doing so, advances in the ability to project climatic and environmental changes on finer scales will be an important consideration. The report provides a foundation for the TAR in another important respect, as it represents a substantial further step forward in increasing the level of participation of scientists and technical experts from developing countries and countries with economies in transition. The IPCC remains committed to building on this accomplishment, and will not relax its efforts to identify experts from these regions and secure their participation in future assessments.

Acknowledgments

We would like to acknowledge the contributions of numerous individuals and organizations to the successful completion of this report. First and foremost, we are grateful for the voluntary efforts of the members of the scientific and technical community who prepared and peer-reviewed the chapters and annexes of the report. These individuals served in several capacities, including Convening Lead Authors, Lead Authors, Contributors/Reviewers, Regional Coordinators and Sector Contributors (authors of the SAR who extracted regional information from their sector-oriented chapters as starting points for the regional assessments). We also gratefully acknowledge the assistance provided by governments to a number of these lead authors.

All of these contributions would have come to nothing had it not been for the tireless and good-natured efforts of David Jon Dokken, Project Administrator, whose roles and responsibilities in preparation of this report are too numerous to mention, and without whom the report would not have been assembled in such a timely and efficient fashion. Other members of the Working Group II Technical Support Unit also provided significant help in preparation of the report, including Sandy MacCracken, Laura Van Wie McGrory and Flo Ormond. The staff of the IPCC Secretariat, including Rudie Bourgeois, Chantal Ettori and Cecilia Tanikie, provided essential support and welcome advice.

Others who contributed to the report in various analytical and organizational roles and to whom we wish to express our thanks include Tererei Abete, Isabel Alegre, Ron Benioff, Carroll Curtis, Paul Desanker, Robert Dixon and his colleagues at the U.S. Country Studies Program, Roland Fuchs, Christy Goodale, David Gray, Mike Hulme, Jennifer Jenkins, Richard Klein, S.C. Majumdar, Scott Ollinger, Erik Rodenberg, Robert Scholes, Joel Smith, Regina Tannon, David Theobald and Hassan Virji.

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THE REGIONAL IMPACTS OF CLIMATE CHANGE: AN ASSESSMENT OF VULNERABILITY

1. Scope of the Assessment

This report has been prepared at the request of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and its subsidiary bodies (specifically, the Subsidiary Body for Scientific and Technological Advice—SBSTA). The special report provides, on a regional basis, a review of state-of-the-art information on the vulnerability to potential changes in climate of ecological systems, socioeconomic sectors (including agriculture, fisheries, water resources and human settlements) and human health. The report reviews the sensitivity of these systems as well as options for adaptation. Though this report draws heavily upon the sectoral impact assessments of the Second Assessment Report (SAR), it also draws upon more recent peer-reviewed literature (*inter alia*, country studies programmes).

2. Nature of the Issue

Human activities (primarily the burning of fossil fuels and changes in land use and land cover) are increasing the atmospheric concentrations of greenhouse gases, which alter radiative balances and tend to warm the atmosphere, and, in some regions, aerosols—which have an opposite effect on radiative balances and tend to cool the atmosphere. At present, in some locations primarily in the Northern Hemisphere, the cooling effects of aerosols can be large enough to more than offset the warming due to greenhouse gases. Since aerosols do not remain in the atmosphere for long periods and global emissions of their precursors are not projected to increase substantially, aerosols will not offset the global long-term effects of greenhouse gases, which are long-lived. Aerosols can have important consequences for continental-scale patterns of climate change.

These changes in greenhouse gases and aerosols, taken together, are projected to lead to regional and global changes in temperature, precipitation and other climate variables—resulting in global changes in soil moisture, an increase in global mean sea level, and prospects for more severe extreme high-temperature events, floods and droughts in some places. Based on the range of sensitivities of climate to changes in the atmospheric concentrations of greenhouse gases (IPCC 1996, WG I) and plausible changes in emissions of greenhouse gases and aerosols (IS92a-f, scenarios that assume no climate policies), climate models project that the mean annual global surface temperature will increase by 1–3.5°C by 2100, that global mean sea level will rise by 15–95 cm, and that changes in the spatial and temporal patterns of precipitation would occur. The average rate of warming probably would be greater than any seen in the past 10 000 years, although the actual annual to decadal rate would include considerable natural variability, and regional changes could differ substantially from the global mean value. These long-term, large-scale, human-induced changes will interact with natural variability on time scales of days to decades [e.g., the El Niño-Southern Oscillation (ENSO) phenomenon] and thus influence social and economic well-being. Possible local climate effects which are due to unexpected events like a climate change-induced change of flow pattern of marine water streams like the Gulf Stream have not been considered, because such changes cannot be predicted with confidence at present.

Scientific studies show that human health, ecological systems and socioeconomic sectors (e.g., hydrology and water resources, food and fiber production, coastal systems and human settlements), all of which are vital to sustainable development, are sensitive to changes in climate—including both the magnitude and rate of climate change—as well as to changes in climate variability. Whereas many regions are likely to experience adverse effects of climate change—some of which are potentially irreversible—some effects of climate change are likely to be beneficial. Climate change represents an important additional stress on those systems already affected by increasing resource demands, unsustainable management practices and pollution, which in many cases may be equal to or greater than those of climate change. These stresses will interact in different ways across regions but can be expected to reduce the ability of some environmental systems to provide, on a sustained basis, key goods and services needed for successful economic and social development, including adequate food, clean air and water, energy, safe shelter, low levels of disease and employment opportunities. Climate change also will take place in the context of economic development, which may make some groups or countries less vulnerable to climate change—for example, by increasing the resources available for adaptation; those that experience low rates of growth, rapid increases in population and ecological degradation may become increasingly vulnerable to potential changes.

3. Approach of the Assessment

This report assesses the vulnerability of natural and social systems of major regions of the world to climate change. Vulnerability is defined as the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the sensitivity of a system to changes in climate (the degree to which a system will respond to a given change in climate, including both beneficial and harmful effects) and the ability to adapt the system to changes in climate (the degree to which adjustments in practices, processes or structures can moderate or offset the potential for damage or take advantage of opportunities created, due to a given change in climate). Under this framework, a highly vulnerable system would be one that is highly sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and one for which the ability to adapt is severely constrained.

Because the available studies have not employed a common set of climate scenarios and methods, and because of uncertainties regarding the sensitivities and adaptability of natural and social systems, the assessment of regional vulnerabilities is necessarily qualitative. However, the report provides substantial and indispensable information on what currently is known about vulnerability to climate change.

In a number of instances, quantitative estimates of impacts of climate change are cited in the report. Such estimates are dependent upon the specific assumptions employed regarding future changes in climate, as well as upon the particular methods and models applied in the analyses. To interpret these estimates, it is important to bear in mind that uncertainties regarding the character, magnitude and rates of future climate change remain. These uncertainties impose limitations on the ability of scientists to project impacts of climate change, particularly at regional and smaller scales.

It is in part because of the uncertainties regarding how climate will change that this report takes the approach of assessing vulnerabilities rather than assessing quantitatively the expected impacts of climate change. The estimates are best interpreted as illustrative of the potential character and approximate magnitudes of impacts that may result from specific scenarios of climate change. They serve as indicators of sensitivities and possible vulnerabilities. Most commonly, the estimates are based upon changes in equilibrium climate that have been simulated to result from an equivalent doubling of carbon dioxide (CO_2) in the atmosphere. Usually the simulations have excluded the effects of aerosols. Increases in global mean temperatures corresponding to these scenarios mostly fall in the range of 2–5°C. To provide a temporal context for these scenarios, the range of projected global mean warming by 2100 is 1–3.5°C accompanied by a mean sea-level rise of 15–95 cm, according to the IPCC Second Assessment Report. General circulation model (GCM) results are used in this analysis to justify the order of magnitude of the changes used in the sensitivity analyses. They are not predictions that climate will change by specific magnitudes in particular countries or regions. The amount of literature available for assessment varies in quantity and quality among the regions.

4. Overview of Regional Vulnerabilities to Global Climate Change

Article 2 of the UNFCCC explicitly acknowledges the importance of natural ecosystems, food production and sustainable economic development (see box). This report's assessment of regional vulnerability to climate change focuses on ecosystems, hydrology and water resources, food and fiber production, coastal systems, human settlements, human health, and other sectors or systems (including the climate system) important to 10 regions that encompass the Earth's land surface. Wide variation in the vulnerability of similar sectors or systems is to be expected across regions, as a consequence of regional differences in local environmental conditions, pre-existing stresses to ecosystems, current resource-use patterns, and the framework of factors affecting decisionmaking—including government policies, prices, preferences and values. Nonetheless, some general observations, based on information contained in the SAR and synthesized from the regional analyses in this assessment, provide a global context for the assessment of each region's vulnerability.

Article 2 of the UNFCCC: Objective

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

4.1 Ecosystems

Ecosystems are of fundamental importance to environmental function and to sustainability, and they provide many goods and services critical to individuals and societies. These goods and services include: (i) providing food, fiber, fodder, shelter, medicines and energy; (ii) processing and storing carbon and nutrients; (iii) assimilating wastes; (iv) purifying water, regulating water runoff and moderating floods; (v) building soils and reducing soil degradation; (vi) providing opportunities for recreation and tourism; and (vii) housing the Earth's entire reservoir of genetic and species diversity. In addition, natural ecosystems have cultural, religious, aesthetic and intrinsic existence values. Changes in climate have the potential to affect the geographic location of ecological systems, the mix of species that they contain, and their ability to provide the wide range of benefits on which societies rely for their continued existence. Ecological systems are intrinsically dynamic and are constantly influenced by climate variability. The primary influence of anthropogenic climate change on ecosystems is expected to be through the rate and magnitude of change in climate means and extremes—climate change is expected to occur at a rapid rate relative to the speed at which ecosystems can adapt and reestablish themselves—and through the direct effects of increased atmospheric CO_2 concentrations, which may increase the productivity and efficiency of water use in some plant species. Secondary effects of climate change involve changes in soil characteristics and disturbance regimes (e.g., fires, pests and diseases), which would favour some species over others and thus change the species composition of ecosystems.

Based on model simulations of vegetation distribution, which use GCM-based climate scenarios, large shifts of vegetation boundaries into higher latitudes and elevations can be expected. The mix of species within a given vegetation class likely will change. Under equilibrium GCM climate scenarios, large regions show drought-induced declines in vegetation, even when the direct effects of CO_2 fertilization are included. By comparison, under transient climate scenarios—in which trace gases increase slowly over a period of years—the full effects of changes in temperature and precipitation lag the effects of a change in atmospheric composition by a number of decades; hence, the positive effects of CO_2 precede the full effects of changes in climate.

Climate change is projected to occur at a rapid rate relative to the speed at which forest species grow, reproduce and re-establish themselves (past tree species' migration rates are believed to be on the order of 4–200 km per century). For mid-latitude regions, an average warming of 1–3.5°C over the next 100 years would be equivalent to a poleward shift of the present geographic bands of similar temperatures (or "isotherms") approximately 150–550 km, or an altitude shift of about 150–550 m. Therefore, the species composition of forests is likely to change; in some regions, entire forest types may disappear, while new assemblages of species and hence new ecosystems may be established. As a consequence of possible changes in temperature and water availability under doubled equivalent-CO_2 equilibrium conditions, a substantial fraction (a global average of one-third, varying by region from one-seventh to two-thirds) of the existing forested area of the world likely would undergo major changes in broad vegetation types—with the greatest changes occurring in high latitudes and the least in the tropics. In tropical rangelands, major alterations in productivity and species composition would occur due to altered rainfall amount and seasonality and increased evapotranspiration, although a mean temperature increase alone would not lead to such changes.

Inland aquatic ecosystems will be influenced by climate change through altered water temperatures, flow regimes, water levels and thawing of permafrost at high latitudes. In lakes and streams, warming would have the greatest biological effects at high latitudes—where biological productivity would increase and lead to expansion of cool-water species' ranges—and at the low-latitude boundaries of cold- and cool-water species ranges, where extinctions would be greatest. Increases in flow variability, particularly the frequency and duration of large floods and droughts, would tend to reduce water quality, biological productivity and habitat in streams. The geographical distribution of wetlands is likely to shift with changes in temperature and precipitation, with uncertain implications for net greenhouse gas emissions from non-tidal wetlands. Some coastal ecosystems (saltwater marshes, mangrove ecosystems, coastal wetlands, coral reefs, coral atolls and river deltas) are particularly at risk from climate change and other stresses. Changes in these ecosystems would have major negative effects on freshwater supplies, fisheries, biodiversity and tourism.

Adaptation options for ecosystems are limited, and their effectiveness is uncertain. Options include establishment of corridors to assist the "migration" of ecosystems, land-use management, plantings and restoration of degraded areas. Because of the projected rapid rate of change relative to the rate at which species can re-establish themselves, the isolation and fragmentation of many ecosystems, the existence of multiple stresses (e.g., land-use change, pollution) and limited adaptation options, ecosystems (especially forested systems, montane systems and coral reefs) are vulnerable to climate change.

4.2 Hydrology and Water Resources

Water availability is an essential component of welfare and productivity. Currently, 1.3 billion people do not have access to adequate supplies of safe water, and 2 billion people do not have access to adequate sanitation. Although these people are dispersed throughout the globe—reflecting sub-national variations in water availability and quality—some 19 countries (primarily in the Middle East and north and southern Africa) face such severe shortfalls that they are classified as either water-scarce or water-stressed; this number is expected to roughly double by 2025, in large part because of increases in demand resulting from economic and population growth. For example, most policy makers now recognize drought as a recurrent feature of Africa's climate. However, climate change will further exacerbate the frequency and magnitude of droughts in some places.

Changes in climate could exacerbate periodic and chronic shortfalls of water, particularly in arid and semi-arid areas of the world. Developing countries are highly vulnerable to climate change because many are located in arid and semi-arid regions, and most derive their water resources from single-point systems such as bore holes or isolated reservoirs. These systems, by their nature, are vulnerable because there is no redundancy in the system to provide resources, should the primary supply fail. Also, given the limited technical, financial and management resources possessed by developing countries, adjusting to shortages and/or implementing adaptation measures will impose a heavy burden on their national economies. There is evidence that flooding is likely to become a larger problem in many temperate and humid regions, requiring adaptations not only to droughts and chronic water shortages but also to floods and associated damages, raising concerns about dam and levee failures.

The impacts of climate change will depend on the baseline condition of the water supply system and the ability of water resources managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions.

Various approaches are available to reduce the potential vulnerability of water systems to climate change. Options include pricing systems, water efficiency initiatives, engineering and structural improvements to water supply infrastructure, agriculture policies and urban planning/management. At the national/regional level, priorities include placing greater emphasis on integrated, cross-sectoral water resources management, using river basins as resource management units, and encouraging sound pricing and management practices. Given increasing demands, the prevalence and sensitivity of many simple water management systems to fluctuations in precipitation and runoff, and the considerable time and expense required to implement many adaptation measures, the water resources sector in many regions and countries is vulnerable to potential changes in climate.

4.3 Food and Fiber Production

Currently, 800 million people are malnourished; as the world's population increases and incomes in some countries rise, food consumption is expected to double over the next three to four decades. The most recent doubling in food production occurred over a 25-year period and was based on irrigation, chemical inputs and high-yielding crop varieties. Whether the remarkable gains of the past 25 years will be repeated is uncertain: problems associated with intensifying production on land already in use (e.g., chemical and biological runoff, waterlogging and salinization of soils, soil erosion and compaction) are becoming increasingly evident. Expanding the amount of land under cultivation (including reducing land deliberately taken out of production to reduce agricultural output) also is an option for increasing total crop production, but it could lead to increases in competition for land and pressure on natural ecosystems, increased agricultural emissions of greenhouse gases, a reduction in natural sinks of carbon, and expansion of agriculture to marginal lands—all of which could undermine the ability to sustainably support increased agricultural production.

Changes in climate will interact with stresses that result from actions to increase agricultural production, affecting crop yields and productivity in different ways, depending on the types of agricultural practices and systems in place. The main direct effects will be through changes in factors such as temperature, precipitation, length of growing season, and timing of extreme or critical threshold events relative to crop development, as well as through changes in atmospheric CO_2 concentration (which may have a beneficial effect on the growth of many crop types). Indirect effects will include potentially detrimental changes in diseases, pests and weeds, the effects of which have not yet been quantified in most available studies. Evidence continues to support the findings of the IPCC SAR that "global agricultural production could be maintained relative to baseline production" for a growing population under $2 \times CO_2$ equilibrium climate conditions. In addition, the regional findings of this special report lend support to concerns over the "potential serious consequences" of increased risk of hunger in some regions, particularly the tropics and subtropics. Generally, middle to high latitudes may experience increases in productivity, depending on crop type, growing season, changes in temperature regimes and the seasonality of precipitation. In the tropics and subtropics—where some crops are near their maximum temperature tolerance and where dryland, nonirrigated agriculture predominates—yields are likely to decrease. The livelihoods of subsistence farmers and pastoral peoples, who make up a large portion of rural populations in some regions, also could be negatively affected. In regions where there is a likelihood of decreased rainfall, agriculture could be significantly affected.

Fisheries and fish production are sensitive to changes in climate and currently are at risk from overfishing, diminishing nursery areas, and extensive inshore and coastal pollution. Globally, marine fisheries production is expected to remain about the same in response to changes in climate; high-latitude freshwater and aquaculture production is likely to increase, assuming that natural climate variability and the structure and strength of ocean currents remain about the same. The principal impacts will be felt at the national and local levels, as centers of production shift. The positive effects of climate change—such as longer growing seasons, lower natural winter mortality and faster growth rates in higher latitudes—may be offset by negative factors such as changes in established reproductive patterns, migration routes and ecosystem relationships.

Given the many forces bringing profound changes to the agricultural sector, adaptation options that enhance resilience to current natural climate variability and potential changes in means and extremes and address other concerns (e.g., soil erosion, salinization) offer no- or low-regret options. For example, linking agricultural management to seasonal climate predictions can assist in incremental adaptation, particularly in regions where climate is strongly affected by ENSO conditions. The suitability of these options for different regions varies, in part because of differences in the financial and institutional ability of the private sector and governments in different regions to implement them. Adaptation options include changes in crops and crop varieties, development of new crop varieties, changes in planting schedules and tillage practices, introduction of new biotechnologies, and improved water-management and irrigation systems, which have high capital costs and are limited by availability of water resources. Other options, such as minimum- and reduced-tillage technologies, do not require such extensive capitalization but do require high levels of agricultural training and support.

In regions where agriculture is well adapted to current climate variability and/or where market and institutional factors are in place to redistribute agricultural surpluses to make up for shortfalls, vulnerability to changes in climate means and extremes generally is low. However, in regions where agriculture is unable to cope with existing extremes, where markets and institutions to facilitate redistribution of deficits and surpluses are not in place, and/or where adaptation resources are limited, the vulnerability of the agricultural sector to climate change should be considered high. Other factors also will influence the vulnerability of agricultural production in a particular country or region to climate change—including the extent to which current temperatures or precipitation patterns are close to or exceed tolerance limits for important crops; per capita income; the percentage of economic activity based on agricultural production; and the pre-existing condition of the agricultural land base.

4.4 Coastal Systems

Coastal zones are characterized by a rich diversity of ecosystems and a great number of socioeconomic activities.

Coastal human populations in many countries have been growing at double the national rate of population growth. It is currently estimated that about half of the global population lives in coastal zones, although there is large variation among countries. Changes in climate will affect coastal systems through sea-level rise and an increase in storm-surge hazards and possible changes in the frequency and/or intensity of extreme events.

Coasts in many countries currently face severe sea-level rise problems as a consequence of tectonically and anthropogenically induced subsidence. An estimated 46 million people per year currently are at risk of flooding from storm surges. Climate change will exacerbate these problems, leading to potential impacts on ecosystems and human coastal infrastructure. Large numbers of people also are potentially affected by sea-level rise—for example, tens of millions of people in Bangladesh would be displaced by a 1-m increase (the top of the range of IPCC Working Group I estimates for 2100) in the absence of adaptation measures. A growing number of extremely large cities are located in coastal areas, which means that large amounts of infrastructure may be affected. Although annual protection costs for many nations are relatively modest—about 0.1 per cent of gross domestic product (GDP)—the average annual costs to many small island states total several per cent of GDP. For some island nations, the high cost of providing storm-surge protection would make it essentially infeasible, especially given the limited availability of capital for investment.

Beaches, dunes, estuaries and coastal wetlands adapt naturally and dynamically to changes in prevailing winds and seas, as well as sea-level changes; in areas where infrastructure development is not extensive, planned retreat and accommodation to changes may be possible. It also may be possible to rebuild or relocate capital assets at the end of their design life. In other areas, however, accommodation and planned retreat are not viable options, and protection using hard structures (e.g., dikes, levees, floodwalls and barriers) and soft structures (e.g., beach nourishment, dune restoration and wetland creation) will be necessary. Factors that limit the implementation of these options include inadequate financial resources, limited institutional and technological capability, and shortages of trained personnel. In most regions, current coastal management and planning frameworks do not take account of the vulnerability of key systems to changes in climate and sea level or long lead times for implementation of many adaptation measures. Inappropriate policies encourage development in impact-prone areas. Given increasing population density in coastal zones, long lead times for implementation of many adaptation measures, and institutional, financial and technological limitations (particularly in many developing countries), coastal systems should be considered vulnerable to changes in climate.

4.5 Human Health

In much of the world, life expectancy is increasing; in addition, infant and child mortality in most developing countries is dropping. Against this positive backdrop, however, there appears to be a widespread increase in new and resurgent vector-borne and infectious diseases, such as dengue, malaria, hantavirus and cholera. In addition, the percentage of the developing world's population living in cities is expected to increase from 25 per cent (in 1960) to more than 50 per cent by 2020, with percentages in some regions far exceeding these averages. These changes will bring benefits only if accompanied by increased access to services such as sanitation and potable water supplies; they also can lead to serious urban environmental problems, including air pollution (e.g., particulates, surface ozone and lead), poor sanitation, and associated problems in water quality and potability, if access to services is not improved.

Climate change could affect human health through increases in heat-stress mortality, tropical vector-borne diseases, urban air pollution problems, and decreases in cold-related illnesses. Compared with the total burden of ill health, these problems are not likely to be large. In the aggregate, however, the direct and indirect impacts of climate change on human health do constitute a hazard to human population health, especially in developing countries in the tropics and subtropics; these impacts have considerable potential to cause significant loss of life, affect communities, and increase health-care costs and lost work days. Model projections (which entail necessary simplifying assumptions) indicate that the geographical zone of potential malaria transmission would expand in response to global mean temperature increases at the upper part of the IPCC-projected range (3–5°C by 2100), increasing the affected proportion of the world's population from approximately 45 per cent to approximately 60 per cent by the latter half of the next century. Areas where malaria is currently endemic could experience intensified transmission (on the order of 50–80 million additional annual cases, relative to an estimated global background total of 500 million cases). Some increases in non-vector-borne infectious diseases—such as salmonellosis, cholera and giardiasis—also could occur as a result of elevated temperatures and increased flooding. However, quantifying the projected health impacts is difficult because the extent of climate-induced health disorders depends on other factors—such as migration, provision of clean urban environments, improved nutrition, increased availability of potable water, improvements in sanitation, the extent of disease vector-control measures, changes in resistance of vector organisms to insecticides, and more widespread availability of health care. Human health is vulnerable to changes in climate—particularly in urban areas, where access to space conditioning may be limited, as well as in areas where exposure to vector-borne and communicable diseases may increase and health-care delivery and basic services, such as sanitation, are poor.

5. Anticipatory Adaptation in the Context of Current Policies and Conditions

A key message of the regional assessments in this report is that many systems and policies are not well-adjusted even to today's climate and climate variability. Increasing costs, in terms of human life and capital, from floods, storms and droughts demonstrate current vulnerability. This situation suggests that there are adaptation options that would make many sectors more resilient to today's conditions and thus would help in adapting to future changes in climate. These options—so-called "win-win" or "no-regrets" options—could have multiple benefits and most likely would prove to be beneficial even in the absence of climate change impacts.

In many countries, the economic policies and conditions (e.g., taxes, subsidies and regulations) that shape private decision making, development strategies and resource-use patterns (and hence environmental conditions) hinder implementation of adaptation measures. In many countries, for example, water is subsidized, encouraging over-use (which draws down existing sources) and discouraging conservation measures—which may well be elements of future adaptation strategies. Other examples are inappropriate land-use zoning and/or subsidized disaster insurance, which encourage infrastructure development in areas prone to flooding or other natural disasters—areas that could become even more vulnerable as a result of climate change. Adaptation and better incorporation of the long-term environmental consequences of resource use can be brought about through a range of approaches, including strengthening legal and institutional frameworks, removing preexisting market distortions (e.g., subsidies), correcting market failures (e.g., failure to reflect environmental damage or resource depletion in prices or inadequate economic valuation of biodiversity), and promoting public participation and education. These types of actions would adjust resource-use patterns to current environmental conditions and better prepare systems for potential future changes.

The challenge is to identify opportunities that facilitate sustainable development by making use of existing technologies and developing policies that make climate-sensitive sectors resilient to today's climate variability. This strategy will require many regions of the world to have more access to appropriate technologies, information, and adequate financing. In addition, the regional assessments suggest that adaptation will require anticipation and planning; failure to prepare systems for projected changes in climate means, variability and extremes could lead to capital-intensive development of infrastructure or technologies that are ill-suited to future conditions, as well as missed opportunities to lower the costs of adaptation. Additional analysis of current vulnerability to today's climate fluctuations and existing coping mechanisms is needed and will offer lessons for the design of effective options for adapting to potential future changes in climate.

6. Regional Vulnerability to Global Climate Change

6.1 Africa

Several climate regimes characterize the African continent; the wet tropical, dry tropical, and alternating wet and dry climates are the most common. Many countries on the continent are prone to recurrent droughts; some drought episodes, particularly in southeast Africa, are associated with ENSO phenomena. Deterioration in terms of trade, inappropriate policies, high population growth rates and lack of significant investment—coupled with a highly variable climate—have made it difficult for several countries to develop patterns of livelihood that would reduce pressure on the natural resource base. Under the assumption that access to adequate financing is not provided, Africa is the continent most vulnerable to the impacts of projected changes because widespread poverty limits adaptation capabilities.

Ecosystems: In Africa today, tropical forests and rangelands are under threat from population pressures and systems of land use. Generally apparent effects of these threats include loss of biodiversity, rapid deterioration in land cover and depletion of water availability through destruction of catchments and aquifers. Changes in climate will interact with these underlying changes in the environment, adding further stresses to a deteriorating situation. A sustained increase in mean ambient temperatures beyond 1°C would cause significant changes in forest and rangeland cover; species distribution, composition and migration patterns; and biome distribution. Many organisms in the deserts already are near their tolerance limits, and some may not be able to adapt further under hotter conditions. Arid to semi-arid subregions and the grassland areas of eastern and southern Africa, as well as areas currently under threat from land degradation and desertification, are particularly vulnerable. Were rainfall to increase as projected by some GCMs in the highlands of east Africa and equatorial central Africa, marginal lands would become more productive than they are now. These effects are likely to be negated, however, by population pressure on marginal forests and rangelands. Adaptive options include control of deforestation, improved rangeland management, expansion of protected areas and sustainable management of forests.

Hydrology and Water Resources: Of the 19 countries around the world currently classified as water-stressed, more are in Africa than in any other region—and this number is likely to increase, independent of climate change, as a result of increases in demand resulting from population growth, degradation of watersheds caused by land-use change and siltation of river basins. A reduction in precipitation projected by some GCMs for the Sahel and southern Africa—if accompanied by high interannual variability—could be detrimental to the hydrological balance of the continent and disrupt various water-dependent socio-economic activities. Variable climatic conditions may render the management of water resources more difficult both within and between countries. A drop in water level in dams and rivers could adversely affect the quality of water by increasing the concentrations of sewage waste and industrial effluents, thereby increasing the potential for the outbreak of diseases and reducing the quality and quantity of fresh water available for domestic use. Adaptation options include water harvesting, management of water outflow from dams and more efficient water usage.

Agriculture and Food Security: Except in the oil-exporting countries, agriculture is the economic mainstay in most African countries, contributing 20–30 per cent of GDP in sub-Saharan Africa and 55 per cent of the total value of African exports. In most African countries, farming depends entirely on the quality of the rainy season—a situation that makes Africa particularly vulnerable to climate change. Increased droughts could seriously impact the availability of food, as in the horn of Africa and southern Africa during the 1980s and 1990s. A rise in mean winter temperatures also would be detrimental to the production of winter wheat and fruits that need the winter chill. However, in subtropical Africa, warmer winters would reduce the incidence of damaging frosts, making it possible to grow horticultural produce susceptible to frosts at higher elevations than is possible at present. Productivity of freshwater fisheries may increase, although the mix of fish species could be altered. Changes in ocean dynamics could lead to changes in the migratory patterns of fish and possibly to reduced fish landings, especially in coastal artisinal fisheries.

Coastal Systems: Several African coastal zones—many of which already are under stress from population pressure and conflicting uses—would be adversely affected by sea-level rise associated with climate change. The coastal nations of west and central Africa (e.g., Senegal, Gambia, Sierra Leone, Nigeria, Cameroon, Gabon, Angola) have low-lying lagoonal coasts that are susceptible to erosion and hence are threatened by sea-level rise, particularly because most of the countries in this area have major and rapidly expanding cities on the coast. The west coast often is buffeted by storm surges and currently is at risk from erosion, inundation and extreme storm events. The coastal zone of east Africa also will be affected, although this area experiences calm conditions through much of the year. However, sea-level rise and climatic variation may reduce the buffer effect of coral and patch reefs along the east coast, increasing the potential for erosion. A number of studies indicate that a sizable proportion of the northern part of the Nile delta will be lost through a combination of inundation and erosion, with consequent loss of agricultural land and urban areas. Adaptation measures in African coastal zones are available but would be very costly, as a percentage of GDP, for many countries. These measures could include erection of sea walls and relocation of vulnerable human settlements and other socio-economic facilities.

Human Settlement, Industry and Transportation: The main challenges likely to face African populations will emanate from extreme climate events such as floods (and resulting landslides in some areas), strong winds, droughts and tidal waves. Individuals living in marginal areas may be forced to migrate to urban areas (where infrastructure already is approaching its limits as a result of population pressure) if the marginal lands become less productive under new climate conditions. Climate change could worsen current trends in depletion of biomass energy resources. Reduced stream flows would cause reductions in hydropower production, leading to negative effects on industrial productivity and costly relocation of some industrial plants. Management of pollution, sanitation, waste disposal, water supply and public health, as well as provision of adequate infrastructure in urban areas, could become more difficult and costly under changed climate conditions.

Human Health: Africa is expected to be at risk primarily from increased incidences of vector-borne diseases and reduced nutritional status. A warmer environment could open up new areas for malaria; altered temperature and rainfall patterns also could increase the incidence of yellow fever, dengue fever, onchocerciasis and trypanosomiasis. Increased morbidity and mortality in subregions where vector-borne diseases increase following climatic changes would have far-reaching economic consequences. In view of the poor economic status of most African nations, global efforts will be necessary to tackle the potential health effects.

Tourism and Wildlife: Tourism—one of Africa's fastest-growing industries—is based on wildlife, nature reserves, coastal resorts and an abundant water supply for recreation. Projected droughts and/or reduction in precipitation in the Sahel and eastern and southern Africa would devastate wildlife and reduce the attractiveness of some nature reserves, thereby reducing income from current vast investments in tourism.

Conclusions: The African continent is particularly vulnerable to the impacts of climate change because of factors such as widespread poverty, recurrent droughts, inequitable land distribution and overdependence on rain-fed agriculture. Although adaptation options, including traditional coping strategies, theoretically are available, in practice the human, infrastructural and economic response capacity to effect timely response actions may well be beyond the economic means of some countries.

6.2 Polar Regions: The Arctic and the Antarctic

The polar regions include some very diverse landscapes, and the Arctic and the Antarctic are very different in character. The Arctic is defined here as the area within the Arctic Circle; the Antarctic here includes the area within the Antarctic Convergence, including the Antarctic continent, the Southern Ocean and the sub-Antarctic islands. The Arctic can be described as a frozen ocean surrounded by land, and the Antarctic as a frozen continent surrounded by ocean. The projected warming in the polar regions is greater than for many other regions of the world. Where temperatures are close to freezing on average, global warming will reduce land ice and sea ice, the former contributing to sea-level rise. However, in the interiors of ice caps, increased temperature may not be sufficient to lead to melting of ice and snow, and will tend to have the effect of increasing snow accumulation.

Ecosystems: Major physical and ecological changes are expected in the Arctic. Frozen areas close to the freezing point will thaw and undergo substantial changes with warming. Substantial loss of sea ice is expected in the Arctic Ocean. As warming occurs, there will be considerable thawing of permafrost—leading to changes in drainage, increased slumping, and altered landscapes over large areas. Polar warming probably will increase biological production but may lead to different species composition on land and in the sea. On land, there will be a tendency for polar shifts in major biomes such as tundra and boreal forest and associated animals, with significant impacts on species such as bear and caribou. However, the Arctic Ocean geographically limits northward movement. Much smaller changes are likely for the Antarctic, but there may be species shifts. In the sea, marine ecosystems will move poleward. Animals dependent on ice may be disadvantaged in both polar areas.

Hydrology and Water Resources: Increasing temperature will thaw permafrost and melt more snow and ice. There will be more running and standing water. Drainage systems in the Arctic are likely to change at the local scale. River and lake ice will break up earlier and freeze later.

Food and Fiber Production: Agriculture is severely limited by the harsh climate. Many limitations will remain in the future, though some small northern extension of farming into the Arctic may be possible. In general, marine ecological productivity should rise. Warming should increase growth and development rates of nonmammals; ultraviolet-B (UV-B) radiation is still increasing, however, which may adversely affect primary productivity as well as fish productivity.

Coastal Systems: As warming occurs, the Arctic could experience a thinner and reduced ice cover. Coastal and river navigation will increase, with new opportunities for water transport, tourism and trade. The Arctic Ocean could become a major global trade route. Reductions in ice will benefit offshore oil production. Increased erosion of Arctic shorelines is expected from a combination of rising sea level, permafrost thaw and increased wave action as a result of increased open water. Further breakup of ice shelves in the Antarctic peninsula is likely. Elsewhere in Antarctica, little change is expected in coastlines and probably in its large ice shelves.

Human Settlements: Human communities in the Arctic will be substantially affected by the projected physical and ecological changes. The effects will be particularly important for indigenous peoples leading traditional lifestyles. There will be new opportunities for shipping, the oil industry, fishing, mining, tourism, and migration of people. Sea ice changes projected for the Arctic have major strategic implications for trade, especially between Asia and Europe.

Conclusions: The Antarctic peninsula and the Arctic are very vulnerable to projected climate change and its impacts. Although the number of people directly affected is relatively small, many native communities will face profound changes that impact on traditional lifestyles. Direct effects could include ecosystem shifts, sea- and river-ice loss and permafrost thaw. Indirect effects could include feedbacks to the climate system such as further releases of greenhouse gases, changes in ocean circulation drivers, and increased temperature and higher precipitation with loss of ice, which could affect climate and sea level globally. The interior of Antarctica is less vulnerable to climate change, because the temperature changes envisaged over the next century are likely to have little impact and very few people are involved. However, there are considerable uncertainties about the mass balance of the Antarctic ice sheets and the future behavior of the West Antarctic ice sheet (low probability of disintegration over the next century). Changes in either could affect sea level and Southern Hemisphere climates.

6.3 Arid Western Asia (Middle East and Arid Asia)

This region includes the predominantly arid and semi-arid areas of the Middle East and central Asia. The region extends from Turkey in the west to Kazakstan in the east, and from Yemen in the south to Kazakstan in the north. The eastern part of the region has a large area dominated by mountains.

Ecosystems: Vegetation models project little change in most arid or desert vegetation types under climate change projections—i.e., most lands that are deserts are expected to remain deserts. Greater changes in the composition and distribution of vegetation types of semi-arid areas—for example, grasslands, rangelands and woodlands—are anticipated. Small increases in precipitation are projected, but these increases are likely to be countered by increased temperature and evaporation. Improved water-use efficiency by some plants under elevated CO_2 conditions may lead to some improvement in plant productivity and changes in ecosystem composition. Grasslands, livestock and water resources are likely to be the most vulnerable to climate change in this region because they are located mostly in marginal areas. Appropriate land-use management, including urban planning, could reduce some of the pressures on land degradation. Management options, such as better stock management and more integrated agro-ecosystems, could improve land conditions and counteract pressures arising from climate change. The region is an important refuge for wild relatives of many important crop species; with appropriate conservation measures it may continue to provide a source of genetic material for future climatic conditions.

Hydrology and Water Resources: Water shortage, already a problem in many countries of this arid region, is unlikely to be reduced, and may be exacerbated, by climate change. Changes in cropping practices and improved irrigation practices could significantly improve the efficiency of water use in some countries. Glacial melt is projected to increase under climate change—leading to increased flows in some river systems for a few decades, followed by a reduction in flow as the glaciers disappear.

Food and Fiber Production: Land degradation problems and limited water supplies restrict present agricultural productivity and threaten the food security of some countries. There are few projections of the impacts of climate change on food and fiber production for the region. The adverse impacts that may result in the region are suggested by the results of studies that estimate that wheat production in Kazakstan and Pakistan would decline under selected scenarios of climate change. The studies, however, are too few to draw strong conclusions regarding agriculture across the entire region. Many of the options available to combat existing problems would contribute to reducing the anticipated impacts of climate change. Food and fiber production, concentrated on more intensively managed land, could lead to greater reliability in food production and reduce the detrimental impacts of extreme climatic events. Countries of the former Soviet Union are undergoing major economic changes, particularly in agricultural systems and management. This transition is likely to provide opportunities to change crop types and introduce more efficient irrigation—providing significant win-win options for conservation of resources to offset the projected impacts of climate change.

Human Health: Heat stress, affecting human comfort levels, and possible spread in vector-borne diseases are likely to result from changes in climate. Decreases in water availability and food production would lead to indirect impacts on human health.

Conclusions: Water is an important limiting factor for ecosystems, food and fiber production, human settlements and human health in this arid region of the world. Climate change is anticipated to alter the hydrological cycle and is unlikely to relieve the limitations placed by water scarcity upon the region. Climate change and human activities may further influence the levels of the Caspian and Aral Seas, which will affect associated ecosystems, agriculture and human health in the surrounding areas. Win-win opportunities exist which offer the potential to reduce current pressures on resources and human welfare in the region and also offer the potential to reduce their vulnerability to adverse impacts from climate change.

6.4 Australasia

Australasia includes Australia, New Zealand and their outlying islands. The region spans the tropics to mid-latitudes and has varied climates and ecosystems, ranging from interior deserts to mountain rainforests. The climate is strongly affected by the oceanic environment and the ENSO phenomenon.

Ecosystems: Some of the region's ecosystems appear to be very vulnerable to climate change, at least in the long term, because alterations to soils, plants and ecosystems are very likely, and there may be increases in fire occurrence and insect outbreaks. Many species will be able to adapt, but in some instances, a reduction of species diversity is highly likely. Any changes will occur in a landscape already fragmented by agricultural and urban development; such changes will add to existing problems such as land degradation, weeds and pest infestations. Impacts on aquatic ecosystems from changes in river flow, flood frequency, and nutrient and sediment inputs are likely to be greatest in the drier parts of the region. Coastal ecosystems are vulnerable to the impacts of sea-level rise and possible changes in local meteorology. Tropical coral reefs, including the Great Barrier Reef, may be able to keep pace with sea-level rise—but will be vulnerable to bleaching and death of corals induced by episodes of higher sea temperatures and other stresses. Measures to facilitate adaptation include better rangeland management; plantings along waterways; and research, monitoring and prediction. Active manipulation of species generally will not be feasible in the region's extensive natural and lightly managed ecosystems.

Hydrology and Water Resources: Vulnerability appears to be potentially high. Any reduction of water availability, especially in Australia's extensive drought-prone areas, would sharpen competition among uses, including agriculture and wetland ecosystem needs. Freshwater supplies on low-lying islands are also vulnerable. More frequent high-rainfall events may enhance groundwater recharge and dam-filling events, but they also may increase the impacts of flooding, landslides and erosion, with flood-prone urban areas being heavily exposed to financial loss. Reduced snowpack and a shorter snow season appear likely, and New Zealand's glaciers are likely to shrink further. Some adaptation options are available, but the cost involved would be high.

Food and Fiber Production: Vulnerability appears to be low, at least in the next few decades (potentially high sensitivity coupled with high adaptability). Agriculture in the region is adaptable, and production increases are likely in some cases. However, there may be a trend toward increased vulnerability in the longer term—especially in warmer and more water-limited parts of Australia, where initial gains for some crops are eroded later as the delayed full effects of climate change (e.g., changes in temperature and precipitation) tend to outweigh the more immediate benefits of increased atmospheric CO_2 concentrations. Impacts will vary widely from district to district and crop to crop. There will be changes in growth and quality of crops and pastures; shifts in the suitability of districts for particular crops; and possibly increased problems with weeds, pests and diseases. Rangeland pastoralism and irrigated agriculture will be especially affected where rainfall changes occur. Changes in food production elsewhere in the world, which affect prices, would have major economic impacts on the region. With regard to forestry, the longer time to maturity results in a relatively large exposure to financial loss from extreme events, fire or any locally rapid change in climate conditions.

Coastal Systems: Parts of the region's coasts and rapidly growing coastal settlements and infrastructure are very vulnerable to any increase in coastal flooding and erosion arising from sea-level rise and meteorological changes. Indigenous coastal and island communities in the Torres Strait and in New Zealand's Pacific island territories are especially vulnerable. Many adaptation options exist, although these measures are not easily implemented on low-lying islands. Moreover, climate change and sea-level rise generally are not well accommodated in current coastal management planning frameworks.

Human Settlements: In addition to hydrological and coastal risks, moderate vulnerability is present from a variety of impacts on air quality, drainage, waste disposal, mining, transport, insurance and tourism. Overall, these effects are likely to be small relative to other economic influences, but they still may represent significant costs for large industries.

Human Health: Some degree of vulnerability is apparent. Indigenous communities and the economically disadvantaged may be more at risk. Increases are expected in heat-stress mortality, vector-borne diseases such as dengue, water and sewage-related diseases, and urban pollution-related respiratory problems. Though small compared with the total burden of ill health, these impacts have the potential to cause considerable community impact and cost.

Conclusions: Australia's relatively low latitude makes it particularly vulnerable to impacts on its scarce water resources and on crops growing near or above their optimum temperatures, whereas New Zealand's cooler, wetter, mid-latitude location may lead to some benefit through the ready availability of suitable crops and likely increases in agricultural production. In both countries, however, there is a wide range of situations where vulnerability is thought to be moderate to high—particularly in ecosystems, hydrology, coastal zones, human settlements and human health.

6.5 Europe

Europe constitutes the western part of the Eurasian continent. Its eastern boundary is formed by the Ural Mountains, the Ural River, and part of the Caspian Sea. The proximity of the relatively warm Gulf Stream and typical atmospheric circulation contribute to the large spatial and temporal variability of the region's temperature and precipitation. South of the main Alpine divide, the climate is of the Mediterranean type.

Ecosystems: Natural ecosystems generally are fragmented, disturbed and confined to poor soils. This situation makes them more sensitive to climate change. Mediterranean and boreal grasslands may shift in response to changes in the amount and the seasonal distribution of precipitation. The northern boundaries of forests in Fennoscandia and northern Russia would likely expand into tundra regions, reducing the extent of tundra, mires and permafrost areas. Survival of some species and forest types may be endangered by the projected movement of climate zones at rates faster than migration speeds. High-elevation ecosystems and species are particularly vulnerable because they have nowhere to migrate. An increase in temperature, accompanied by decreases in soil moisture, would lead to a substantial reduction in peat formation in Fennoscandian and northern Russian peatlands. Thawing of the permafrost layer would lead to lowered water tables in some areas and would flood thaw lakes in others, altering current wetland ecosystem types. Although the diversity of freshwater species may increase in a warmer climate, particularly in middle and high latitudes, there may be an initial reduction in species diversity in cool temperate and boreal regions. Ecosystems in southern Europe would be threatened mainly by reduced precipitation and subsequent increases in water scarcity.

Hydrology and Water Resources: Most of Europe experienced temperature increases this century larger than the global average, and enhanced precipitation in the northern half and decreases in the southern half of the region. Projections of future climate, not taking into account the effect of aerosols, indicate that precipitation in high latitudes of Europe may increase, with mixed results for other parts of Europe. The current uncertainties about future precipitation are mainly exacerbated by the effects of aerosols.

Water supply may be affected by possible increases in floods in northern and northwest Europe and by droughts in southern portions of the continent. Many floodplains in western Europe already are overpopulated, which hampers effective additional flood protection. Pollution is a major problem for many rivers; a warmer climate could lead to reduced water quality, particularly if accompanied by reduced runoff. Warmer summers would lead to increased water demand, although increased demand for irrigation would be at least partly offset for many crops by increased water-use efficiency associated with CO_2 fertilization.

Expected changes in snow and ice will have profound impacts on European streams and rivers. Up to 95 per cent of Alpine glacier mass could disappear by 2100, with subsequent consequences for the water flow regime—affecting, for example, summer water supply, shipping and hydropower. Also, in some areas, winter tourism would be negatively affected.

Water management is partly determined by legislation and cooperation among government entities, within countries and internationally; altered water supply and demand would call for a reconsideration of existing legal and cooperative arrangements.

Food and Fiber Production: Risks of frost would be reduced in a warmer climate, allowing winter cereals and other winter crops to expand to areas such as southern Fennoscandia and western Russia. Potential yields of winter crops are expected to increase, especially in central and southern Europe, assuming that neither precipitation nor irrigation are limiting and that water-use efficiency increases with the ambient atmospheric concentration of CO_2. Increasing spring temperatures would extend suitable zones for most summer crops. Summer crop yield increases are possible in central and eastern Europe, though decreases are possible in western Europe. Decreases in precipitation in southern Europe would reduce crop yields and make irrigation an even larger competitor to domestic and industrial water use. Along with potential crop yields, farmer adaptation, agricultural policy and world markets are important factors in the economic impact of climate change on the agricultural sector.

Coastal Systems: Coastal zones are ecologically and economically important. Settlement and economic activity have reduced the resilience and adaptability of coastal systems to climate variability and change, as well as to sea-level rise. Some coastal areas already are beneath mean sea level, and many others are vulnerable to storm surges. Areas most at risk include the Dutch, German, Ukrainian and Russian coastlines; some Mediterranean deltas; and Baltic coastal zones. Storm surges, changes in precipitation, and changes in wind speed and direction add to the concern of coastal planners. In general, major economic and social impacts can be contained with relatively low investment. This is not true, however, for a number of low-lying urban areas vulnerable to storm surges, nor for ecosystems—particularly coastal wetlands—which may be even further damaged by protective measures.

Human Settlements: Supply and demand for cooling water will change. Energy demand may increase in summer (cooling) and decrease in winter (heating), and peak energy demand will shift. Infrastructure, buildings and cities designed for cooler climates will have to be adjusted to warming, particularly heat waves, to maintain current functions. In areas where precipitation increases or intensifies, there are additional risks from landslides and river floods.

Human Health: Heat-related deaths would increase under global warming and may be exacerbated by worsening air quality in cities; there would be a reduction in cold-related deaths. Vector-borne diseases would expand. Health care measures could significantly reduce such impacts.

Conclusions: Even though capabilities for adaptation in managed systems in many places in Europe are relatively well established, significant impacts of climate change still should be anticipated. Major effects are likely to be felt through changes in the frequency of extreme events and precipitation, causing more droughts in some areas and more river floods elsewhere. Effects will be felt primarily in agriculture and other water-dependent activities. Boreal forest and permafrost areas are projected to undergo major change. Ecosystems are especially vulnerable due to the projected rate of climate change and because migration is hampered.

6.6 Latin America

Latin America includes all continental countries of the Americas from Mexico to Chile and Argentina, as well as adjacent seas. The region is highly heterogeneous in terms of climate, ecosystems, human population distribution and cultural traditions. Several Latin American countries—especially those of the Central American isthmus, Ecuador, Brazil, Peru, Bolivia, Chile and Argentina—are significantly affected with adverse socioeconomic consequences by seasonal to interannual climate variability, particularly the ENSO phenomenon. Most production is based on the region's extensive natural ecosystems, and the impacts of current climate variability on natural resources suggest that the impacts of projected climate changes could be important enough to be taken into account in national and regional planning initiatives. Land use is a major force driving ecosystem change at present, interacting with climate in complex ways. This factor makes the task of identifying common patterns of vulnerability to climate change very difficult.

Ecosystems: Large forest and rangeland areas are expected to be affected as a result of projected changes in climate, with mountain ecosystems and transitional zones between vegetation types extremely vulnerable. Climate change could add an additional stress to the adverse effects of continued deforestation in the Amazon rainforest. This impact could lead to biodiversity losses, reduce rainfall and runoff within and beyond the Amazon basin (reduced precipitation recycling through evapotranspiration), and affect the global carbon cycle.

Hydrology and Water Resources: Climate change could significantly affect the hydrological cycle, altering the intensity and temporal and spatial distribution of precipitation, surface runoff and groundwater recharge, with various impacts on different natural ecosystems and human activities. Arid and semi-arid areas are particularly vulnerable to changes in water availability. Hydropower generation and grain and livestock production are particularly vulnerable to changes in water supply, particularly in Costa Rica, Panama and the Andes piedmont, as well as adjacent areas in Chile and western Argentina between 25°S and 37°S. The impacts on water resources could be sufficient to lead to conflicts among users, regions and countries.

Food and Fiber Production: Decreases in agricultural production —even after allowing for the positive effects of elevated CO_2 on crop growth and moderate levels of adaptation at the farm level—are projected for several major crops in Mexico, countries of the Central American isthmus, Brazil, Chile, Argentina and Uruguay. In addition, livestock production would decrease if temperate grasslands have to face substantial decreases in water availability. Extreme events (e.g., floods, droughts, frosts, storms) have the potential to adversely affect rangelands and agricultural production (e.g., banana crops in Central America). The livelihoods of traditional peoples, such as many Andean communities, would be threatened if the productivity or surface area of rangelands or traditional crops is reduced.

Coastal Systems: Losses of coastal land and biodiversity (including coral reefs, mangrove ecosystems, estuarine wetlands, and marine mammals and birds), damage to infrastructure, and saltwater intrusion resulting from sea-level rise could occur in low-lying coasts and estuaries in countries such as those of the Central American isthmus, Venezuela, Argentina and Uruguay. Sea-level rise that blocks the runoff of flatland rivers into the ocean could increase the risks of floods in their basins (e.g., in the Argentine Pampas).

Human Settlements: Climate change would produce a number of direct and indirect effects on the welfare, health, and security of the inhabitants of Latin America. Direct impacts resulting from sea-level rise, adverse weather and extreme climatic conditions (e.g., floods, flash floods, windstorms, landslides, and cold and heat outbreaks), as well as indirect effects through impacts on other sectors such as water and food supply, transportation, energy distribution and sanitation services, could be exacerbated by projected climate change. Particularly vulnerable groups include those living in shanty towns in areas around large cities, especially where those settlements are established in flood-prone areas or on unstable hillsides.

Human Health: Projected changes in climate could increase the impacts of already serious chronic malnutrition and diseases for some Latin American populations. The geographical distributions of vector-borne diseases (e.g., malaria, dengue, Chagas') and infectious diseases (e.g., cholera) would expand southward and to higher elevations if temperature and precipitation increase. Pollution and high concentrations of ground-level ozone, exacerbated by increasing surface temperature, would have the potential to negatively affect human health and welfare, especially in urban areas.

Conclusions: Increasing environmental deterioration (e.g., changes in water availability, losses of agricultural lands and flooding of coastal, riverine and flatland areas) arising from climate variability, climate change and land-use practices would aggravate socio-economic and health problems, encourage migration of rural and coastal populations, and deepen national and international conflicts.

6.7 North America

This region consists of Canada and the United States south of the Arctic Circle. Within the region, vulnerability to and the impacts of climate change vary significantly from sector to sector and from subregion to subregion. This "texture" is important in understanding the potential effects of climate change on North America, as well as in formulating and implementing viable response strategies.

Ecosystems: Most ecosystems are moderately to highly sensitive to changes in climate. Effects are likely to include both beneficial and harmful changes. Potential impacts include northward shifts of forest and other vegetation types, which would affect biodiversity by altering habitats and would reduce the market and non-market goods and services they provide; declines in forest density and forested area in some subregions, but gains in others; more frequent and larger forest fires; expansion of arid land species into the great basin region; drying of prairie pothole wetlands that currently support over 50 per cent of all waterfowl in North America; and changes in distribution of habitat for cold-, cool- and warm-water fish. The ability to apply management practices to limit potential damages is likely to be low for ecosystems that are not already intensively managed.

Hydrology and Water Resources: Water quantity and quality are particularly sensitive to climate change. Potential impacts include increased runoff in winter and spring and decreased soil moisture and runoff in summer. The Great Plains and prairie regions are particularly vulnerable. Projected increases in the frequency of heavy rainfall events and severe flooding also could be accompanied by an increase in the length of dry periods between rainfall events and in the frequency and/or severity of droughts in parts of North America. Water quality could suffer and would decline where minimum river flows decline. Opportunities to adapt are extensive, but their costs and possible obstacles may be limiting.

Food and Fiber Production: The productivity of food and fiber resources of North America is moderately to highly sensitive to climate change. Most studies, however, have not fully considered the effects of potential changes in climate variability; water availability; stresses from pests, diseases and fire; or interactions with other, existing stresses. Warmer climate scenarios (4–5°C increases in North America) have yielded estimates of negative impacts in eastern, southeastern and corn belt regions and positive effects in northern plains and western regions. More moderate warming produced estimates of predominately positive effects in some warm-season crops. Vulnerability of commercial forest production is uncertain, but is likely to be lower than less intensively managed systems due to changing technology and management options. The vulnerability of food and fiber production in North America is thought to be low at the continental scale, though subregional variation in losses or gains is likely. The ability to adapt may be limited by information gaps; institutional obstacles; high economic, social and environmental costs; and the rate of climate change.

Coastal Systems: Sea level has been rising relative to the land along most of the coast of North America, and falling in a few areas, for thousands of years. During the next century, a 50-cm rise in sea level from climate change alone could inundate 8 500 to 19 000 km^2 of dry land, expand the 100-year floodplain by more than 23 000 km^2 and eliminate as much as 50 per cent of North America's coastal wetlands. The projected changes in sea level due to climate change alone would underestimate the total change in sea level from all causes along the eastern seabord and Gulf coast of North America. In many areas, wetlands and estuarine beaches may be squeezed between advancing seas and dikes or seawalls built to protect human settlements. Several local governments are implementing land-use regulations to enable coastal ecosystems to migrate landward as sea level rises. Saltwater intrusion may threaten water supplies in several areas.

Human Settlements: Projected changes in climate could have positive and negative impacts on the operation and maintenance costs of North American land and water transportation. Such changes also could increase the risks to property and human health and life as a result of possible increased exposure to natural hazards (e.g., wildfires, landslides and extreme weather events) and result in increased demand for cooling and decreased demand for heating energy—with the overall net effect varying across geographic regions.

Human Health: Climate can have wide-ranging and potentially adverse effects on human health via direct pathways (e.g., thermal stress and extreme weather/climate events) and indirect pathways (e.g., disease vectors and infectious agents, environmental and occupational exposures to toxic substances, food production). In high-latitude regions, some human health impacts are expected due to dietary changes resulting from shifts in migratory patterns and abundance of native food sources.

Conclusions: Taken individually, any one of the impacts of climate change may be within the response capabilities of a subregion or sector. The fact that they are projected to occur simultaneously and in concert with changes in population, technology, economics, and other environmental and social changes, however, adds to the complexity of the impact assessment and the choice of appropriate responses. The characteristics of subregions and sectors of North America suggest that neither the impacts of climate change nor the response options will be uniform.

Many systems of North America are moderately to highly sensitive to climate change, and the range of estimated effects often includes the potential for substantial damages. The technological capability to adapt management of systems to lessen or avoid damaging effects exists in many instances. The ability to adapt may be diminished, however, by the attendant costs, lack of private incentives to protect publicly owned natural systems, imperfect information regarding future changes in climate and the available options for adaptation, and institutional barriers. The most vulnerable sectors and regions include long-lived natural forest ecosystems in the east and interior west; water resources in the southern plains; agriculture in the southeast and southern plains; human health in areas currently experiencing diminished urban air quality; northern ecosystems and habitats; estuarine beaches in developed areas; and low-latitude cool- and cold-water fisheries. Other sectors and subregions may benefit from opportunities associated with warmer temperatures or, potentially, from CO_2 fertilization—including west coast coniferous forests; some western rangelands; reduced energy costs for heating in the northern latitudes; reduced salting and snow-clearance costs; longer open-water seasons in northern channels and ports; and agriculture in the northern latitudes, the interior west and the west coast.

6.8 Small Island States

With the exception of Malta and Cyprus in the Mediterranean, all of the small island states considered here are located within the tropics. About one-third of the states comprise a single main island; the others are made up of several or many islands. Low-lying island states and atolls are especially vulnerable to climate change and associated sea-level rise because in many cases (e.g., the Bahamas, Kiribati, the Maldives, the Marshall Islands), much of the land area rarely exceeds 3–4 m above present mean sea level. Many islands at higher elevation also are vulnerable to climate change effects, particularly in their coastal zones, where the main settlements and vital economic infrastructure almost invariably are concentrated.

Ecosystems: Although projected temperature rise is not anticipated to have widespread adverse consequences, some critical ecosystems, such as coral reefs, are very sensitive to temperature changes. Although some reefs have the ability to keep pace with the projected rate of sea-level rise, in many parts of the tropics (e.g., the Caribbean Sea, the Pacific Ocean) some species of corals live near their limits of temperature tolerance. Elevated seawater temperatures (above seasonal maxima) can seriously damage corals by bleaching and also impair their reproductive functions, and lead to increased mortality. The adaptive capacity of mangroves to climate change is expected to vary by species, as well as according to local conditions (e.g., the presence or absence of sediment-rich, macrotidal environments, the availability of adequate fresh water to maintain the salinity balance). The natural capacity of mangroves to adapt and migrate landward also is expected to be reduced by coastal land loss and the presence of infrastructure in the coastal zone. On some islands, ecosystems already are being harmed by other anthropogenic stresses (e.g., pollution), which may pose as great a threat as climate change itself. Climate change would add to these stresses and further compromise the long-term viability of these tropical ecosystems.

Hydrology and Water Resources: Freshwater shortage is a serious problem in many small island states, and many such states depend heavily on rainwater as the source of water. Changes in the patterns of rainfall may cause serious problems to such nations.

Coastal Systems: Higher rates of erosion and coastal land loss are expected in many small islands as a consequence of the projected rise in sea level. In the case of Majuro atoll in the Marshall Islands and Kiribati, it is estimated that for a 1-m rise in sea level as much as 80 per cent and 12.5 per cent (respectively) of total land would be vulnerable. Generally, beach sediment budgets are expected to be adversely affected by reductions in sediment deposition. On high islands, however, increased sediment yield from streams will help to compensate for sand loss from reefs. Low-lying island states and atolls also are expected to experience increased sea flooding, inundation and salinization (of soils and freshwater lenses) as a direct consequence of sea-level rise.

Human Settlements and Infrastructure: In a number of islands, vital infrastructure and major concentrations of settlements are likely to be at risk, given their location at or near present sea level and their proximity to the coast (often within 1–2 km; e.g., Kiribati, Tuvalu, the Maldives, the Bahamas). Moreover, vulnerability assessments also suggest that shore and infrastructure protection costs could be financially burdensome for some small island states.

Human Health: Climate change is projected to exacerbate health problems such as heat-related illness, cholera, dengue fever and biotoxin poisoning, and would place additional stress on the already over-extended health systems of most small islands.

Tourism: Tourism is the dominant economic sector in a number of small island states in the Caribbean Sea and the Pacific and Indian Oceans. In 1995, tourism accounted for 69 per cent, 53 per cent, and 50 per cent of gross national product (GNP) in Antigua, the Bahamas and the Maldives, respectively. This sector also earns considerable foreign exchange for a number of small island states, many of which are heavily dependent on imported food, fuel and a range of other vital goods and services. Foreign exchange earnings from tourism also provided more than 50 per cent of total revenues for some countries in 1995. Climate change and sea-level rise would affect tourism directly and indirectly: loss of beaches to erosion and inundation, salinization of freshwater aquifers, increasing stress on coastal ecosystems, damage to infrastructure from tropical and extra-tropical storms, and an overall loss of amenities would jeopardize the viability and threaten the long-term sustainability of this important industry in many small islands.

Conclusions: To evaluate the vulnerability of these island states to projected climate change, a fully integrated approach to vulnerability assessments is needed. The interaction of various biophysical attributes (e.g., size, elevation, relative isolation) with the islands' economic and sociocultural character ultimately determines the vulnerability of these islands. Moreover, some islands are prone to periodic nonclimate-related hazards (e.g., earthquakes, volcanic eruptions, tsunamis); the overall vulnerability of these islands cannot be accurately evaluated in isolation from such threats. Similarly, vulnerability assessments for these small island states should take into consideration the value of nonmarketed goods and services (e.g., subsistence assets, community structure, traditional skills and knowledge), which also may be at risk from climate change. In some island societies, these assets are just as important as marketed goods and services.

Uncertainties in climate change projections may discourage adaptation, especially because some options may be costly or require changes in societal norms and behavior. As a guiding principle, policies and development programmes which seek to use resources in a sustainable manner, and which can respond effectively to changing conditions such as climate change, would be beneficial to the small island states, even if climate change did not occur.

The small island states are extremely vulnerable to global climate change and global sea-level rise. A range of adaptation strategies are theoretically possible. On some small low-lying island states and atolls, however, retreat away from the coasts is not an option. In some extreme cases, migration and resettlement outside of national boundaries might have to be considered.

6.9 Temperate Asia

Temperate Asia includes countries in Asia between 18°N and the Arctic Circle, including the Japanese islands, the Korean peninsula, Mongolia, most parts of China, and Russian Siberia. The east-west distance of the area is about 8 000 km, and its north-south extent is about 5 000 km. Distinct subregions include arid/semi-arid, monsoonal and Siberian regions.

Ecosystems: Although the area of potential distribution of temperate forests in Temperate Asia is, to a large extent, cleared and used for intensive agriculture, global climate change can be considered sufficient to trigger structural changes in the remaining temperate forests. The nature and magnitude of these changes, however, depend on associated changes in water availability, as well as water-use efficiency. Shifts in temperature and precipitation in temperate rangelands may result in altered growing seasons and boundary shifts between grasslands, forests and shrublands. Some model studies suggest that in a doubled CO_2 climate there would be a large reduction in the area (up to 50 per cent) and productivity of boreal forests (primarily in the Russian Federation), accompanied by a significant expansion of grasslands and shrublands. There also would be a decrease in the area of the tundra zone of as much as 50 per cent—accompanied by the release of methane from deep peat deposits—and an increase (less than 25 per cent), in CO_2 emissions.

Hydrology and Water Resources: Overall, most $2{\times}CO_2$ equilibrium scenario simulations show a decrease in water supply, except in a few river basins. Warmer winters may affect water balances because water demands are higher in spring and summer. Equilibrium climate conditions for doubled equivalent CO_2 concentrations indicate that a decrease of as much as 25 per cent in mountain glacier mass is possible by 2050. Initially, runoff from glaciers in central Asia is projected to increase threefold by 2050, but by 2100 glacier runoff would taper to two-thirds of its present value. Model results suggest that runoff in the northern part of China is quite vulnerable to climate change, mainly as a consequence of changes in precipitation in spring, summer and autumn, especially during the flood season. To balance water supply with water demand, increasingly efficient water management is likely the best approach for Japan. In other parts of Temperate Asia, water-resource development will remain important; the central adaptation issue is how the design of new water-resource infrastructure should be adjusted to account for uncertainties resulting from climate change. The most critical uncertainties are the lack of credible projections of the effects of global change on the Asian monsoon or the ENSO phenomenon, which have great influence on river runoffs. Multiple-stress impact studies on water resources in international river basins are needed in the future.

Food and Fiber Production: Projected changes in crop yields using climate projections from different GCMs vary widely. In China, for example, across different scenarios and different sites, the changes for several crop yields by 2050 are projected to be: rice, -78 per cent to +15 per cent; wheat, -21 per cent to +55 per cent; and maize, -19 per cent to +5 per cent. An increase in productivity may occur if the positive effects of CO_2 on crop growth are considered, but its magnitude remains uncertain. A northward shift of crop zones is expected to increase agricultural productivity in northern Siberia but to decrease (by about 25 per cent) grain production in southwestern Siberia because of a more arid climate. Aquaculture is particularly important to Temperate Asia. Greater cultivation of warm-water species could develop. Warming will require greater attention to possible oxygen depletion, fish diseases, and introduction of unwanted species, as well as to potential negative factors such as changes in established reproductive patterns, migration routes and ecosystem relationships.

Coastal Systems: An increase in sea level will exacerbate the current severe problems of tectonically and anthropogenically induced land subsidence in delta areas. Saltwater intrusion also would become more serious. A sea-level rise of 1 m would threaten certain coastal areas—for example, the Japanese coastal zone, on which 50 per cent of Japan's industrial production is located (e.g., Tokyo, Osaka and Nagoya); in addition, about 90 per cent of the remaining sandy beaches in Japan would be in danger of disappearing.

Human Health: Heat-stress mortality and illness (predominantly cardiorespiratory) are projected to more than double by 2050 resulting from an increase in the frequency or severity of heat waves under climate-change conditions projected by a transient GCM (GFDL X2, UKMO X6). Net climate change-related increases in the geographic distribution (elevation and latitude) of the vector organisms of infectious diseases (e.g., malarial mosquitoes, schistosome-spreading snails) and changes in the life-cycle dynamics of vectors and infective parasites would, in aggregate, increase the potential transmission of many vector-borne diseases. Increases in nonvector-borne infectious diseases—such as cholera, salmonellosis and other food- and water-related infections—also could occur because of climatic impacts on water distribution, temperature and micro-organism proliferation. Disease surveillance could be strengthened and integrated with other environmental monitoring to design early warning systems; develop early, environmentally sound public health interventions; and develop anticipatory societal policies to reduce the risk of outbreaks and subsequent spread of epidemics.

Conclusions: The major impacts in Temperate Asia under global climate change are projected to be large shifts of the boreal forests, the disappearance of significant portions of mountain glaciers and water supply shortages. The most critical uncertainty in these estimates stems from the lack of credible projections of the hydrological cycle under global climate change scenarios. The effects of climate change on the Asian monsoon and the ENSO phenomenon are among the major uncertainties in the modeling of the hydrological cycle. Projections of agricultural crop yields are uncertain, not only because of the uncertainty in the hydrological cycle but also because of the potential positive effects of CO_2 and production practices. Sea-level rise endangers sandy beaches in the coastal zones, but remains an anthropogenically induced problem in delta areas. Integrated impact studies considering multi-stress factors are needed.

6.10 Tropical Asia

Tropical Asia is physiographically diverse and ecologically rich in natural and crop-related biodiversity. The present total population of the region is about 1.6 billion, and it is projected to increase to 2.4 billion by 2025. The population is principally rural-based, although in 1995, the region included 6 of the 25 largest cities in the world. The climate in Tropical Asia is characterized by seasonal weather patterns associated with the two monsoons and the occurrence of tropical cyclones in the three core areas of cyclogenesis (the Bay of Bengal, north Pacific Ocean and South China Sea). Climate change will add to other stresses such as rapid urbanization, industrialization and economic development, which contribute to unsustainable exploitation of natural resources, increased pollution, land degradation and other environmental problems.

Ecosystems: Substantial elevational shifts of ecosystems in the mountains and uplands of Tropical Asia are projected. At high elevation, weedy species can be expected to displace tree species—though the rates of vegetation change could be slow compared to the rate of climate change and constrained by increased erosion in the Greater Himalayas. Changes in the distribution and health of rainforest and drier monsoon forest will be complex. In Thailand, for instance, the area of tropical forest could increase from 45 per cent to 80 per cent of total forest cover, whereas in Sri Lanka, a significant increase in dry forest and a decrease in wet forest could occur. Projected increases in evapotranspiration and rainfall variability are likely to have a negative impact on the viability of freshwater wetlands, resulting in shrinkage and desiccation. Sea-level rise and increases in sea-surface temperature are the most probable major climate change-related stresses on coastal ecosystems. Coral reefs may be able to keep up with the rate of sea-level rise but suffer bleaching from higher temperatures. Landward migration of mangroves and tidal wetlands is expected to be constrained by human infrastructure and human activities.

Hydrology and Water Resources: The Himalayas have a critical role in the provision of water to continental monsoon Asia. Increased temperatures and increased seasonal variability in precipitation are expected to result in increased recession of glaciers and increasing danger from glacial lake outburst floods. A reduction in average flow of snow-fed rivers, coupled with an increase in peak flows and sediment yield, would have major impacts on hydropower generation, urban water supply and agriculture. Availability of water from snow-fed rivers may increase in the short term but decrease in the long run. Runoff from rain-fed rivers may change in the future. A reduction in snowmelt water will put the dry-season flow of these rivers under more stress than is the case now. Increased population and increasing demand in the agricultural, industrial and hydropower sectors will put additional stress on water resources. Pressure on the drier river basins and those subject to low seasonal flows will be most acute. Hydrological changes in island and coastal drainage basins are expected to be relatively small in comparison to those in continental Tropical Asia, apart from those associated with sea-level rise.

Food and Fiber Production: The sensitivity of major cereal and tree crops to changes in temperature, moisture and CO_2 concentration of the magnitudes projected for the region has been demonstrated in many studies. For instance, impacts on rice yield, wheat yield and sorghum yield suggest that any increase in production associated with CO_2 fertilization will be more than offset by reductions in yield from temperature or moisture changes. Although climate change impacts could result in significant changes in crop yields, production, storage and distribution, the net effect of the changes regionwide is uncertain because of varietal differences; local differences in growing season, crop management, etc.; the lack of inclusion of possible diseases, pests, and microorganisms in crop model simulations; and the vulnerability of agricultural areas to episodic environmental hazards, including floods, droughts and cyclones. Low-income rural populations that depend on traditional agricultural systems or on marginal lands are particularly vulnerable.

Coastal Systems: Coastal lands are particularly vulnerable; sea-level rise is the most obvious climate-related impact. Densely settled and intensively used low-lying coastal plains, islands and deltas are especially vulnerable to coastal erosion and land loss, inundation and sea flooding, upstream movement of the saline/freshwater front and seawater intrusion into freshwater lenses. Especially at risk are large delta regions of Bangladesh, Myanmar, Viet Nam and Thailand, and the low-lying areas of Indonesia, the Philippines and Malaysia. Socio-economic impacts could be felt in major cities and ports, tourist resorts, artisinal and commercial fishing, coastal agriculture and infrastructure development. International studies have projected the displacement of several millions of people from the region's coastal zone, assuming a 1-m rise in sea level. The costs of response measures to reduce the impact of sea-level rise in the region could be immense.

Human Health: The incidence and extent of some vector-borne diseases are expected to increase with global warming. Malaria, schistosomiasis and dengue—which are significant causes of mortality and morbidity in Tropical Asia—are very sensitive to climate and are likely to spread into new regions on the margins of presently endemic areas as a consequence of climate change. Newly affected populations initially would experience higher fatality rates. According to one study that specifically focused on climate influences on infectious disease in presently vulnerable regions, an increase in epidemic potential of 12–27 per cent for malaria and 31–47 per cent for dengue and a decrease of schistosomiasis of 11–17 per cent are anticipated under a range of GCM scenarios as a consequence of climate change. Waterborne and water-related infectious diseases, which already account for the majority of epidemic emergencies in the region, also are expected to increase when higher temperatures and higher humidity are superimposed on existing conditions and projected increases in population, urbanization, declining water quality and other trends.

Conclusions: The potential direct effects of climate change assessed here, such as changes in water availability, crop yields and inundation of coastal areas, all will have further indirect effects on food security and human health. The suitability of adaptation strategies to different climatic environments will vary across the diverse subregions and land uses of the region. Adaptive options include new temperature- and pest-resistant crop varieties; new technologies to reduce crop yield loss; improvements in irrigation efficiency; and integrated approaches to river basin and coastal zone management that take account of current and longer-term issues, including climate change.

7. Research Needs

The gaps and deficiencies revealed in this special report suggest some priority areas for further work to help policymakers in their difficult task.

These needs include:

- Better baseline data, both climatic and socio-economic
- Better scenarios, especially of precipitation, extreme events, sulfate aerosol effects and regional-scale changes
- Better understanding of the ecological and physiological effects of increasing CO_2 concentrations, taking account of species competition and migrations, soil and nutrients, acclimation, and partitioning between crop yields, roots, stems and leaves
- Dynamic models of climate, biospheric processes and other socio-economic factors to take account of the developing, time-varying nature of global change
- Impact assessments across a range of scenarios and assumptions to enable the assessment of risk, particularly in regions comprised primarily of developing countries and small island states, where resources for research and assessment have been inadequate to date
- Analysis of adaptation options, including the need for development of new technologies and opportunities for adapting existing technologies in new settings
- Integrated assessments across sectors, from climate change to economic or other costs, across countries and regions, including adaptations, and including other socio-economic changes.

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LIST OF IPCC OUTPUTS

I. IPCC FIRST ASSESSMENT REPORT, 1990

a) **CLIMATE CHANGE — The IPCC Scientific Assessment.** The 1990 report of the IPCC Scientific Assessment Working Group *(also in Chinese, French, Russian and Spanish).*
b) **CLIMATE CHANGE — The IPCC Impacts Assessment.** The 1990 report of the IPCC Impacts Assessment Working Group *(also in Chinese, French, Russian and Spanish).*
c) **CLIMATE CHANGE — The IPCC Response Strategies.** The 1990 report of the IPCC Response Strategies Working Group *(also in Chinese, French, Russian and Spanish).*
d) **Overview and Policymaker Summaries, 1990.**

Emissions Scenarios (prepared by the IPCC Response Strategies Working Group), 1990.

Assessment of the Vulnerability of Coastal Areas to Sea Level Rise — A Common Methodology, 1991.

II. IPCC SUPPLEMENT, 1992

a) **CLIMATE CHANGE 1992 — The Supplementary Report to the IPCC Scientific Assessment.** The 1992 report of the IPCC Scientific Assessment Working Group.
b) **CLIMATE CHANGE 1992 — The Supplementary Report to the IPCC Impacts Assessment.** The 1990 report of the IPCC Impacts Assessment Working Group.

CLIMATE CHANGE: The IPCC 1990 and 1992 Assessments — IPCC First Assessment Report Overview and Policymaker Summaries, and 1992 IPCC Supplement *(also in Chinese, French, Russian and Spanish).*

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Preliminary Guidelines for Assessing Impacts of Climate Change, 1992.

III. IPCC SPECIAL REPORT, 1994

a) **IPCC Guidelines for National Greenhouse Gas Inventories** (3 volumes), 1994 *(also in French, Russian and Spanish).*
b) **IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations,** 1994 *(also in Arabic, Chinese, French, Russian and Spanish).*
c) **CLIMATE CHANGE 1994 — Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios.**

IV. IPCC SECOND ASSESSMENT REPORT, 1995

a) **CLIMATE CHANGE 1995 — The Science of Climate Change.** (including Summary for Policymakers). Report of IPCC Working Group I, 1995.
b) **CLIMATE CHANGE 1995 — Scientific-Technical Analyses of Impacts, Adaptations and Mitigation of Climate Change.** (including Summary for Policymakers). Report of IPCC Working Group II, 1995.
c) **CLIMATE CHANGE 1995 — The Economic and Social Dimensions of Climate Change.** (including Summary for Policymakers). Report of IPCC Working Group III, 1995.
d) **The IPCC Second Assessment Synthesis of Scientific-Technical Information Relevant to Interpreting Article 2 of the UN Framework Convention on Climate Change,** 1995.

(Please note: the IPCC Synthesis and the three Summaries for Policymakers have been published in a single volume and are also available in Arabic, Chinese, French, Russian and Spanish).

V. IPCC SPECIAL REPORT, 1996

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VI. IPCC TECHNICAL PAPERS

Technologies, Policies and Measures for Mitigating Climate Change — IPCC Technical Paper 1, 1996.
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An Introduction to Simple Climate Models used in the IPCC Second Assessment Report — IPCC Technical Paper 2, 1997.
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VII. IPCC SPECIAL REPORT, 1997

The Regional Impacts of Climate Change: An Assessment of Vulnerability. (Including Summary for Policymakers). A special Report of IPCC Working Group II, 1997.