Climate Change Impact and Vulnerability in the Eastern Himalayas – Synthesis Report

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Climate Change Vulnerability of Mountain Ecosystems in the Eastern Himalayas

MacArthur Foundation

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Preface

Mountains are among the most fragile environments on Earth. They are also rich repositories of biodiversity and water and providers of ecosystem goods and services on which downstream communities (both regional and global) rely. Mountains are home to some of the world's most threatened and endemic species, as well as to some of the poorest people, who are dependent on the biological resources. Realising the importance of mountains as ecosystems of crucial significance, the Convention on Biological Diversity specifically developed a Programme of Work on Mountain Biodiversity in 2004 aimed at reducing the loss of mountain biological diversity at global, regional, and national levels by 2010. Despite these activities, mountains are still facing enormous pressure from various drivers of global change, including climate change. Under the influence of climate change, mountains are likely to experience wide ranging effects on the environment, natural resources including biodiversity, and socioeconomic conditions.

Little is known in detail about the vulnerability of mountain ecosystems to climate change. Intuitively it seems plausible that these regions, where small changes in temperature can turn ice and snow to water, and where extreme slopes lead to rapid changes in climatic zones over small distances, will show marked impacts in terms of biodiversity, water availability, agriculture, and hazards, and that this will have an impact on general human well being. But the nature of the mountains, fragile and poorly accessible landscapes with sparsely scattered settlements and poor infrastructure, means that research and assessment are least just where they are needed most. And this is truest of all for the Hindu Kush-Himalayas, with the highest mountains in the world, situated in developing and least developed countries with few resources for meeting the challenges of developing the detailed scientific knowledge needed to assess the current situation and likely impacts of climate change.

The International Centre for Integrated Mountain Development (ICIMOD) undertook a series of research activities together with partners in the Eastern Himalayas from 2007 to 2008 to provide a preliminary assessment of the impacts and vulnerability of this region to climate change. Activities included rapid surveys at country level, thematic workshops, interaction with stakeholders at national and regional levels, and development of technical papers by individual experts in collaboration with institutions that synthesised the available information on the region. A summary of the findings of the rapid assessment was published in 2009, and is being followed with a series of publication comprising the main vulnerability synthesis report (this publication) and technical papers on the thematic topics climate change projections, biodiversity, wetlands, water resources, hazards, and human wellbeing.

Clearly much more, and more precise, information will be needed to corroborate the present findings. Nevertheless, this series of publications highlights the vulnerability of the Eastern Himalayan ecosystems to climate change as a result of their ecological fragility and economic marginality. It is hoped that it will both inform conservation policy at national and regional levels, and stimulate the coordinated research that is urgently needed.

Andreas Schild, PhD
Director General, ICIMOD

Executive Summary

From July 2007 to December 2008, the International Centre for Integrated Mountain Development (ICIMOD) carried out a rapid 'Assessment of Climate Change Vulnerability of Mountain Ecosystems in the Eastern Himalayas', with support from the MacArthur Foundation. This synthesis report is the outcome of this work.

The Eastern Himalayas (EH) lie between 82.70°E and 100.31°E longitude and 21.95°N to 29.45°N latitude, covering a total area of 524,190 sq.km. The region extends from the Kaligandaki Valley in central Nepal to northwest Yunnan in China, and includes Bhutan, parts of India (North East Indian states, and the Darjeeling hills of West Bengal), southeast Tibet and parts of Yunnan in China, and northern Myanmar. These five countries have different geo-political and socioeconomic systems, as well as diverse cultures and ethnic groups.

The project undertook various research activities to assess the climate change vulnerability of mountain ecosystems in the EH. Activities included surveys at country level, thematic workshops, interaction with stakeholders at national and regional levels, and development of technical papers by individual experts in collaboration with institutions that synthesised the available information on the region. Available climate models were used to develop climate predictions for the region based on the observed data. The findings are summarised in detail in this synthesis report, following publications of a brief summary in 2009, preparation of an internal in depth report, and individual papers, all of which feed into this synthesis. The six technical papers produced on thematic areas are being published separately and are included on a CD-ROM with this synthesis.

Recent scientific opinion led by the Intergovernmental Panel on Climate Change (IPCC) is that global climate change is happening and will present practical challenges to local ecosystems. The analysis and predictions showing an increase in the magnitude of climate change with altitude (in terms of both temperature and variation in precipitation). The study explored the impact and future projections of changing climatic conditions and showed the critical linkages between biodiversity, ecosystem functioning, ecosystem services, drivers of change, and human wellbeing. The study highlights the region's vulnerability to climate change as a result of its ecological fragility and economic marginality. This is in line with the broad consensus on climate change vulnerability, and need for adaptation of conservation policy at national and regional levels.

Many factors contribute to the loss of biodiversity such as habitat loss and fragmentation, colonisation by invasive

species, overexploitation of resources, pollution, nutrient loading, and global climate change. The threats to biodiversity arising from climate change are very acute in the EH as the region is rich in threatened and endemic species with restricted distributions. Fragmentation and loss of habitat directly impinge on the survival of species, especially those that are endemic to the region. Species in high altitude areas – especially in the transition zone between sub-alpine and alpine – are more vulnerable to climate change. In addition, the region's wetlands are being affected by the erratic weather observed in many parts of the region.

The assessment also looked at the perception of climate change by the people in the region. People see climate change as a big threat and challenge. They perceive climate change to be a result of excessive human activity and, to a certain extent, natural cyclical climatic variation. The majority of the respondents from the region associated climate change with floods, landslides, increases in temperature, land degradation, the drying of water sources, pest outbreaks, and food shortages.

The assessment revealed a gap in our knowledge on the climate change vulnerability of mountain ecosystems in the EH and the inadequacy of human resources and institutional setups, as well as a lack of policy imperatives to address the issues. The lack of systematic research, monitoring, and documentation on the status of biodiversity in the region was highlighted in all the studies undertaken for this assessment. The region also lacks adequate scientific evidence to determine the impact of climate change on human wellbeing with any certainty. Equally, the majority of available research focuses on the adverse impacts of climate change and overlooks both the adaptation mechanisms adopted by the local people and the new opportunities presented. The enormous challenge for the region is to adapt to the impacts of climate change by integrating responses and adaptation measures into local level poverty reduction strategies.

In the process of assessing climate change vulnerabilities in the EH, ICIMOD has been able to network, initiate, and advocate for biodiversity conservation with regional cooperation on critical areas. This assessment is expected to advance our thinking about climate variability and change, and the vulnerability and adaptation of important impact areas, with a view to developing future strategies on both conservation and development. It indicates shortcomings and identifies research gaps in relation to biodiversity, wetland conservation, the resilience of ecosystems and their services, and hazards assessment, and points out the unreliability of trends and model projections due to the lack of country-wise consistent data related to climate change. The research gaps and lessons learned provide a good platform for initiating concrete projects and activities on biodiversity and climate change in the Eastern Himalayas. It is also hoped that the rapid assessment will be helpful in guiding the MacArthur Foundation, ICIMOD, and their partners in developing new strategies and plans for research on biodiversity conservation and enhancing human wellbeing.

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1 Introduction

Background

Climate and natural ecosystems are tightly coupled, and the stability of that coupled system is an important ecosystem service. Chapter 13 of Agenda 21, which was adopted at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 (UNEP 1992), explicitly recognises that mountains and uplands are a major component of the global environment. The Chapter sets the scene by stating the role of mountains within the global ecosystem and expresses serious concern about the decline in the general environmental quality of many mountain areas. Since Agenda 21, mountains have no longer been on the periphery of the global debate on development and environment, but have moved to centre-stage.

The Eastern Himalayas (EH) are considered multifunctional because they provide a diverse range of ecosystem services (provisioning, regulating, cultural, supporting); this also makes them useful for studying the relationship between loss of biodiversity and loss of ecosystem services. The world's most diverse mountain forests are found among the peaks and valleys of the EH (CEPF 2007). Rapid changes of altitude over relatively short horizontal distances have resulted in rich biodiversity with a wide variety of plants and animals, often with sharp transitions in vegetation sequences (ecotones), ascending into barren land, snow, and ice.

The survival of these ecosystems and the wildlife within them is being threatened by human activities such as timber harvesting, intensive livestock grazing, agricultural expansion into forestlands, and, above all, by climate change. Mountain areas are especially susceptible to global warming, which is the result of rising concentrations of greenhouse gases (GHGs) generated by human activity in the atmosphere. At the same time landscapes and communities in mountain regions are being affected by rapid socioeconomic changes like outmigration. Identification and understanding of the key ecological and socioeconomic parameters of mountain ecosystems, including their sensitivities and vulnerabilities to climate changes, has become crucial for planning and policy making for the environmental management and sustainable development of mountain regions, as well as downstream areas (APN 2003). The welfare of half a billion people downstream is inextricably linked to the state of natural resources in the Eastern Himalayas.

The Eastern Himalayas Study

The study presented here was concerned with establishing a correlation between biodiversity, ecosystem functioning, and ecosystem services for human wellbeing and was motivated by concern about climate change and its effects on the supply of a range of ecosystem services. The project was funded by the MacArthur Foundation and implemented by ICIMOD. This synthesis report provides a review of the climate change assessment with a focus on impact areas considered important for addressing climate change vulnerability in the mountain ecosystems of the EH. A brief summary was published in 2009 (Sharma et al. 2009) and the six technical papers produced on thematic areas are also being published separately in this series. The EH is a priority area for the MacArthur Foundation and the assessment was made to help guide the MacArthur Foundation, ICIMOD, and their partners in developing new strategies for biodiversity conservation and enhancing human wellbeing.

The regional assessment was conducted by an interdisciplinary team at ICIMOD together with support and contributions from various stakeholders, partners, and the countries concerned. This report synthesises the assessment sector-by-sector findings from the technical papers generated as part of this project, and other documents, using an applied research methodology. As such, it both collates previous studies and information, and extrapolates toward the specific requirements of ICIMOD and the MacArthur Foundation's biodiversity and ecosystems assessment. It also attempts to assess the trends, perceptions and projections of climate change and variability, as well as the impacts of climate change on biodiversity conservation, and identifies which impacts might be most important for the EH, taking into account the degree of uncertainty related to each category of impact. The ultimate aim is to reach a broad consensus on conservation policies, practices, and governance in climate change adaptation, with a view to developing a future strategy on both conservation and development. This report also identifies actions that could be taken to reduce the region's vulnerability, and summarises data and research priorities needed to guide interventions addressing climate change issues.

Five questions guided the assessment process:

1. What is the status of mountain ecosystems in the EH, and what are the current stresses and issues that provide the context for determining the impacts of climate change?
2. How might changes in climate and climate variability exacerbate or ameliorate these stresses or create new ones?
3. How much will the provision of ecosystem services in the EH change due to the effects of climate change?
4. What actions might increase the region's resilience to climate variability; and what are the potential strategies for coping with risk and to take advantage of new opportunities created by climate change?
5. What are the priorities for new information and policy-relevant research areas to better answer the above questions?

Underlying the approach in this assessment is the question: What aspects of ecosystems are important to people in the EH? Unfortunately, our understanding of how people depend upon ecosystems and how people value different aspects of ecosystems is incomplete. Aspects of ecosystems that we believe are important to the people of the EH, based on currently available information, were emphasised.

The following activities were undertaken:

- Review of major reports with a general and specific focus on the Eastern Himalayan region and other diverse professional contributions
- Contact and consultations with regional stakeholders
- Downloading and compilation of historical climatology, time series, and climate change scenario results for the EH, and synthesis of the broad trends as documented in recent regional and global reports
- Synthesis and categorisation of climate change impacts on biodiversity in the EH and biodiversity management actions that address these impacts
- Identification of potential data and knowledge gaps, and exploration of potential areas of research

This assessment specifically focuses on the following impact areas considered sensitive to climate change:

- biodiversity and impacts of climate change,
- water, wetlands and hazards, and
- threats to human wellbeing.

This synthesis provides an in depth analysis of the existing knowledge and information on: 1) the current trends, perceptions and projections of climate variability and climate change; 2) the potential for major positive or negative climate change impacts; 3) the vulnerable aspects and features of mountain ecosystems in the EH; 4) options to make the EH more resilient to climate change; and 5) priorities for improving such regional assessments through new research initiatives to close knowledge gaps. The assessment also attempts to consolidate past efforts in climate change studies and come out with a clear perspective on a future course of action. The synthesis wraps up with possible policy options and governance mechanisms to address the vulnerabilities associated with climate change in the priority impact areas. Gaps in our current knowledge and understanding are translated into recommendations for research agendas in the Eastern Himalayas.

Knowledge of Climate Change

There is a growing consensus in the scientific community that climate change is happening (Box 1). Research summarised in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) indicates that in the Himalayas global average surface temperatures are increasing, and snow cover and ice

Box 1: **The IPCC**

During the course of this century the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of change in climate and change in other global change drivers (especially land use change and overexploitation), if greenhouse gas emissions and other changes continue at or above current rates. By 2100 ecosystems will be exposed to atmospheric CO_2 levels substantially higher than in the past 650,000 years, and global temperatures at least among the highest of those experienced in the past 740,000 years. This will alter the structure, reduce biodiversity and perturb functioning of most ecosystems, and compromise the services they currently provide.

Source: IPCC (2007a)

extent are decreasing (IPCC 2007a). While the absolute magnitude of predicted changes is uncertain, there is a high degree of confidence in the direction of changes and in the recognition that climate change effects will persist for many centuries. The report noted that the average global surface temperature has increased by nearly 1°C over the past century and is likely to rise by another 1.4 to 5.8°C over the next century. Such simple statements, however, mask the highly variable, site-specific, and complex interactions among climate change effects.

Climate change and the Convention on Biological Diversity

There has been ongoing interest in the potential impacts of climate change on biodiversity in the EH over the past decade or more. All five countries of the Eastern Himalayas (Bhutan, China, India, Myanmar, Nepal) are signatories to the 1992 Convention on Biological Diversity (CBD), and their commitment was renewed during the World Summit on Sustainable Development (WSSD) in 2002. In 2004, the CBD adopted the Programme of Work on Mountain Biological Diversity with the overall purpose of achieving a significant reduction of loss of mountain biological diversity by 2010.

The broad objectives of the CBD and the Ramsar Convention on Wetlands are mutually compatible (conservation and wise use) and scope exists for close cooperation between the two agreements at all levels. Ramsar has been designated as the lead partner of the CBD in relation to inland water ecosystems. Natural ecosystems play a critical role in the carbon cycle, and, hence, act as sources and sinks for greenhouse gases. They are also extremely vulnerable to the impacts of climate change. The nature of the national activities in the CBD framework may thus have significance for reducing global climatic change and adapting to its effects. Cooperation between countries in the Eastern Himalayas under these two agreements to address climate change challenges is, therefore, essential.

Climate change, ecosystem services and human wellbeing

Atmospheric warming affects other aspects of the climate system: pressure and composition of the atmosphere; temperature of surface air, land, water, and ice; water content of air, clouds, snow, and ice; wind and ocean currents; ocean temperature, density, and salinity; and physical processes such as precipitation and evaporation. Climate affects humans directly through the weather experienced (physically and psychologically) day to day and the impacts of weather on daily living conditions, and indirectly through its impacts on economic, social, and natural environments. The potential for climate change to impact on biodiversity has long been noted by the IPCC, various other bodies (Feenstra et al. 1998), and research biologists (e.g., Peters and Lovejoy 1992). Climate change, including variability and extremes, continues to impact on mountain ecosystems, sometimes beneficially, but frequently with adverse effects on the structure and functioning of ecosystems. Fortunately, the functioning of many ecosystems can be restored if appropriate action is taken in time. The linkage between climate and human wellbeing is complex and dynamic as shown in Figure 1.

The concept of 'ecosystem services' introduced by the Millennium Ecosystem Assessment (MEA 2005) forms a useful link between the functioning of ecosystems and their role for society, including the dynamics of change over space and time. Most services can be quantified, even if no single metric is applied across their entire range. Impacts of climate change on ecosystem structure, functioning, and services have been observed (Parmesan and Yohe 2003; IPCC 2007a, c) which in turn affect human society mainly by increasing human vulnerability.

Humans rely on ecosystems, because they depend on ecosystem services (de Groot 1992; Daily 1997; MEA 2005). Ecosystems offer provisioning services (e.g., food, freshwater, fuelwood, biochemicals), regulating services (e.g., climate and disease regulation, pollination), cultural services (e.g., spiritual, recreational, aesthetic value, inspirational), and supporting services (e.g., soil formation, nutrient cycling, primary production). They influence our security, basic materials for a good life, health, social relations, and, ultimately, our freedoms and choices – in short, our wellbeing (MEA 2003).

Clearly, the human economy depends upon the services performed 'for free' by ecosystems. Natural ecosystems also perform fundamental life-support services without which human civilisations would cease to thrive. Many of the human activities that modify or destroy natural ecosystems may cause the deterioration of ecological services the value of which, in the long term, dwarfs the short-term economic benefits to society. We are bound to the human perspective, even if we recognise the intrinsic value of ecosystems and biodiversity. Social systems and natural systems are inseparable because ecosystem services weave people into ecosystems (Figure 2).

Figure 1: **Linkages between climate change, biodiversity, ecosystem services, and human wellbeing (adapted from MEA 2003)**

CLIMATE CHANGE

- Temperature
- Precipitation
- Atmospheric composition
- Variability and extremes

HUMAN WELLBEING

Security

- A safe environment
- Resilience to ecological shocks or stresses such as droughts, floods, and pests
- Secure rights and access to ecosystem services

Basic material for a good life

- Access to resources for a viable livelihood (including food and building materials) or the income to purchase them

Health

- Adequate food and nutrition
- Avoidance of disease
- Clean and safe drinking water
- Clean air
- Energy for comfortable temperature control

Good social relations

- Realisation of aesthetic and recreational values
- Ability to express cultural and spiritual values
- Opportunity to observe and learn from nature
- Development of social capital
- Avoidance of tension and conflict over a declining resource base

Freedom and choice

- Ability to influence decisions regarding ecosystem services and wellbeing
- Opportunity to be able to achieve what an individual values doing and being

BIODIVERSITY (ecosystem, habitat, species)

- Number
- Distribution
- Abundance
- Composition
- Interaction

ECOSYSTEM FUNCTIONS

ECOSYSTEM SERVICES

Provisioning services

Food and fodder, fibre, fuel, timber, pharmaceuticals, biochemicals, genetic resources, freshwater and air

Regulating services

Invasion resistance, herbivory, pollination, seed dispersal, climate regulation, pest and disease regulation, natural hazard protection, erosion regulation, flood regulation, water purification

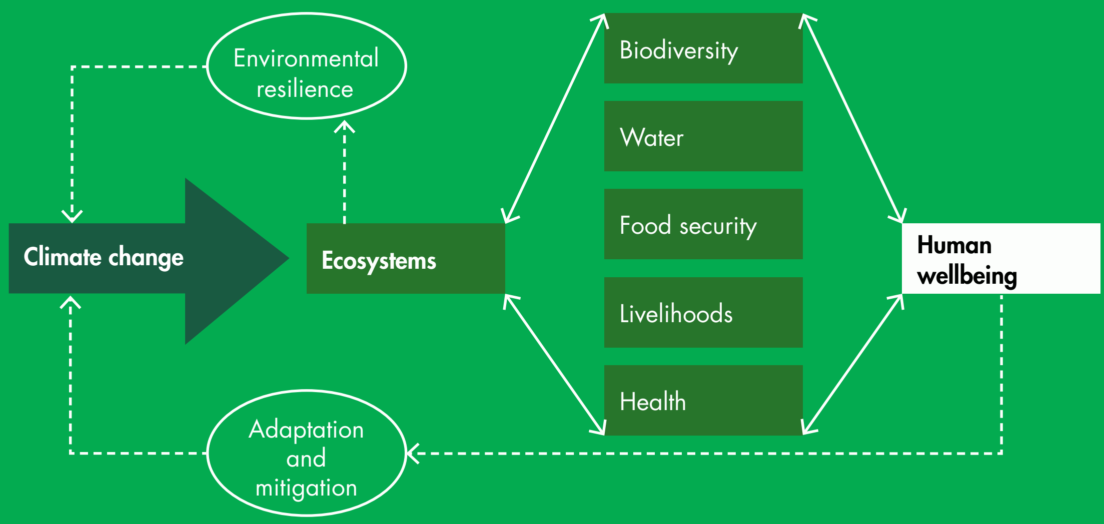
Cultural services

Spiritual and religious values, knowledge system, education and inspiration, recreation and aesthetic values, sense of place

Supporting services

Primary production, provision of habitat, nutrient cycling, soil formation and retention, oxygen production, water cycling

Figure 2: **Role of ecosystems in assessment of climate change effects on human wellbeing** (modified from Metzger and Schröter 2006)



Mountain Ecosystems

An ecosystem is an interdependent, functioning system of plants, animals, and microorganisms. An ecosystem can be as large as the Tibetan Plateau or as small as a waterhole at the fringe of a subtropical forest. Ecosystems are of fundamental importance to environmental functioning and sustainability, and they provide many goods and services critical to individuals and societies. These goods and services include: i) providing food, fibre, fodder, shelter, medicines and energy; ii) processing and storing carbon and nutrients; iii) assimilating waste; 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 reservoir of genetic and species diversity. In addition, natural ecosystems have cultural, religious, and aesthetic value as well as an intrinsic existence value. Without the support of the other organisms within their own ecosystem, life forms would not survive, much less thrive. Such support requires that predators and prey, fire and water, food and shelter, clean air and open space remain in balance with each other and with the environment around them.

Mountain ecosystems are found throughout the world, from the equator almost to the poles, occupying approximately one-fifth of the Earth's land surface. Beyond their common characteristics of high relative relief and steep slopes, mountains are remarkably diverse (Ives et al. 1997) and globally important as centres of biological diversity. On a global scale, mountains' greatest value may be as sources of all the world's major rivers, and many smaller ones (Mountain Agenda 1998).

Climate is an integral part of mountain ecosystems and organisms have adapted to their local climate over time. Climate change has the potential to alter these ecosystems and the services they provide to each other and to human society at large. Human societies depend on ecosystem provisioning, regulating, cultural and supportive services for their wellbeing. The goods and services provided by mountain ecosystems sustain almost half the human population worldwide, and also maintain the integrity of the Earth system through the provision of vital environmental regulation and rejuvenation functions.

Production agriculture and extractive forestry are the mainstay of food security and subsistence livelihoods in mountain regions. Livelihood strategies are built around indigenous knowledge and traditional practices of ecological sustainability in natural resources management. Mountain farming systems integrating arable agriculture, horticulture, livestock, and silviforestry have moderated utilisation with conservation ethics to ensure that ecosystem services are not exploited beyond their renewable capacities. Unfortunately, these practices are losing their relevance as a result of globalisation, at the expense of customary rights to ecosystem services. Without policy support for, and legal recognition of, traditional practices, mountain communities are confronted with limited livelihood options and less incentive to stay in balance with surrounding ecosystems. Problems associated with modernisation, like GHG emissions, air pollution, land use conversion, deforestation, and land degradation, are slowly creeping into mountain regions. The out-migration of the rural workforce has brought economic activities in some rural areas to a standstill. Thus, landscapes and communities in mountain regions are being simultaneously affected by rapid environmental and socioeconomic threats and perturbations.

With the advent of a globalised world, the mutual relationship between humans and mountains is now threatened by a growing population and its increasing demands on ecosystem services, which are beyond tolerance thresholds. Traditional resilience is being rapidly eroded leading to dependence on external inputs and the overexploitation of selective resources, threatening their sustainability. Rapid changes to fragile ecosystems driven by both natural and anthropogenic determinants pose unprecedented threats, not only to the livelihoods of the local people, wildlife, and culture, but also to the billions living downstream, and ultimately to the global environment. Besides demographic and socioeconomic changes, the political economics of marginalisation imposes an additional layer of vulnerability. The inherent environmental fragility of mountain ecosystems and the socioeconomic vulnerability of mountain people have brought the issues of mountain ecosystems to the top of the global sustainability agenda.

The Eastern Himalayas

The EH covers an area of 524,190 sq.km, stretching from eastern Nepal to Yunnan in China, between 82.70°E and 100.31°E longitude and 21.95°N and 29.45°N latitude. The limits of the region as defined for the purposes of this study are shown in Figure 3. The region extends through parts of five countries (Table 1)

Characteristics

The Eastern Himalayan region (EH), with its mountains, valleys, and flood plains, is physiographically diverse and ecologically rich in natural and crop-related biodiversity. It is also significant from geopolitical, environmental, cultural, and ethnic perspectives, and in terms of its ecosystems and the tectonic orogeny of the encompassing Himalayan mountain system. The lowlands are characterised by braided rivers emerging from deeply dissected foothills and converging into slow meandering rivers further downstream. The ecological diversity of the EH is, in part, a function of the large variation in topography, soil, and climate within the region. The human population is also unevenly distributed: the highest population densities are found in the Nepal Terai, West Bengal, and the Assam Duars, and in dispersed pockets in the Brahmaputra basin, Meghalaya, Tripura, and Manipur. During the past 30 years, the human population of the region has increased at approximately 2.1% annually (WWF 2005), with higher rates in and around urban centres, and low or sometimes negative growth rates in many of the rural and isolated areas.

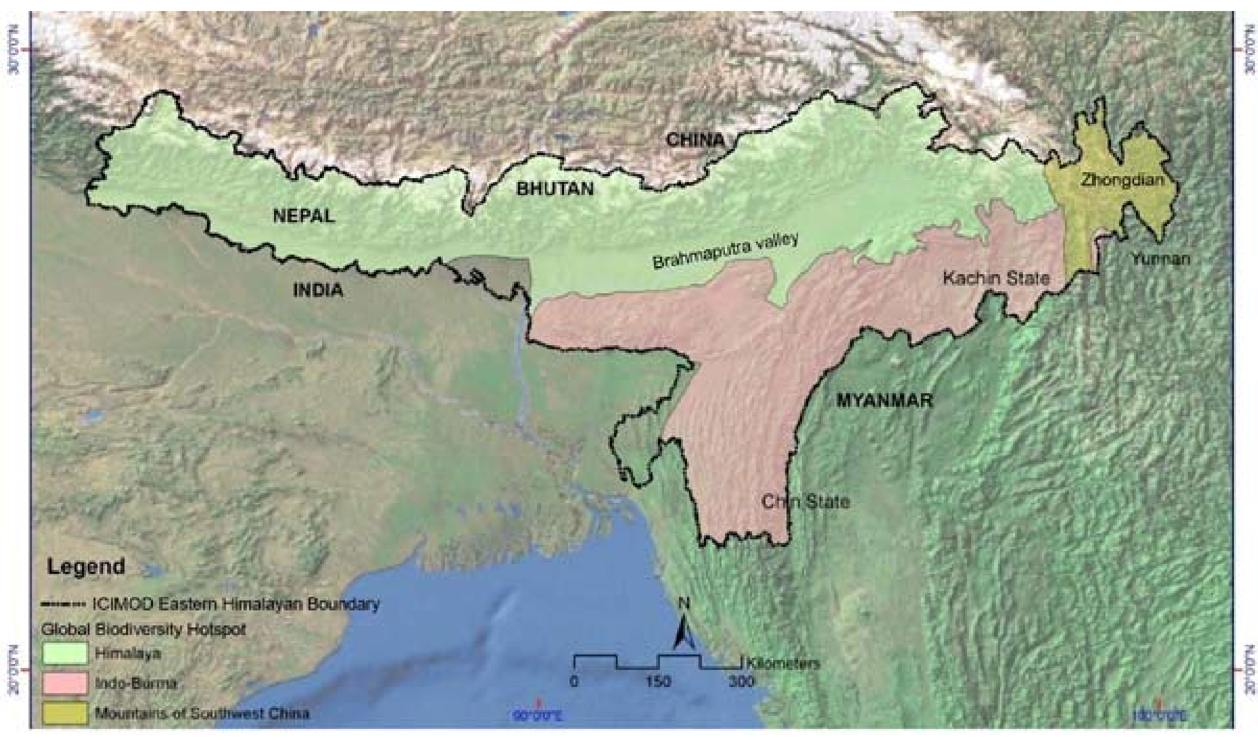
Table 1: **Percentage share of the aerial extent of the Eastern Himalayas by country**

Country	Areas	% of EH area
India	Sikkim, Arunachal Pradesh, Assam, Meghalaya, Nagaland, Mizoram, Manipur, Tripura; and Darjeeling Hills of West Bengal	52.03
Myanmar	Chin and Kachin states	17.90
Nepal	Kaligandaki Valley, Koshi Basin, Mechi Basin	16.08
Bhutan	Whole country	7.60
China	ZhongDian, DeQin, GongShan, Weixi, FuGong	6.26

The focus of this study on the EH reflects its position as a globally significant region for ecosystem biodiversity, and the enormity of its services command area in geopolitical, demographic, and socioeconomic terms. A common feature of the Eastern Himalayan region is the complexity of its topography. Orographic features include rapid and systematic changes in climatic parameters (e.g., temperature, precipitation, radiation) and environmental factors (e.g., differences in soil types).

The region lies between China and India, the two countries with the fastest economic growth rates and largest populations in the world; hence, there is a great risk of fragmentation of ecosystems as economic development supersedes environmental concerns. The region has multiple biogeographic origins, being at the intersection of the Indo-Malayan Realm, Palearctic Realm, and the Sino-Japanese Region. It also marks the frontier of the collision between the monsoonal and mountain systems associated with intense thunderstorms and lightning. The region is steeped in metaphors and held in reverence as the 'Water Tower of Asia', with the Himalayas as a whole providing about 8.6 x 10^6 m^3 of water annually to the region and downstream. It is also referred to as the 'Third Pole.' The Himalayas have the largest concentration of glaciers outside the polar caps covering 33,000 km^2 (Dyurgerov and Meier 1997). The EH region also contains numerous 'hotspots' of biodiversity. For all these reasons and more, the EH region warrants protection in order to maintain ecosystem integrity and adaptability (Figure 3).

Figure 3: **The Eastern Himalayan region as defined for the study**



Ecoregions

The abundance of terrestrial ecosystems in the region are grouped into 25 ecoregions, including the category rock, snow, and ice, based on past biogeographical studies (WWF 2004). These ecoregions are nested within two higher-order classifications: biomes (7) and biogeographic realms (2), which together provide a framework for comparison among units and the identification of representative habitats and species assemblages. The eocregions provide crucial habitats for wildlife and the vegetation communities are home to hundreds of endangered plant species.

Flora and fauna

The EH contains some of the largest contiguous blocks of forest habitat in the HKH region with a diverse array of communities and species. The diversity of trees provides the basis for the wide range of forested community types dominated by deciduous as well as evergreen communities of hardwood forests in the tropics and sub-tropics; deciduous/evergreen and broad/needle-leaf forests in the temperate zone; and dominant needle-leaf, meadows, scrub, and conifers in the alpine zone. Extensive stands of riverine evergreen and deciduous forests form unique habitats for rare plants and animals on the Brahmaputra and Koshi floodplains.

Less well known are the Eastern Himalayan broadleaf and conifer forest ecoregions, which blanket the lowlands to the inner valleys of the Himalayas in northern India, Nepal, and Bhutan (CEPF 2007; WWF 2006a). These middle-elevation forests are located between 800 and 4000 m.

Temperatures vary widely throughout the year, and rain follows the monsoon season. The weather is warm and wet from the first hailstorms of April to the last monsoon drizzle sometime in October, and mushrooms grow everywhere. But, from the beginning of autumn, the months may go by with scarcely any rain, although snow can blanket the high altitude areas anytime during the winter. These conditions are ideal for broadleaf evergreen trees at the lower elevations, and for deciduous trees and conifers higher up. At certain elevations, where conditions are neither too cold nor too dry, the trees themselves are draped with all kinds of small plants: orchids, lichens, and ferns. The forests here are vibrant with life and provide homes for a tremendous diversity of plant and animal species.

Among the peaks and valleys of the EH, mammals as varied as the Bengal tiger, snow leopard, sloth bear, rhino, elephant, takin, and red panda make their home in the world's most diverse sub-tropical and temperate forests. The EH is home to a number of extraordinary mammals like the lesser panda, clouded leopard, and rare golden langur, as well as leeches and orb-weaver spiders. Many kinds of birds inhabit these forests – some just passing through and others breeding. They include black-necked cranes, Kashmir flycatchers, striped laughing thrushes, Blyth's tragopans, Himalayan quails, and iridescent fire-tailed sunbirds.

Wetlands and freshwater ecosystems

Wetlands and marshes play a role in nutrient cycling, water storage, provide crucial fish and wildlife habitats, and remove pollutants from water. Several types of wetlands exist in the EH, from ephemeral streambeds to huge lakes fed by either meltwater or precipitation. Wetlands and marshes provide important ecosystem services: they contribute to the flow of mountain streams and river systems, provide habitat for wetland flora and fauna, serve as carbon sinks, regulate floods, and purify water. Many of the wetlands in the region are designated as Ramsar sites and wetlands of significance in recognition of their vital role in maintaining natural processes and providing services.

The importance of freshwater ecosystems to residents of the EH is difficult to quantify, in part because of the deep attachments that many people have to streams, rivers, and reservoirs in their community. Freshwater resources have multiple, sometimes conflicting, values. These include fishing, swimming, boating, water supply, beauty, flood control, navigation and transportation, and hydropower. Freshwater ecosystems support aquatic plants and animals, as well as organisms in wetland and terrestrial ecosystems that depend upon freshwater. Freshwater ecosystems, like forest and wetland ecosystems, are stressed by habitat alteration, pollution, and non-native invasive species. Stream habitat alterations include dams, road crossings, channelisation, and loss of stream bank vegetation. Dams are built to supply water for human uses, to control flooding, and to generate electricity. Dams also alter stream flow, sedimentation, temperature, and dissolved oxygen concentrations, impairing the ability of streams and rivers to support native fauna, especially freshwater fish, aquatic plants, and benthic microorganisms. The largest electricity-producing structures are in mountainous areas and in future dams are likely to occur in greater numbers in Bhutan, Nepal, and Arunachal Pradesh.

Hazards and disaster

The rate of retreat of glaciers and the thawing of permafrost has rapidly increased in recent times. The region has witnessed unprecedented melting of permanent glaciers during the past three decades, with the vast Himalayan glaciers showing the fast rate of retreat, resulting in increases in glacial runoff and glacial lake outburst floods (GLOFs), and an increased frequency of events such as floods, mudflows, and avalanches affecting human settlements. GLOFs have occurred in the EH at various locations in Nepal, India, Bhutan, and China. GLOF events can have widespread impacts on socioeconomic systems, hydrology, and ecosystems. Recent studies suggest that loss of glacier volume, and eventual disappearance of many glaciers, may cause water stress to millions of people in India and China. As glacier mass reduces, the reduced volume of runoff will have serious consequences for downstream hydropower and land use systems including agriculture.

Other key water-related natural disasters include droughts, floods, landslides, wildfires from lightning, thunderstorms, and cloudbursts.

Earthquakes pose another risk in the region and can amplify the potential impacts of climate change and exacerbate vulnerability. Frequent slope failure, mass wasting, and landslides along the Himalayan foothills are evidence of these reinforcing stresses causing ecological damage and economic losses. The Main Himalayan Seismic Belt, a 50 km wide zone between the Main Boundary Thrust and the Main Central Thrust, is seismically the most active in the region. Massive earthquakes (M>8) have occurred along the detachment surface that separates the under-thrusting Indian plate from the Lesser Himalaya (1897 Assam, 1905 Kangra, 1934 Bihar-Nepal, 1950 Assam). The regions between the epicentres of these earthquakes, known as seismic gaps, are potential sites for future big earthquakes.

Drivers of Change, Ecosystem Stresses

Climate change has synergistic effects with many of the biggest existing impacts on biodiversity. Many authors stress that potential climate change impacts on biodiversity will occur in concert with other well-established stressors. A few specific examples evident in the EH are highlighted in Box 2.

Box 2: **Synergistic effects of climate change and other ecosystem stressors in the EH**

1. **Habitat loss and fragmentation:** With temperature rises and reduced precipitation, alpine meadows and shrubs may migrate to places higher up the mountains. However, this process will be constrained by environments that do not have soils of sufficient depth for anchorage and nutrient storage. Wetlands will shrink in response to high evaporation, which is further exacerbated by the expansion of settlements and other human activities.
2. **Invasive species:** The rising temperature of water bodies renders them more suitable habitats for invasive species that outcompete native species and synergistically interact with climate change to threaten native organisms.
3. **Species exploitation:** Synergistic action between commercial harvesting and climate change will have detrimental impacts on subtropical and temperate timber forests.
4. **Environmental contamination:** Nutrient enrichment from agricultural runoff could act synergistically with warming water temperatures due to climate change to enhance eutrophication in freshwater systems.

Impacts can be assessed using the concept of 'proximate cause' (the specific biophysical event that causes the loss of genetic, species, or ecosystem diversity), 'intermediate cause' (the human act that triggers the biophysical event), and 'ultimate cause' (the underlying economic, social, or policy reason motivating the human act). Much of our current attention is focused on proximate and intermediate causes. Proximate causes tend to be amenable to technical solutions; ultimate causes generally require major economic, political, and cultural solutions. The ultimate causes of biodiversity impact are growth-based economics, excessive personal consumption and associated waste, and excessive per capita energy use. However, a great deal of energy is expended in stopgap solutions to address proximate causes, winning a few biodiversity battles, but losing the war.

Ecosystems in the EH are being impaired and destroyed by a wide variety of human activities. The survival of the ecosystems and wildlife in the EH is being threatened by human activities like timber harvesting, intensive grazing by livestock, and agricultural expansion into forestland. The EH has environmental and socioeconomic problems, common to the entire Hindu Kush-Himalayan (HKH) region in sectors such as water, agriculture, and land use; ecosystems and biodiversity; and human wellbeing. The majority of the problems in these sectors are related to management issues and are exacerbated by the associated impacts of climate change.

Rapid and unsustainable economic and population growth in the region is imposing increasing stress on the natural environment. The economic level of a country determines to a large extent its resource requirements, in particular its requirements for energy, industrial commodities, agricultural products, and freshwater. Threats to ecosystems are driven by rapid growth in population, economic production, and social consumption behaviours, and by the failure to appreciate the monetary terms of the services and reflect this in fiscal policies. The consequence of changes taking place in the structure and functioning of ecosystems due to human impacts render them more vulnerable to climate change stresses, as their underlying resiliency and functional integrity have been severely eroded by non-climatic interference. Threats include the alteration of the Earth's carbon, nitrogen, and other biogeochemical cycles through the burning of fossil fuels and the heavy use of nitrogen fertiliser; degradation of farmlands through unsustainable agricultural practices; squandering of freshwater resources; poisoning of land and waterways; and overharvesting of wild food, managed forests, and other theoretically renewable systems. As a result, environmental deterioration in mountains is driven by numerous factors, including deforestation, overgrazing by livestock, and the cultivation of marginal soils leading to soil erosion, landslides, and the rapid loss of habitat and genetic diversity. The obvious outcomes are widespread unemployment, poverty, poor health, and bad sanitation (Price et al. 2000). These problems are amplified by the unequal impacts of ecosystem degradation and the unequal distribution of benefits from ecosystem services. The latter is a paradox in that ecosystem services favour the rich and powerful when pristine, and afflict the poor when degraded.

Rising population levels weigh heavily upon the resources available per capita. Water supply is one of the major challenges, because of the growing demand for water driven by high population, increasing urbanisation, and rapid economic and social development. With the expansion of human settlements and rapid economic growth, water has been increasingly used for the treatment and disposal of waste, exacerbating water shortages and reducing water quality. The replacement of forests and wetlands by urban and agricultural ecosystems generally increases the input of sediment, nutrients, and toxic chemicals into rivers, streams, lakes, and estuaries. Drainage (for agricultural and urban purposes) is the main threat to freshwater wetlands, besides pollution and non-native invasive species. While non-native invasive species can force out more beneficial native marsh plants, high levels of chemical pollutants can accumulate in wetlands as pollutant carrying sediments are trapped in wetland vegetation.

The EH suffers from both water overabundance and extreme water shortages and acute moisture stress during the dry months, which adversely affect the ecology and agricultural production. A change in the onset, continuity, and withdrawal patterns of the southwest monsoon in recent years has also led to considerable spatial and temporal variations in rainwater availability. At least half of the severe failures of the Indian summer monsoon since 1871 have occurred during El Niño years (Webster et al. 1998).

Forest ecosystems are stressed by habitat change and fragmentation, which occurs as humans subdivide forest plots into ever smaller and more isolated sections. Fragmentation can result in reduced genetic diversity within populations, loss of species, and increases in undesirable, non-native, and weedy species. Large continuous forest patches still exist in the region's subtropical and warm temperate broadleaf areas, but forests in the region's tropical belts and floodplains are now heavily fragmented. Forests are also threatened by the invasion of non-native species. Pollution can also stress forest trees, especially in urban, industrial, and heavily populated areas. Non-native fungal diseases and insect pests can severely stress forests and cause the effective extinction of previously dominant trees and threaten others. The most irreversible of human impacts on ecosystems will most likely be the loss of native biodiversity.

Stream flows are moderated in vegetated watersheds because rain is absorbed into the ground and slowly released into streams. Stream channelisation and wetland loss increase the EH's vulnerability to precipitation changes. An increase in the frequency or intensity of storms could exacerbate existing problems. In heavily paved urban areas, increases in peak flows during storms scour stream banks, which decreases reproductive success, while reduced stream flow during dry periods reduces available habitats for fish and aquatic insects. According to the IPCC (2007a,b,d) increases in hydrological variability (such as greater floods and longer droughts) could result in increased sediment loading and erosion, degraded hillsides and watersheds, reduced water quality, and reduced stability of aquatic ecosystems, with the greatest impacts occurring in urban areas with a high percentage of impervious surface area. Sediments reduce water clarity, smother bottom organisms, and clog waterways; excessive nutrient input causes eutrophication; and toxic chemicals affect plants and animals. These changes may reduce productivity and biodiversity in streams and rivers (IPCC 1998).

Increased temperature is the most-often cited primary climate change driver. While this highlights the key role of temperature and heat accumulation in ecological systems, it also reflects the reality that future climate change predictions related to temperature are the most certain, followed by those for precipitation and other climate variables (e.g., wind patterns, relative humidity, solar radiation, cloud conditions). There is less certainty regarding derived variables (e.g., soil moisture, potential evapotranspiration), if such projections are available at all.

Changes in long-term climate patterns and climatic variability are likely to have significant effects on natural ecosystems, and a particularly large impact on the already-stressed ecosystems of the eastern Himalayas. For example, the traits of successful invasive species tend to increase their resilience to a variety of disturbances, including climate and non-climate stresses, and climate change could work in concert with other stresses to further reduce populations of rare and endemic species, while increasing populations of already abundant, widespread species. Table 2 describes how climate variability and change might impact on ecosystems already weakened by other stresses.

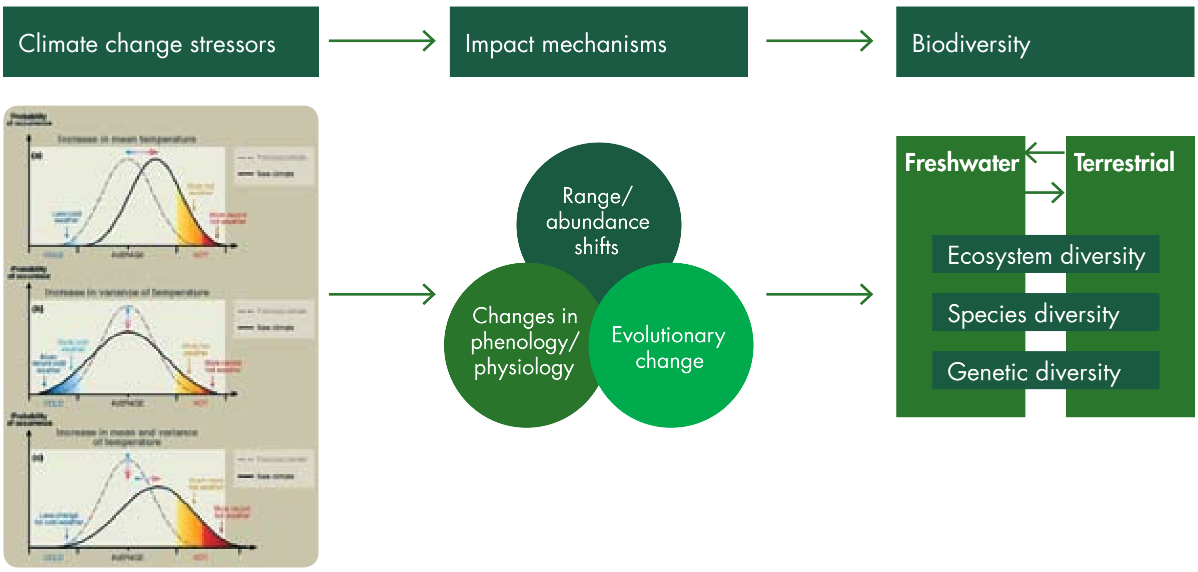
Analytical Framework

Climate change is one of many possible stressors on biodiversity. Climate change may manifest itself as a shift in mean conditions or as changes in the variance and frequency of extremes of climatic variables. These changes can impact on biodiversity either directly or indirectly through many different impact mechanisms. Range and abundance shifts, changes in phenology, physiology, and behaviour, and evolutionary change are the most often cited species-level responses. At the ecosystem level, changes in structure, function, patterns of disturbance, and the increased dominance of invasive species is a noted concern. Having a clear understanding of the exact impact mechanisms is crucial for evaluating potential management actions.

Table 2: **The potential for adverse ecosystem impacts when changes in climate and climate variability interact with existing stresses**

Ecosystem	Existing stress	Interaction with climatic changes
Multiple ecosystems	Non-native invasive species Air pollution	• Climatic changes will probably tend to favour invasive species over rare and threatened species. • Adverse interactions with climatic changes
Forests	Fragmentation	• Fragmentation may hinder the migration of some species, and the loss of genetic diversity within fragments will reduce the potential for populations to respond to changing conditions through adaptive evolution.
Wetlands	Habitat loss	• Habitat loss reduces the resilience of wetlands to the negative effects of storms, because wetlands play a role in moderating destructively high stream flows and pollution runoff.
Freshwater systems	Habitat degradation: stream channelisation, altered stream flows in urban areas Pollution: nutrients, sediments, toxic substances	• Straightening of stream channels reduces resilience to destructively high flows. • Increases in the frequency or intensity of storms could exacerbate this problem. • Increased precipitation could increase pollution runoff.

Figure 4: **Conceptual framework for the assessment of climate change impacts on biodiversity**



In this synthesis, the assessment of biodiversity impacts is structured using an Ecosystems/Species X Terrestrial/ Freshwater framework, i.e., assessing biodiversity impacts at ecosystem and species levels within functional terrestrial and freshwater systems. In short, this involves making specific linkages along the continuum from climate change stressors to impact mechanisms and biodiversity management endpoints. Figure 4 presents an overview of the analytical framework of climate change impacts on biodiversity that shape the structure of this synthesis.

Limiting factors

One of the key difficulties in any attempt to understand climate change in the EH is to account for the modifying effect of the high Himalayan range on weather and climate, the complexity of the physiographic environment, and the natural variations and cycles of the large-scale monsoonal circulation. Despite these climate change assessment challenges and major uncertainties, certain conclusions are emerging. Of particular relevance to the EH is the conclusion that climate change effects in the region are expected to occur faster and be more pronounced than the global average (IPCC 2007a,d).

2 Climate Trends and Projections

Introduction

Due to the complexity of the topography and the orographic features, it is more difficult to understand climatic characteristics in the mountains than in the plains. Existing knowledge of the climatic characteristics of the EH is limited by both paucity of observations and the limited theoretical attention paid to the complex interaction of spatial scales in weather and climate phenomena in mountains. In order to determine the degree and rate of climatic trends, there is a need for long-term data sets, which are currently lacking for most of the EH. Research has tended to focus on the influence of barriers on air flow and on orographic effects on weather systems, rather than on conditions within the mountain environment. As much as climate shapes the mountain environment and determines its constituent characteristics, so do the mountains in turn influence the climate and related environmental features through altitude, continentality, latitude, and topography, each of which affects several important climate variables. The roles of these factors are summarised schematically in Table 3. The mountain ecosystems not only significantly influence atmospheric circulation, they also exhibit a great deal of variation in local climatic patterns. These climatic differences are expressed in vegetation type and cover, and geomorphic and hydrological features.

The Fourth Assessment Report (AR4) of the IPCC concludes that changes in the atmosphere, the oceans, and glaciers and ice caps show unequivocally that the world is warming. It further concludes that major advances in climate modelling and the collection and analysis of data now give scientists "very high confidence" (higher than what could be achieved in the Third Assessment Report) in their understanding of how human activities are contributing to global warming. This was the strongest conclusion to date, making it virtually impossible to blame natural forces for global warming. The average temperature increase across the globe during the 20th Century has been around 0.74°C. These changes have been accompanied by changes in precipitation, including an increase in precipitation at higher latitudes and a decline at lower latitudes, and an increase in the frequency and intensity of extreme precipitation events. Floods and droughts have also been observed to be increasing in frequency and intensity, and this trend is likely to continue.

Projections of temperature increases in the 21st Century have been made on the basis of established and plausible scenarios of the future. A warming of about 0.2°C is projected for each of the next two decades and the best estimate of temperature increase by the end of the 21st Century is placed at 1.8°C to 4°C. These projections are based on the assumption that no specific action is taken to mitigate GHG emissions. Hot extremes, heat waves, and heavy precipitation events will become more frequent, future tropical cyclones (typhoons and hurricanes) are likely to become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases in tropical sea-surface temperatures. Increases in the amount of precipitation are very likely at high-latitudes, while decreases are likely in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100) (IPCC 2007a).

Table 3: **Climatic effects of mountain factors**

Factors	Primary effects	Secondary effects
Altitude	Reduced air density, vapour pressure; increased solar radiation receipts; lower temperatures	Increased wind velocity (mid-latitude); increased precipitation (mid-latitude); reduced evaporation; physiological stress
Continentality	Increased annual/diurnal temperature range; modified cloud/ precipitation regimes	Snowline altitude rises
Latitude	Seasonal variation in day length and solar radiation totals	Snowfall proportion increases; annual temperatures decrease
Topography	Spatial contrasts in solar radiation/ temperature regimes and precipitation as a result of slope and aspect	Diurnal wind regimes; snow cover related to topography

A growing number of studies on past climate and model-based projections have been reported in recent times at different spatio-temporal scales, some of which cover the EH in part or as a whole. There are several constraints and issues that need to be resolved at the policy, institutional, and field levels to improve the observational and prediction basis for accurate and conclusive statements on climate variability and change. There is a need to probe deeper into the dynamics of mountain climate systems in search of signs of climate change. There has been limited coordination in such efforts across the EH region, and the different countries in the region have interpreted the existing observational and prediction results within their respective political boundaries only, despite the fact that climate systems are large-scale processes.

For this vulnerability assessment, it was necessary to reflect on climate trends and projections determined at the country level from a large compilation of national reports. In this synthesis, climate variability refers to day-to-day, year-to-year, and decade-to-decade patterns of weather and climate; climate change refers to longer trends, usually measured by temperature and precipitation. Historical climatic conditions provide the context for potential future changes.

Past information was consolidated and the latest updates incorporated, and a synthesis review made with a reassessment of climate trends and change projections to the end of this century . The findings confirm earlier studies that temperatures will continue to rise and rainfall patterns will be more variable, with both localised increases and decreases. The figures for the EH are not a drastic deviation from the IPCC outcomes for the South Asian region. Nonetheless, they reinforce the scientific basis for the contention that the EH is undergoing a warming trend.

Trends

Few studies provide an exclusive and comprehensive analysis of the EH. There is a need for a concerted effort to formally document the magnitude and direction of climate trends that have taken place. Dash et al. (2007) observed that during the last century the maximum temperature increased over North East India by 1°C during winter and 1.1°C during the post-monsoon months. There have been small increases in rainfall during winter, pre- and post-monsoon seasons. They also noted a decreasing trend in high-intensity depressions and cyclonic storms, but increases in the number of low pressure areas during the monsoon. Conversely, another study reported a slightly negative trend of -0.008 to -0.06°C in the annual mean temperature in North East India from 1960 to 1990 (APN 2003).

There have been investigations into climate trends and characteristics in the Himalayan regions of southwest and northwest China using time series data of varying lengths (Yunling and Yiping 2005; Yin 2006). In the southwest region covering the counties of Deqin and Weixi of the Hengduan mountain range, over the observation period of 41 years, the mean annual air temperature increased at the rate of 0.01°C/yr to 0.04°C/yr. The changes in precipitation, however, are very different and complex. At some locations, mean annual precipitation decreased by 2.9 to 5.3 mm/yr, and at others by 5.8 to 7.4 mm/yr. Trends in air temperature were more significant in the dry season than in the rainy season, with precipitation showing the opposite behaviour. Climate trends differed from climate element to climate element, region to region, and season to season.

Significant warming has been observed on the Tibetan Plateau (Liu and Chen 2000), with warming more pronounced at higher altitude stations, than lower ones. The unexpected observed decreases in potential evapotranspiration (PET) in Tibet AR has been linked to reduced wind speed under the decreasing strength of the Asian monsoon (Chen et al. 2006).

An increasing rate of warming with elevation was also observed in a similar study encompassing the whole physiographic region of Nepal using climatological data from 1977 to 2000 (updated from Shrestha et al. 1999). The altitudinal dependency was less clear during the post-monsoon period, with the middle mountain region recording the highest positive trend (Table 4). The results suggest that the seasonal temperature variability is increasing and the altitudinal lapse rate of temperature is decreasing. Unlike temperature, precipitation does not show any consistent spatial trends. Annual precipitation changes are quite variable, decreasing at one site and increasing at a site nearby.

In Bhutan, the analysis of available observations on surface air temperatures has shown a warming trend of about 0.5°C from 1985 to 2002, mainly during the non-monsoon seasons. Temperatures in the summer monsoon season do not show a significant trend in any major part of the country. Rainfall fluctuations are largely random with no systematic change detectable on either an annual or monthly scale (Tse-ring 2003).

Table 4: **Regional mean temperature trends in Nepal 1977–2000 (°C/year)**

	Seasonal				Annual
Regions	**Winter**	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Jan-Dec**
	Dec-Feb	**Mar-May**	**Jun-Sep**	**Oct-Nov**	
Trans-Himalaya	0.12	0.01	0.11	0.10	0.09
Himalaya	0.09	0.05	0.06	0.08	0.06
Middle Mountains	0.06	0.05	0.06	0.09	0.08
Siwalik	0.02	0.01	0.02	0.08	0.04
Terai	0.01	0.00	0.01	0.07	0.04

Source: updated from Shrestha et al. (1999) and Xu et al. (2007)

Table 5: **Changes in primary climate change drivers and climate system responses in the Eastern Himalayas from 1977-2000**

Climate change drivers	**Biophysical responses to climate change**
• Average annual temperature increased by 0.01°C in the foothills, 0.02°C in the middle mountains, and 0.04°C in the higher Himalayas • Night-time temperatures increased across most of the EH in spring and summer • Annual precipitation changes are quite variable, decreasing at one site and increasing at a site nearby	• Duration of snow cover reduced and snow disappears earlier • Less snowfall • Flow in river basins reduced/increased • Glacier retreat 20-30 m/year • Net primary production (NPP) increased • Wetlands contract • Early spring and late autumn flowering

The technical papers written for this assessment capture much of the detail on how the climate of the EH changed during the 20th Century using a set of indicators including primary climate change drivers (e.g., temperature, precipitation), climate system responses (e.g., receding glaciers, hydrological systems, water-related hazards), and ecosystem responses (e.g., ecotone shifts, phenological changes, ecosystem structure, function, type and distribution, decoupled trophic levels). Some of the changes detected in the primary climate change drivers and climate system responses are summarised in Table 5.

Examination of observational records from different sites distributed across the region, and an analysis of the Climate Research Unit, University of East Anglia, United Kingdom, dataset on global historical time series (Mitchell et al. 2004) show that the global climate has already changed significantly. In the EH, the annual mean temperature is increasing at a rate of 0.01°C/yr (0.01-0.04°C yr-1) or higher. The warming trend has been greatest during the post-monsoon season and at higher elevations. Increases in temperature during the period (1977-2000) have been spatially variable indicating the biophysical influence of the land surface on the surrounding atmospheric conditions. In general, there is a diagonal zone with a south-west to north-east trend of relatively less or no annual and seasonal warming. This zone encompasses the Yunnan province of China, part of the Kachin State of Myanmar, and the North Eastern states of India. Eastern Nepal and eastern Tibet record relatively higher warming trends. Warming in the winter (DJF) is much higher and more widespread. In addition, a significant positive trend with altitude has been observed throughout the region. High altitude areas have been exposed to comparatively greater warming effects than those in the lowlands and adjacent plains.

The temperature trends in the three elevation zones are given in Table 6. The analysis suggests the following major points:

1. The Eastern Himalayan region is experiencing widespread warming. The warming is generally higher than 0.01°C/yr.

Table 6: **Temperature trends by elevation zone for the period 1977–2000 (°C/year)**

Elevation zone	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
Level 1: (<1000 m)	0.01	0.03	0.00	- 0.01	0.02
Level 2: (1000-4000 m)	0.02	0.03	0.02	- 0.01	0.02
Level 3: (> 4000 m)	0.04	0.06	0.04	0.02	0.03

Source: Shrestha and Devkota (2010)

2. The highest rates of warming are occurring in winter (DJF) and lowest or even cooling trends are observed in summer (JJA).
3. There is progressively more warming with elevation, with the areas >4000 m experiencing the highest warming rates.

The results from the stakeholder workshops and the questionnaire survey on people's perceptions of climate change in the region are presented in the technical report on biodiversity (Chettri et al 2010). Some of the perceived changes in primary climate change drivers and climate system responses are summarised in Table 7.

Projections

A considerable amount of work has been done to predict future climates by downscaling General Circulation Model (GCM) outputs using statistical or dynamic methods. In most cases, the results are not comparable due to differences in the choice of GCMs, spatial and temporal resolutions, emission scenarios associated with diverse socioeconomic assumptions, and the formats in which the results are published, although all of them describe plausible models of future climate meaningful to the research context. For this assessment, climate scenarios were reconstructed specifically for the EH domain using data generated by recent model runs at regional and global levels. The climate scenarios developed are summarised first to put the remaining results into perspective.

Regional projections

The current spatial resolution of general circulation models (GCMs) is generally too crude to adequately represent the orographic detail of most mountain regions and inadequate for assessing future projections in the regional climate. Since the mid-1990s, the scaling problem related to complex orography has been addressed through regional modelling techniques, pioneered by Giorgi and Mearns (1991), and through statistical-dynamic downscaling techniques (e.g., Zorita and von Storch 1999). The following discussion of potential ecological responses to changes in climate and climate variability primarily uses the Indian Institute of Tropical Meteorology (IITM) regional climate scenarios, which are based on a transient HadCM3 model downscaled using HadRM2 and PRECIS (Providing Regional Climates for Impacts Studies; Hadley Centre) regional climate models (RCMs) run under two future GHG emission scenarios (A2 and B2 of the SRES [Special Report on Emissions Scenarios]). This approach, which applies general methods in accordance with the IPCC Data Distribution Center guidelines on the use of scenario data for impacts and adaptation assessments (IPCC-TGCIA 1999), allows us to identify both potential trends and the range of uncertainty around them. The discussion is rather general and presumes no major surprises due to uncertainties regarding the rate, magnitude, spatial distribution, and seasonality of temperature and precipitation changes.

In order to accommodate some level of sensitivity analysis, the RCM simulation runs were supplemented with data from the IPCC's SRES runs performed with three Coupled General Circulation Models (GCMs), the HadCM3, CGCM2, and CSIRO Mk2, interpolated to higher temporal and spatial resolution for the development of WorldClim (www.worldclim.org) (Hijmans et al. 2005). The GCM results are given as 30-year monthly mean changes (i.e., no information is presented about changes in inter-annual or inter-daily variability). All data is extracted as change values, expressed either in absolute or percentage terms using the 1961 to 1990 model-simulated baseline period. Results are, therefore, generally reported as the change between the 1961 to 1990 30-year mean period, and the future 30-year mean periods (2020s, 2050s or 2080s). These time periods represent 30-year mean fields centred on the decade used to name the time period, e.g., the 2020s represent the 30-year mean period 2010–2039, the 2050s represent 2040–2069 and the 2080s represent 2070–2099. For all the models, the response to the middle forcing emission scenarios A2 and B2 was referred to, and future climate change was presented for two 30-year time slices centred on the 2020s and 2050s for WorldClim using HadCM3, and 2050s and 2080s for HadRM2 and PRECIS, each relative to the baseline period 1961–1990. Among the three models, the HadCM3 provided the closest match to observed data.

Table 7: **Perceived changes in primary climate change drivers and climate system responses in the Eastern Himalayas**

Climate change drivers	Biophysical responses to climate change
• Temperatures have been rising across the entire region, with winter and spring temperatures rising more rapidly than those in summer • The daily temperature range has gone down • Total annual precipitation has increased in some areas and decreased in others	• Longer growing season • Reduced snowfall in frequency and amount • Tree line moving to higher elevation • Ice fields contracting • Biomass increase in wetlands

Table 8: **Summary of plausible future climates considered for the assessment of the Eastern Himalayas in terms of character, magnitude and rate**

Time slice	Exposure	Climate model/SRES scenario			
		HadCM3/A2	HadCM3/B2	CGCM2/A2	CSIROMk2/A2
2020s	Δ T (°C)	0.99	0.80	0.49	1.11
	Δ P (%)	5.43	4.55	47.05	12.40
2050s	Δ T (°C)	2.22	2.06	1.43	1.90
	Δ P (%)	14.07	6.23	60.80	18.96
2080s[a]	Δ T (°C)	4.3	2.9		
	Δ P (%)	34	13		

[a] Values from PRECIS RCM runs; Δ T = mean annual temperature change; Δ P = mean annual precipitation change

Table 9: **Climate change projections for the Eastern Himalayas based on RCM outputs**

Temperature change (°C)	HadRM2	PRECIS (B2)	PRECIS (A2)	Precipitation change (%)	HadRM2	PRECIS (B2)	PRECIS (A2)
Winter (DJF)	3.2	3.6	5.3	**Winter (DJF)**	57	23	35
Spring (MAM)	2.0	2.6	3.8	**Pre-monsoon (MAM)**	46	8	46
Summer (JJA)	3.0	2.8	3.8	**Monsoon (JJA)**	7	17	28
Autumn (SON)	3.2	2.5	4.3	**Post-monsoon (ON)**	15	12	18
Annual	2.9	2.9	4.3	**Annual**	18	13	34

Notes: HadRM2 is used for 2050s for 2xCO_2 and PRECIS for 2080s for A2 and B2 SRES scenarios.
Source: Shrestha and Devkota (2010)

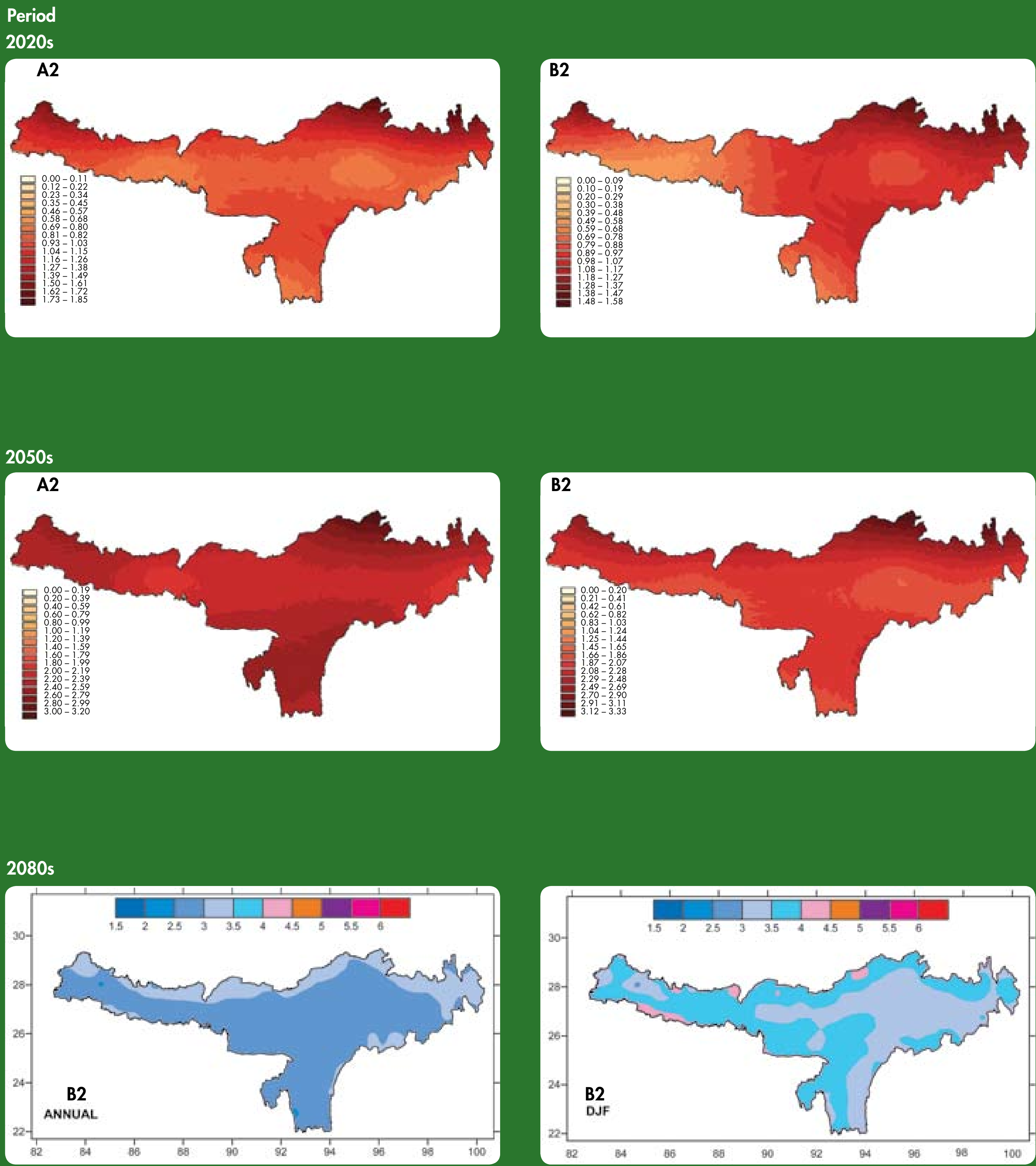
Figures 5 and 6 show maps of the spatial variation of mean annual temperature change and mean annual precipitation change, respectively, for each scenario at each future time period based on the interpolated HadCM3 (2020s and 2050s) and PRECIS (2080s) simulation runs. By the 2080s, the mean annual temperature change for all of the EH is shown to be in the range of +2.9 to +4.3°C and the mean annual precipitation change in the range of 13 to 34%. The PRECIS simulation indicated a slightly higher warming in winter than in summer . Changes in monsoon precipitation showed enormous spatial variability predicted to range anywhere between minus 20% to plus 50% of the baseline period.

The mean projected annual temperature and precipitation changes under three GCMs plus PRECIS, three time-slices, and two SRE scenarios are summarised in Table 8, to present a wider range of future climate scenarios. The differences across the scenario results reinforces the need to explicitly recognise and account for the uncertainties that exist in projections of future climate. That said, the results are generally consistent with those reported by the IPCC for the northern hemisphere (IPCC 2001a) although the magnitude of climate change is predicted to be greater for the EH than that projected by the IPCC for the Asia region both for the mid and for the end of the century. Future winters are likely to experience larger temperature increases above the current level. Such increases will be greater under the SRES A2 emission trajectory, which describes the region as geared towards economic development with a regional orientation in strategic approaches. Precipitation changes will be greater in winter and spring, while the monsoon season is not expected to experience significant changes in mean conditions. There are important seasonal differences and trends that are not generally reflected in these annual maps. The seasonally differentiated values are summarised in Table 9. Any specific impact assessment that is sensitive to seasonal climate trends would need to generate maps and data specific to the season of interest.

Temperature scenarios vary across space and over time, but show a clear trend towards warming with average projected increases from 0.80 to 0.99°C (2020s) to 2.06 to 2.22°C (2050s) across the A2 and B2 scenarios calculated with HadCM3, and from 0.49 to 1.11°C (2020s), and 1.43 to 1.90°C (2050s) for A2 across GCMs, with the greatest increase in the high altitude area. All the GCMs indicated a higher rate of warming at higher elevations.

The spatial variation of changes in precipitation was considerable with enormous contradictions between the models in the pattern of changes. HadCM3 projected a decrease in precipitation along the northeastern

Figure 5: **Spatial variation of mean annual temperature changes (°C) over the EH**

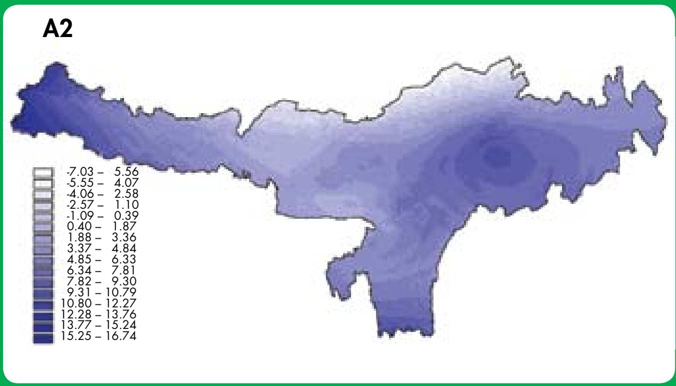


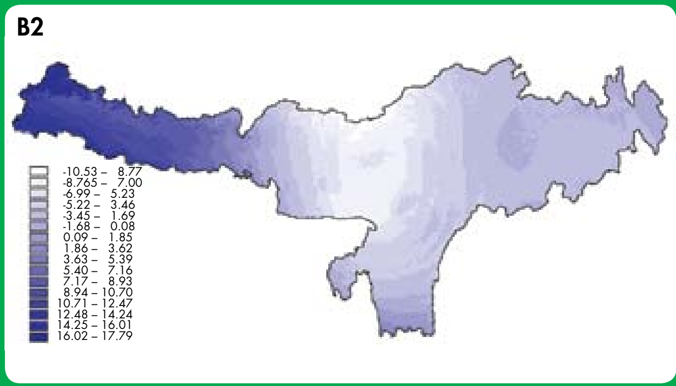
Notes: A2 and B2 scenarios are simulated by HadCM3 (2020 and 2050) and PRECIS (2080).
Changes are relative to the 1961–1990 model-simulated baseline period.
Maps in the 2080s row show mean annual and winter temperature changes under the B2 scenario.

Figure 6: **Spatial variation of mean annual precipitation changes (%) over the EH**

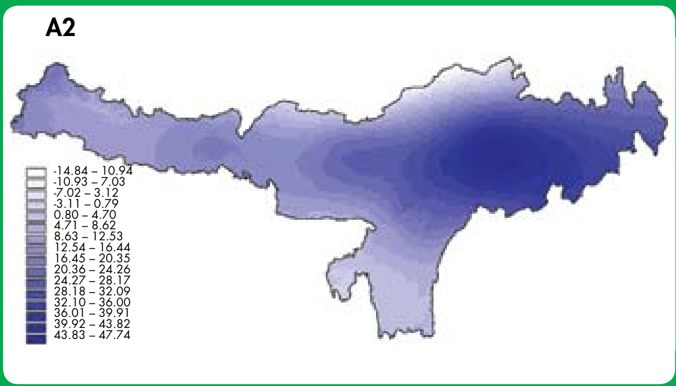
Period

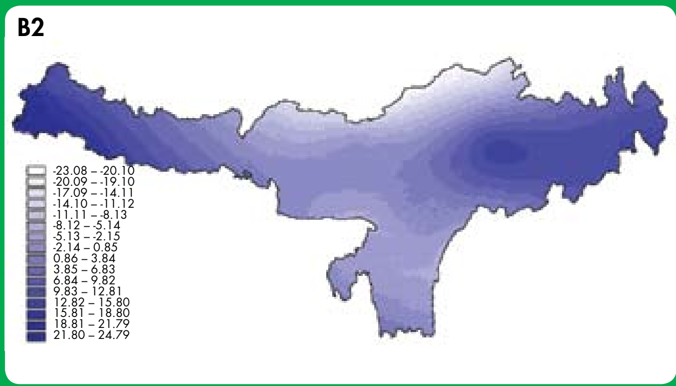
2020s



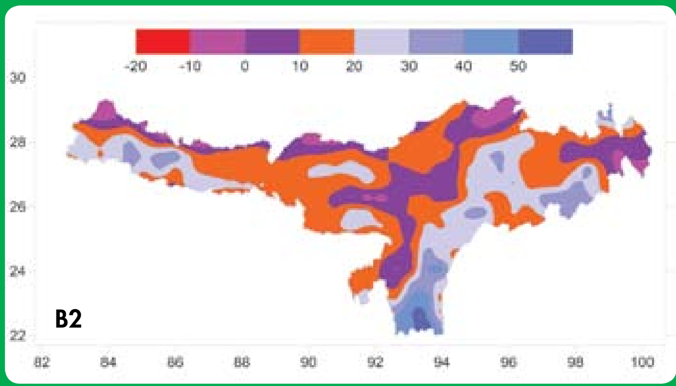


2050s





2080s



Notes: A2 and B2 scenarios are simulated by HadCM3 (2020 and 2050) and PRECIS (2080).
Changes are relative to the 1961-1990 model-simulated baseline period.
Maps in the 2080s row are for monsoon season (JJA).

fringes of the region, while the CSIRO-Mk2 projected a decrease along the southeastern fringes of the region. The lack of spatial concurrence in the model simulations of the magnitude and direction of precipitation changes confirms the inadequacy of GCMs in capturing the mountain influence on the weather and climate of the region, as described by temperature and precipitation characteristics. A slight, sub-regional trend is discernible with decreasing precipitation towards the east and increasing precipitation over much of the western part of the region. Variation in the spatial pattern and magnitude of projected changes is considerable between models for the same A2 SRES scenario, but the relative spatial pattern projected by HadCM3 remains the same for different emission scenarios (A2 and B2), varying only in the size of the anomaly.

The climate models suggest the following:

1. The rate of future winter warming to the 2080s is projected to vary from 3.6 to 5.3°C, while the summer temperature increase is projected to vary from 2.8 to 3.8°C.
2. Winter precipitation averaged across the EH is likely to increase by 23 to 35%, and summer (monsoon) precipitation by 17 to 28%; at the local level some places may experience negative anomalies.
3. In contrast to the small increase in summer rainfall, a much higher increase is expected in evapotranspiration depending on the ecosystem. In general, the modelled scenarios project dry and hot summers and milder winters with generally enhanced precipitation.

Projections of climate change and its impacts beyond about 2050 are strongly scenario- and model-dependent. Options for considering other transient periods and a full range of SRES development pathways are constrained by the availability of usable outputs from other GCMs and limited runs of the RCMs. Although the results do not account for the range of uncertainties, the probability of these scenarios is normally higher, being closer to the central measures in an empirical sense. The RCM results are only as good as the driving GCM within which they are nested (HadCM3 in this case). Even the RCM resolution is too crude to adequately represent the orographic detail of the EH. Further, it is also extremely difficult to model the monsoon with the current limitations in model representation of the underlying physics and the computing power currently available.

Nonetheless, the scientific evidence is unequivocal on the emergence of climate change as an important stress in the EH over the span of this century, despite considerable uncertainty about precise mechanisms and impacts, especially in precipitation.

Climatic variables projected to change in the EH include: carbon dioxide concentrations (increases are certain), temperature (increases are highly likely, but the distribution across space and time is uncertain), precipitation (projections are uncertain, increased frequency and intensity of severe storms and overall increases in precipitation are possible), and fires (predictions remain uncertain) (IPCC 2007a,c). It is increasingly unlikely that greenhouse gas emissions will be reduced quickly enough to fully prevent significant warming.

Country projections

In the assessment of future climates over India (Table 10), there is a broad consensus that both minimum and maximum temperatures will increase by 2 to 4°C leading to a mean surface temperature rise of 3.5 to 5°C by the end of the century. Mean annual precipitation may increase by 7 to 20%. Substantial spatial differences in precipitation changes are also expected (Aggarwal and Lal 2001). A 10 to 15% increase in monsoon precipitation in many regions, a simultaneous decline in precipitation of 5 to 25% in semi-arid and drought-prone central India, and a sharp decline in winter rainfall in northern India is also projected (Ramesh and Yadava 2005). A decrease in the number of rainy days (by 5-15 days on average) is expected over much of India, along with an increase in heavy rainfall days and in the frequency of heavy rainfall events in the monsoon season (Rupa Kumar et al. 2006).

Future climates based on eight Coupled Atmosphere-Ocean GCMs (AOGCMs) over west China project a clear warming in the 21st Century, showing an increase in temperature anomalies for SRES (Special Report on Emissions Scenarios) by 1.0 to 2.5°C by about 2050. A higher rate of warming is indicated than the mean warming for the whole country. The annual mean temperature change around 2050 relative to 1961 to 1990 is expected to be 3.5 to 6.5°C for scenario A2 and 2.5 to 4.5°C for scenario B2. Precipitation over most parts of the region is likely to increase by about 5 to 30% for A2 and 5 to 25% for B2 by about 2050, relative to 1961 to 1990. A future decrease is expected in the diurnal temperature range due to relatively larger increases in minimum temperature than in maximum temperature (Yunling and Yiping 2005).

The values averaged over the whole area of GCM ensemble experiments for Nepal indicate an increase

Table 10: **Climate change projections for India based on an ensemble of four GCM outputs**

Year	Temperature change (°C)			Precipitation change (%)			Sea level rise (cm)
	Annual	Winter	Monsoon	Annual	Winter	Monsoon	
2020s	1.36±0.19	1.61±0.16	1.13±0.43	2.9±3.7	2.7±17.7	2.9±3.7	4 to 8
2050s	2.69±0.41	3.25±0.36	2.19±0.88	6.7±8.9	-2.9±26.3	6.7±8.9	15 to 38
2080s	3.84±0.76	4.52±0.49	3.19±1.42	11.0±12.3	5.3±34.4	11.0±12.3	46 to 59

Source: Aggarwal and Lal 2001

Table 11: **Climate change projections for Nepal for A2 scenario based on 13-GCM ensemble**

Year	Temperature change (°C)			Precipitation change (%)		
	Annual	Winter	Monsoon	Annual	Winter	Monsoon
2020s	1.24 ± 0.20	1.49 ± 0.11	1.05 ± 0.11	-3.60 ± 3.08	-11.74 ± 2.69	-0.76 ± 4.07
2050s	2.47 ± 0.33	2.89 ± 0.14	2.09 ± 0.18	1.81 ± 4.76	-10.93 ± 3.63	5.88 ± 6.67
2080s	4.29 ± 0.47	4.96 ± 0.19	3.67 ± 0.24	6.22 ± 6.56	-17.58 ± 2.53	14.98 ± 9.74

Note: Errors are standard deviations worked out on the basis of spread of the ensemble member values around the mean value.
Source: APN 2005

Table 12: **Climate change projections* for Bhutan under SRE scenarios**

Scenarios		Temperature change (°C)				Rainfall change (mm)			
		A1	A2	B1	B2	A1	A2	B1	B2
2020s	Annual	1.197	1.107	1.039	1.103	61.339	57.559	26.660	28.918
2030s	Annual	1.859	1.785	1.461	1.672	98.908	80.951	40.393	44.924
2040s	Annual	2.642	2.597	2.000	2.448	143.857	110.812	59.153	63.849
2050s	Annual	3.412	3.321	2.561	3.157	183.986	141.903	76.290	82.443

* Based on PRECIS RCM experiments; country level area-averages
Source: Tse-ring (2003)

in annual temperature overall, as well as for summer/monsoon (JJAS) and winter (DJFM) for all three time horizons across the scenarios evaluated.

The increase in temperature is projected to be higher in the north than in the central or southern parts of the country. A relatively larger temperature increase in winter than in summer is predicted over this century (Table 11). Precipitation is expected to increase in summer and decrease in winter, while on an annual basis it will show no significant change. The projected increase in temperature for the EH is slightly higher than the projected average increase over the South Asian region, but precipitation change is consistent with projected regional changes. The central part of the country will have the lowest temperature increase. Precipitation changes will be higher in the eastern and southern parts of Nepal, than in the northern parts (APN 2005).

The projections for Bhutan (Table 12) indicate that surface air temperature will increase with the greatest change in the west, gradually decreasing towards the east. The projected surface warming will be more pronounced during the pre-monsoon than during the summer monsoon season. Climate change maps show that the spatial pattern of temperature change has a large seasonal dependency. The temperature increase will be higher in the inner valleys than in the northern and southern parts of the country. The model predicts peak warming of about 3.5°C by the 2050s in Bhutan. This pattern of change is consistent for all months and all time slices.

In general, Bhutan is expected to experience a significant overall increase in precipitation, but with an appreciable change in the spatial pattern of winter and summer monsoon precipitation, including a 20 to 30% decrease in winter precipitation, over the north-east and south-west parts of Bhutan for the 2050s.

3 Sensitivity of Mountain Ecosystems to Climate Change

Introduction

This section deals with the sensitivity of mountain hydrology and water resources, biodiversity, wetlands, and ultimately human wellbeing, in the Eastern Himalayas, to climate change. Issues and concerns related to some ecosystem connected disasters, such as floods, droughts, and GLOFs, are also discussed briefly.

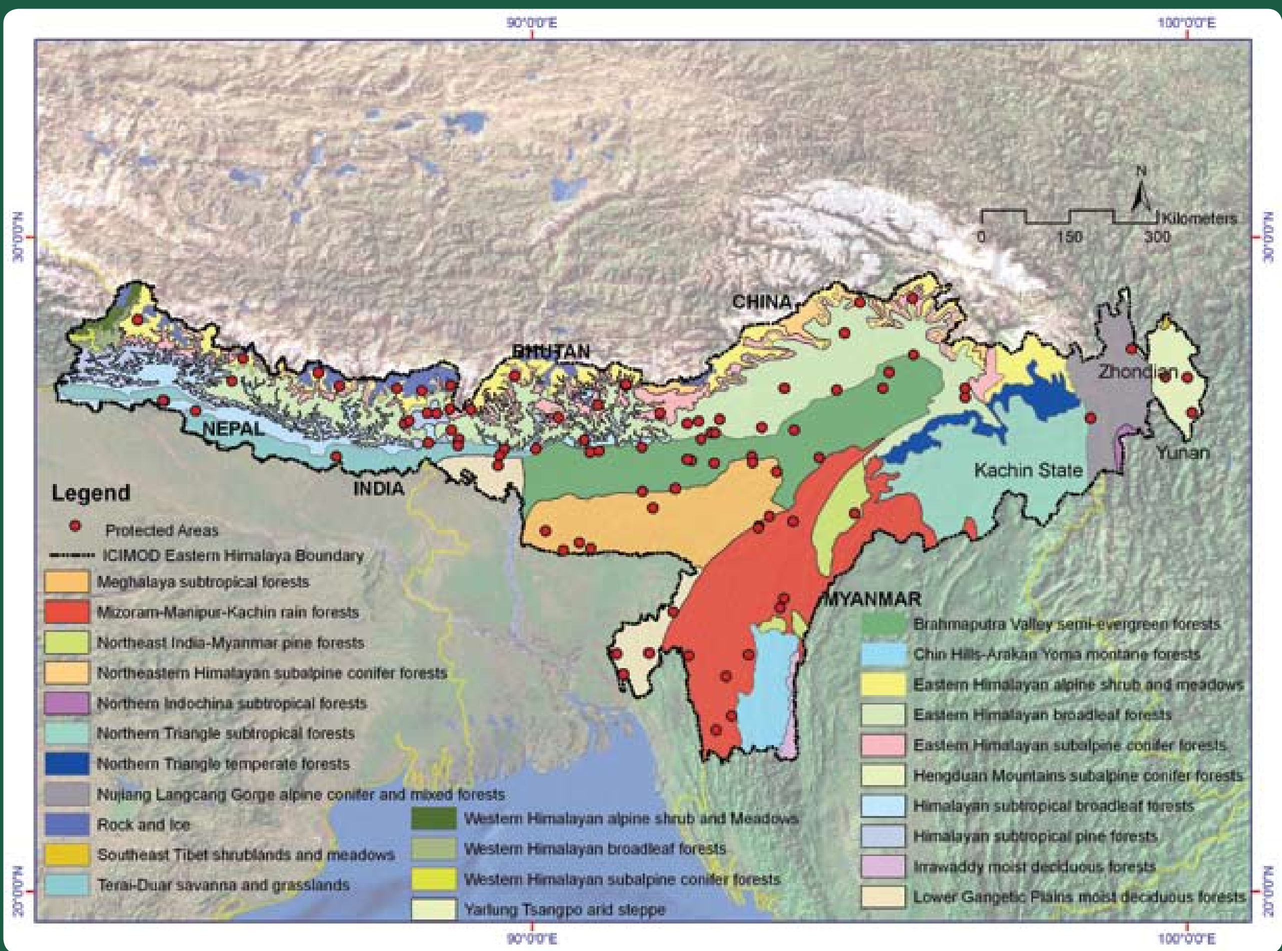
Sensitivity of Biodiversity

Range of biodiversity

The EH region intersects three global biodiversity hotspots; it contains 38.9% of the Himalayan hotspot, 7.7% of the Indo-Burma hotspot, and 12.6% of the Mountains of Southwest China hotspot. WWF (2004) has identified 25 ecoregions within the EH boundary; 12 in the Himalayan, 8 in the Indo-Burma, and 5 in the Mountains of Southwest China hotspot (Chettri et al. 2010). At present, there are 17 protected area complexes, 41 candidate priority areas of high biodiversity importance, 175 key biodiversity areas, and 5 landscape complexes (Terai Arc Landscape, Bhutan Biological Conservation Complex, Kangchenjunga-Singhalila Complex, Kaziranga-Karbi Anlong Landscape, and North Bank Landscape), which are of high conservation significance (CEPF 2005) (Figure 7).

The EH, has diverse climatic conditions and complex topography, and thus contains different types of forests

Figure 7: **Ecoregions and protected areas in the EH**



and vegetation. The vegetation types can be broadly categorised into: tropical, sub-tropical, warm temperate, cool temperate, sub-alpine, and alpine types, which can be further classified into layers based on other bioclimatic attributes (Chettri et al. 2010). A recent review revealed that the EH is home to a remarkable number of globally significant mammals (45 species); birds (50 species); reptiles (16 species); amphibians (12 species); invertebrates (2 species); and plants (36 species). The majority of these species (about 144) are found particularly in the North Eastern states of India (CEPF 2005). Besides supporting one of the world's richest arrays of alpine flora, about one-third of the total flora is endemic to the region (WWF and ICIMOD 2001; Dhar 2002). Details on species significance, distribution, endemism, and other measures of conservation status are replete in documentation elsewhere and require no further mention here.

Farming systems

The majority of people living in the EH depend on pastoralism, agriculture, and agroforestry systems for their subsistence livelihoods. These farming systems support a wide range of agrobiodiversity that nurtures and maintains the region's genetic resources for food, nutrition, and economic prosperity. The EH is also recognised as the centre of origin of over 50 important tropical and subtropical fruits, cereals, and rice (Vavilov 1926; Chakravorty 1951; Hore 2005). High-altitude rangelands could be the most sensitive agroecosystem in terms of the effects of erratic shifts in rainfall patterns, greater variability, and frequent extreme events of both precipitation and temperature. The fertility of agricultural soil may deteriorate with increased temperature, higher evapotranspiration rates, and soil erosion from intense precipitation events. Such productivity loss would translate into a greater risk of food insecurity. Temperature (hot and cold) and moisture (dry and wet) related stresses, along with reduced availability of feed and fodder could lower livestock productivity and pollinator activities. Alien invasive species may overwhelm extant communities bringing drastic changes to ecosystems, and rendering them less functional and useful to other plants and animals and to humans. Climate change can also exacerbate pests and diseases in plants, animals, and humans, thereby deepening the poverty trap and frustrating efforts to achieve the Millennium Development Goals (MDGs).

Species distribution

Climate change has contributed to substantial species range contractions and extinctions in the past, and future projections indicate that climate change will influence species persistence leading to a disproportionate distribution of species along ecological zones (Wilson et al. 2007). The consequences of biodiversity loss from climate change are likely to be the greatest for poor and marginalised people, who depend almost exclusively on natural resources. Grabherr et al. (1994) estimated that a 0.5°C rise in temperature per 100 m elevation could lead to a theoretical shift in altitudinal vegetation belts of 8 to 10 m per decade. In the EH, this altitudinal shift is expected to be around 20 to 80 m per decade (based on current estimates of temperature increases of around 0.01°C to 0.04°C/yr) with greater shifts at higher altitudes, as the rate of warming is expected to increase with altitude. However, such projections assume that species will adapt or shift with climate change. Apart from animals and some seasonal, annual, and biannual plant species, the scope for species to keep pace with projected climate change is very limited.

Unfortunately, there is still no straightforward explanation as to how ecosystems and ranges may shift; notwithstanding this, the mechanistic hypothesis has assumed almost factual dimensions. The multiple factors in the ecological and physiographic changes along the altitudinal gradient and the difference in species survival strategies means that the communities remaining within a bioclimatic regime could be quite different in the future with climate change.

Land cover and land use

Land cover and land use changes can lead to deforestation, land degradation, habitat modification, forest fragmentation, and biotic attrition, besides transmitting positive feedback to the climate system and thereby accelerating climate change. The latest land cover change assessment from the 1970s to 2000s uncovered significant changes in the EH (Table 13).

Table 13: **Land cover and land cover change in the Eastern Himalayas from the 1970s to 2000s (sq.km)**

Broad land cover types	1970s	2000s	Change %
Forest	273,426	264,117	-3.4
Shrubland	43,050	60,443	40.4
Cultivated land	112,631	113,233	0.5
Grassland	39,902	36,639	-8.2
Bare land	22,589	23,953	6.0
Water bodies	4,119	4,108	-0.2
Snow cover	27,514	20,741	-24.6

At the broad classification level, shrubland increased by 40% and bare area by 6%, whereas snow cover decreased by 25%, grassland by 8%, and forest by 3%. From an ecoregional perspective, EH broadleaf forests increased by 10,449 km^2; Brahmaputra Valley semi-evergreen forests decreased by 3678 km^2; Himalayan subtropical pine forests increased by 1183 km^2; shrubland in the Brahmaputra Valley semi-evergreen forests, and Eastern Himalaya broadleaf forest decreased by 4289 km^2 and 2073 km^2, respectively; grassland in the Eastern Himalaya broadleaf forests decreased by 4483 km^2; and snow cover in the Eastern Himalayan alpine and meadows decreased by 2775 km^2. These figures are at best indicative as there are inherent limitations with the time-series imageries used for inputs, as well as differences in scale in land cover and in the ecoregional data.

Critical habitats

The EH contains numerous critical habitats, and species like the greater one-horned rhinoceros, now mostly under protected area systems. Among the ecoregions, the EH broadleaf forests, Brahmaputra Valley semi-evergreen forests, and Himalayan subtropical pine forests have the highest conservation value due to the presence of more mammals and birds, and plant richness (WWF and ICIMOD 2001). The alluvial grasslands of the tropical forests support a high density of tigers. The Brahmaputra and Ganges rivers are home to the endangered Gangetic dolphin (*Platanista gangetica*). Herptiles residing in the moist forests and ephemeral freshwater habitats are also vulnerable to the impacts of climate change. A list of sensitive ecosystems was identified in close consultation with stakeholders in the region taking into account the significance of composite impacts observed from multiple stressors, including climate change, and the vulnerable biodiversity entities they are associated with (Table 14).

Table 14: **Critical ecosystems in the Eastern Himalayas with respect to climate change**

Critical habitat	Change indicator	Example of observed changes	Vulnerable entities
Alpine/sub-alpine ecosystems lying between the tree line at 4000 m and the snow line at 5500 m	• Changes in ecotones • Desertification • Declining snowfall, glaciation events • Changes in species composition • Growth in unpalatable species; decreasing productivity of alpine grasslands	Transformation of earlier *Quercus-betula* forest into the 'Krummholz-type' of vegetation comprising species of *Rhododendron*, *Salix*, and *Syringia*	Ungulate species, Himalayan pica, high value medicinal plants, botanically fascinating species (bhootkesh, rhododendron, etc.), curious species (succulents, *Ephedra*), alpine scrub flora
Cool-moist forests	• Changes in ecotones • Loss of habitat • Blockage of migration routes	Decline in population of species of *Mantesia*, *Ilex* and insectivorous plants	Habitat specialists such as red panda, blood pheasant, microflora and associated fauna
Cloud forests at temperate elevations where moisture tends to condense and remain in the air	• Less precipitation and cloud formation during warmer growing season • Loss of endemics/specific flora and fauna • Upward range shift • Desertification of soil affecting the water retention capacity of forests	-	Endemic epiphytes and lichen, wildlife dependent on cloud forest vegetation (diversity of insects)
Areas with intensive agriculture	• Reduced agro-biodiversity (monoculture) • Low employment/gradual loss of traditional knowledge • Degradation of soil quality • Potential increase of GHG emissions	Loss of traditional varieties such as upland varieties of rice, indigenous bean, cucurbits and citrus varieties; pest increases in citrus species	Crops, cereals, and vegetables
Freshwater wetlands	• Loss of wetlands due to sedimentation, eutrophication, drying, drainage • Successional shift to terrestrial ecosystems • Increased salinity in aquifers	Decrease in population of *Sus salvanius*; beels and associated biodiversity are changing	Large mammals such as crocodiles, river dolphins, wild buffaloes; wetland plant species; migratory avian species
Riparian habitats nurtured by silt deposited by overflowing rivers	• Damage or destruction of riparian habitats by floods/GLOFs/ riverbank erosion • Degradation due to increased/reduced deposition of sediments • Reduced stream flow • Disrupted successional stage	Loss of pioneer species such as *Saccharum spontaneum* and other tree species leading to a change in species composition of alluvial grasslands	*Ibis bill* (has nesting habitat in riparian zones); market-valuable tree species found in riparian zone as sisso, simal
Ephemeral stream habitats	• Loss of ephemeral stream habitats • Increased salinity • Riverine systems impacted	Riverine island ecosystems such as Majuli in Assam are being threatened	Ephemeral stream species, especially herpetofauna

Source: Compiled from information provided during the consultation processes

Sensitivity of Hydrology and Water Resources

Water is one of the most important sectors on which climate change can have a profound impact, which in turn can have second order impacts on other sectors. While a consensus exists on the likely impacts of climate change on the water resources of the Himalayas, quantitative analyses of such changes are sparse due to the dearth of baseline data essential for such analyses. The climate modelling described in the previous section for the whole region was further refined for the two major river basins in the EH: the Brahmaputra and Koshi basins. Basin-level hydrological modelling was conducted for the two SRES storylines (A2 and B2) using PRECIS-generated future climate scenarios to the end of the century. These potential impacts serve as an indication of the sensitivity of hydrology and water resources. More details are provided in Gosain et al. (2010).

The results of the hydrological modelling for the transient period centred on the 2080s and the A2 SRES storyline indicate that the total annual rainfall received by the Brahmaputra basin part of the region is likely to increase by about 23% with associated increases in groundwater recharge (31%) and surface runoff (48%). Snowfall during the period will decline by 12% in water equivalent depth, but the snowmelt is like to increase by about 32% from the present rate. The water balance sheet shows an overall increase in water yield (38%). Earlier suggestions that snowfields may disappear from the EH remain a plausible future outlook. Changes in snow-cover dynamics will directly affect biodiversity at high elevations. PET is also likely to increase (20%), due to enhanced soil water availability and higher temperatures in this future. The greater percentage increase in PET compared with precipitation over the North Eastern states of India, excluding the West Bengal Hills, Sikkim, and the western part of Assam, means relatively drier years lie ahead, with implications for water resources and drought-related problems in that part of the EH.

Similarly, the 14% increase in future precipitation simulated for the B2 scenario was associated with a 7% decrease in snowfall, a 29% increase in snowmelt, a 28% increase in surface runoff, and a 19% increase in groundwater recharge, resulting in a 22% net increase in total annual water yield in the Brahmaputra basin. This potential impact on the annual water balance components is summarised in Table 15.

Sediment loading in the rivers is predicted to increase by 39 to 95% by the 2080s over the assessed futures. As a result, water quality is expected to decrease drastically increasing the risk to human health. Dams, reservoirs, canals, and waterways are likely to suffer from massive siltation, reducing their economic lifespan and incurring huge costs in de-silting and restoration work. The impact on hydropower plants could, in turn, affect human wellbeing through reduced quality of life, reduced productivity, and loss of revenue from power export for countries like Bhutan, where economic success is premised on sustained hydropower generation.

Spatial analysis of the basin level prediction of water balance components indicates that stream flows will increase significantly across most of the Brahmaputra basin in response to precipitation and temperature changes. The hydrological system of the basin is sensitive to climatic variations, both on a seasonal basis and over longer time periods. The scenario outcomes indicate that precipitation and increased temperature shifts will have a much greater impact on future flow changes. The results also show that the effects will vary spatially across the basin in A2 and B2 scenarios, relative to baseline conditions.

The Koshi basin drains much of the western part of the EH. The impacts of climate change on water balance components will be far more extreme in the Koshi basin than in the Brahmaputra basin (Table 16). Precipitation increases are expected to be between 2.3 and 9.5% for the range bounded within the B2 and A2 scenarios for the time slice centred on the 2080s. Within the same scenario envelope of plausible climate change, snowfall may reduce by 19.3 to 23% compared to current levels, while snowmelt may increase by 74 to 76% compared to present rates of melting. Such a grave situation would basically mean dry streams and riverbeds in winter, loss of high altitude wetlands, even faster receding glaciers, and far greater risk of GLOFs.

Potential evapotranspiration is predicted to increase by 20.5 to 35.5% during the same period, which is 4 to 10 times more than predicted increases in precipitation. Under such a situation, drought-related disasters could become more frequent. Biodiversity is likely to trend towards a reduction in species richness; species composition may shift towards xeric communities with the remaining biodiversity concentrated in a few localised and shrinking habitats. Agriculture will be impacted severely with serious implications for people's livelihood strategies.

On the other hand, the projections of 48 to 79% increase in groundwater recharge, 48 to 66% increase in surface

Table 15: **Projected average annual water balance components (mm) for the Brahmaputra basin**

Water balance component (mm)	Simulated (baseline)	Scenario A2	Scenario B2	% Change A2	% Change B2
Precipitation	2136.9	2631.2	2429.2	23.13	13.68
Snowfall	341.4	301.1	318.6	-11.79	-6.68
Snowmelt	113.8	150.2	146.5	32.01	28.69
Groundwater recharge	511.2	670.1	606.1	31.08	18.57
Water yield	1230.4	1704.9	1506.8	38.56	22.46
Surface runoff	709.4	1048.5	904.8	47.81	27.54
AET	538.4	611.6	597.9	13.59	11.05
PET	916.5	1097	1020	19.70	11.30

Source: Gosain et al. (2010)

Table 16: **Projected average annual water balance components for the Koshi basin (mm)**

Water balance component (mm)	Simulated (baseline)	Scenario A2	Scenario B2	% Change A2	% Change B2
Precipitation	1966.7	2153.6	2012.4	9.50	2.32
Snowfall	1225.4	945.2	988.8	-22.86	-19.31
Snowmelt	259.4	456.8	451.8	76.10	74.17
Groundwater recharge	161.6	289.1	238.8	78.93	47.78
Water yield	786.5	1338.9	1170.9	70.23	48.88
Surface runoff	582.0	965.2	860.2	65.84	47.79
AET	143.9	205.3	187.8	42.67	30.51
PET	333.6	452.1	402.1	35.52	20.53

Source: Gosain et al. (2010)

runoff, and a total flow increase of 49 to 70% is an encouraging deviation from those components of the water balance discussed earlier. Against this, sediment loading in the basin is projected to increase from the present day simulation of 1882 t/ha to 3590 to 4194 t/ha by the 2080s, depending on the development trajectory selected. This could mean serious management problems for water resources projects and may cause the degradation of wetlands.

The hydrological systems of the Brahmaputra and Koshi river basins are very sensitive to climate change, variability, and extremes, both on a seasonal basis and over longer time periods. Simple shifts in precipitation and temperature can have a considerable impact on future flow regimes. Furthermore, increases in water yield and surface runoff are much higher during the wet months and less so, or absent, during the dry months, suggesting the possibility of an increase in flood frequency and magnitude as well as an increase in droughts. The effects, however, vary spatially across the basins and under different assumptions about the future, with more prominence in the lower parts of the basins. The study is preliminary in view of the data used for analysis, and the results are far from conclusive.

Wetlands

Ecologically, wetlands are transitional (ecotonal) systems between upland terrestrial systems and deep open water systems. They are typically characterised by the presence of aquatic vegetation (hydrophytes) (Mitsch and Gosselink 2007). Wetlands are an integral component of a river basin. Spatially, they occupy positions all along river courses, from their headwaters to their mouth (delta). The EH is extremely diverse in this respect due to the presence of large river basins and an altitude-defined ecological range from glaciers to floodplains (Gopal et al. 2010).

The Millennium Ecosystem Assessment (MEA 2005) grouped ecosystem services into four types: i) provisioning (such as food and water); ii) regulating (such as regulation of floods, droughts, land degradation, and disease); iii) supporting (such as soil formation and nutrient cycling); and iv) cultural (such as recreational, spiritual, religious, and other non-material services). Some of these are summarised briefly in Table 17.

The Global Lake and Wetland Database (GLWD; Lehner and Doll 2004) recognises lakes as distinct from wetlands and maps only lakes larger than 10 ha. Their

Table 17: **Ecosystem services provided by wetlands (ecosystem services types taken from MEA 2005)**

Services	Examples
Provisioning	
Food	Production of fish, wild game, fruits, and grains
Freshwater	Storage and retention of water for domestic, industrial, and agricultural use
Fibre and fuel	Production of logs, fuelwood, peat, fodder
Biochemicals	Extraction of medicines and other materials from biota
Genetic materials	Genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation	Source of, and sink for, greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	Groundwater recharge/discharge
Water purification and waste treatment	Retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	Retention of soils and sediments
Natural hazard regulation	Flood control, storm protection
Pollination	Habitat for pollinators
Cultural	
Spiritual and inspirational	Source of inspiration; many religions attach spiritual and religious value
Recreational	Opportunities for recreational activities
Aesthetic	Many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	Opportunities for formal and informal education and training
Supporting	
Soil formation	Sediment retention and accumulation of organic matter
Nutrient cycling	Storage, recycling, processing, and acquisition of nutrients

Source: Gopal et al. (2010)

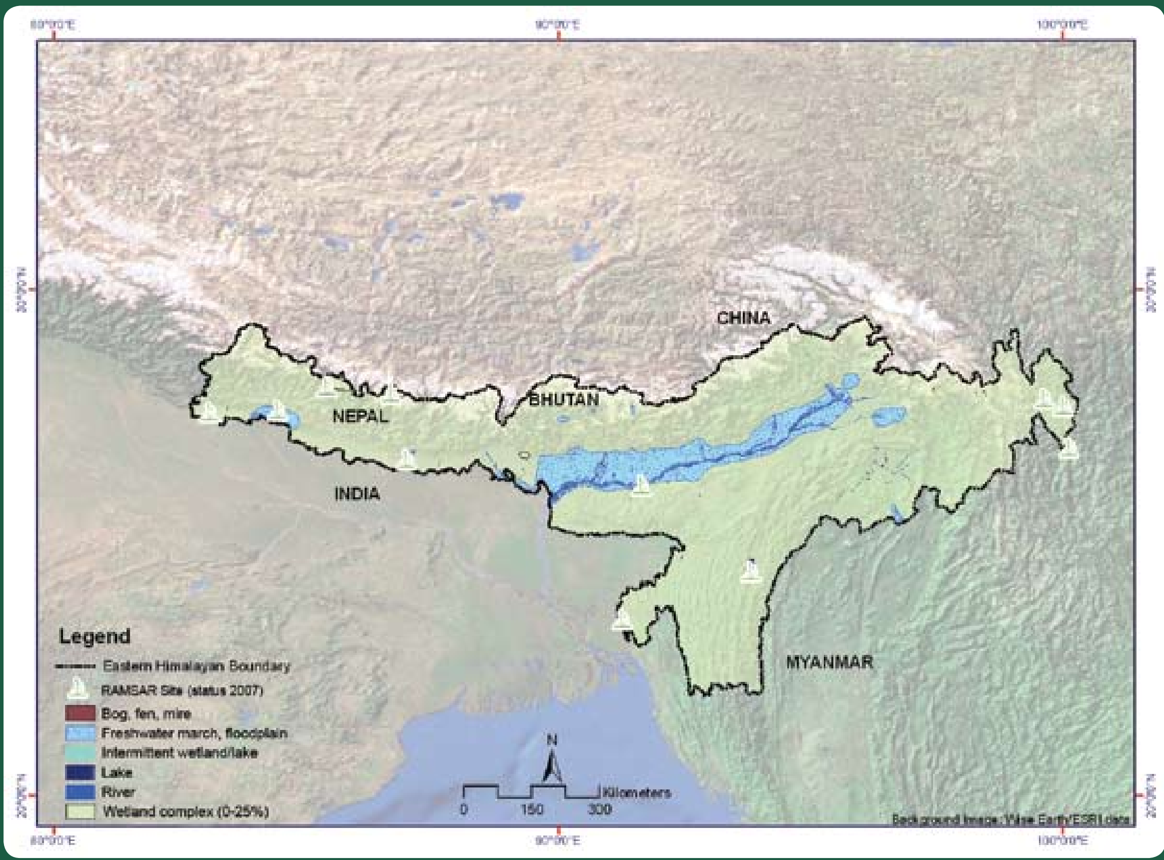
maps show only four lakes larger than 50 km^2 in the EH region, and only 210 between 50 km^2 and 10 ha. The vast majority of lakes in the region are very small (<1 ha) and remain unmapped. Lehner and Doll (2004) estimated the maximum area under all kinds of wetlands by superimposing published maps from different sources. These maps treat the entire Brahmaputra River valley as a wetland (floodplain) (Figure 8).

There are almost no studies or assessments of climate change impacts on freshwater wetlands in developing countries in general, and in the Himalayan region in particular. Thus the following account is more general, and based largely on extrapolation of information from temperate regions (NIE 2008). An important consideration in the EH is the difference in impacts along altitudinal gradients, and their cascading influence at successively lower elevations. However, very little is known about the altitudinal differences in climate change, except for a general positive trend in temperature increase with altitude.

An increase in CO_2 concentration generally enhances the rate of photosynthesis to a certain level, unless other factors become limiting. The plant communities of EH wetlands range from alpine to tropical and are likely to respond differently. This will certainly have major implications for the carbon sequestration potential of the wetlands. For aquatic plants and phytoplankton in rivers and lakes, increased CO_2 levels may enhance rates of photosynthesis at higher elevations, but at lower elevations the increased temperature may result in lower solubility of CO_2 and, hence, it is unlikely to affect photosynthesis.

The temperature increase will affect practically all biological activity. Almost invariably, rises in surface air temperature increase net productivity in cooler regions. However, the response could be quite different in the tropical-type climate where further temperature rises could actually reduce photosynthetic rates as the physiological mechanisms are activated to cope with heat stress. An increase in temperature will result in an ascending snowline, and species distribution is expected to shift to higher elevations. The temperature lapse rate in the EH is around 0.5°C for every 100 m rise in elevation, and for every 1°C rise in temperature, most species are likely to extend their distribution upwards by about 200 m. Exotic invasive species such as potomogaton (locally

Figure 8: **Wetlands in the Eastern Himalayas**



known as sochum) have been extending their range into the mountains in Bhutan and may spread further to higher elevations where wetland rice has occupied new production areas.

Increased water temperature results in lower availability of dissolved oxygen, alters the ice-free period, increases biological activity which exhausts remaining oxygen, and changes the pattern of thermal mixing in water bodies to create anaerobic conditions leading to eutrophication. The consequences of these changes for food web interactions, community structure, nutrient dynamics, and water quality are likely to be critical for the ecological health of the wetlands and living communities deriving benefits from them.

Wetlands are highly vulnerable to hydrological changes, not only in quantity and quality, but also in the frequency, duration, and timing of water availability. Changes in hydrological regimes caused by the melting of glaciers and changes in precipitation regimes will have the most significant and pronounced impacts on wetlands in the EH. The cascading effect due to the hydrological connectivity between upstream and downstream wetlands will result in places in the valleys and lower elevation areas being doubly vulnerable to climate change impacts. Besides, wetlands are both a source of, and sink for, greenhouse gases and this balance is again affected by changes in hydrology. Changes in organic matter production, its accumulation or mineralisation, and the microbial activities caused by water level changes will determine the amount of methane emission.

The sensitivity of wetlands to, and potential impact of, climate change in terms of their services is difficult to assess without proper information of specific relevance to the EH. However, the importance of wetlands to the ecological integrity of the mountain environment and people living there needs no further emphasis. The provision of water, food, biodiversity, and shelter/habitat are likely to be the most sensitive and experience the greatest impacts from climate change. Wetlands are rich in biodiversity, especially fish and waterfowl, and contain a large variety of grasses, herbs, and medicinal plants. Changes in water flow and high water temperatures could affect insects and other invertebrates with repercussions up the food chain for fish, amphibians, and waterfowl. Cold and cool water fish could face localised extinction, as they are highly temperature-sensitive. Changes in the timing and amount of rainfall could affect migration, spawning, dispersal, and growth in fishes like *Schizothorax sp.* and *Tor sp.* Wetland paddy sustains the livelihoods of a large population in EH countries, as well as providing fish, fodder, and sediments from lakes, streams, and floodplains. Increases in minimum temperatures above a threshold of 26°C at grain filling will reduce paddy grain yield by about 10% for every 1°C increase above the threshold. Therefore, rice yields could be affected by both increase and decrease in different altitudinal zones. Climate change will affect habitat characteristics through changes in water regimes, vegetation types, and sediment characteristics, and influence the migration pattern of birds and fish. Loss or degradation of wetland habitats will threaten many vulnerable and endangered species.

The capacity of wetlands to regulate floods and droughts is limited by their morphological and hydrological characteristics. Increased runoff from melting snow and glaciers will increase erosion and enhance sediment flow loading. Siltation with sediment deposits in lake basins and floodplains will reduce their capacity for floodwater retention. Acute water supply this century will affect their drought regulating function, as there may later be little or no water in the wetlands. Changes in plant communities will also contribute to the alteration of this wetland function. Declining levels of dissolved oxygen with increased water temperature, and changes in mixing patterns in deep water wetlands, will degrade water quality. The ability of microorganisms and benthic invertebrate communities to degrade organic matter is likely to decline significantly with negative implications for water quality and methane emission. Climate change will trigger increased emission of GHGs from many wetlands, as lower solubility of oxygen at increased temperature will lead to eutrophication. Methane emission occurs from a variety of wetlands during the summer thawing of ice in permafrost regions (e.g., Rinne et al. 2007). Longer and warmer growing seasons are projected to result in the desiccation of peat and the production of CO_2. Melting ice will result in the production and ebullition of methane from glacial lakes that have accumulated organic matter from littoral vegetation and organic sediment.

Wetlands in the EH have great spiritual and cultural value as they are considered sacred in different faiths and are important for cultural tourism. The high altitude lakes are of particular significance in this respect (Gopal et al. 2008). Changes in their ecological characteristics caused by climate change may affect their significance as sites of cultural and religious tourism.

Hydrometeorological hazards

Natural hazards in the EH are mainly hydrometeorological in nature, amplified by the fragile environment, which is extremely sensitive to external perturbations. The extreme relief of the mountains coupled with monsoonal vagaries has left communities vulnerable to natural hazards like floods, landslides, and droughts (Pathak et al. 2010). The most common occurrences are flash floods associated with extreme weather events, glacial lake outburst floods, and rivers breaking their banks from excessive runoff due to incessant monsoonal downpours. Frequently, these events assume disastrous proportions with large-scale destruction of mountain ecosystems and untold human suffering. The fragile Himalayan geology facilitates mass wasting when intense precipitation occurs. Intense rainfall events in mountainous areas can overwhelm the water storage capacity of the regolith (the surface layer of loose rock) and trigger hill slope failures (e.g., Gabet et al. 2004). Huge rock avalanches and landslides can create landslide dams in the narrow river valleys (for example, Tsatichhu in Bhutan). Over the coming decades, there is likely to be a steady increase in human exposure to events such as droughts, floods, and storms. Extreme weather events will become more frequent and more intense, with less certainty and predictability in the timing of the monsoon and rainfall.

The impacts of climate change on mountain glaciers and permafrost are not only important in the context of ecosystem services, but also in connection with glacier and permafrost related hazards. In the Eastern Himalayas, particularly in Bhutan and Nepal, there is concern about supraglacial and moraine-dammed lakes, caused by general glacier retreat since the Little Ice Age ended, because of their potential to breach catastrophically (Quincey et al. 2007). The glaciers of the EH are shrinking at an alarming rate with meltwater feeding into the ever-expanding lakes. Recent observations have estimated the maximum rate of glacial retreat at about 41 m/yr in the Indian Himalayas, 74 m/yr in Nepal, and 160 m/yr in Bhutan (Bajracharya et al. 2007). The retreat of the Luggye glacier in Bhutan between 1988 and 1993 is the fastest on record in the whole of the Himalayas.

Considering the significant warming trends projected for the future, glacial lakes are likely to expand, increasing the potential for larger GLOFs in the region. GLOFs are not recent occurrences, but their frequency and the threat they pose have increased several fold in recent times. A number of glacial lakes in the EH have the potential to burst with catastrophic consequences to nature and humans alike. Nepal has 12 potentially dangerous lakes, there are 14 in Sikkim, and 24 lakes are reported to be potentially dangerous in Bhutan (Mool et al. 2001a,b) [but note that these figures have recently been revised, Ives et al. 2010, ed]. GLOFs have hit Bhutan before, most recently in 1994 when the 140 m deep Luggye Tsho burst releasing 10 million m^3 of flood water. Hazard levels of floods are expected to increase and human settlements will be exposed to greater risk, not only to the loss of livelihood, but also from increased morbidity and mortality as a result of poor health. A GLOF event could also trigger dam breach flooding downstream. Elaboration on the natural and human-induced hazards, associated risks, and their evolution to disastrous proportions are provided in other sections of this report on ecosystem functioning and service provision.

Fire

Changing climatic conditions are likely to modify the frequency of fire outbreaks and intensity. Prolonged periods of summer drought may transform areas already sensitive to fire into regions of sustained fire hazard. Fires could also break out in regions that are currently relatively unaffected, as critical climatic, environmental, and biological thresholds for fire outbreaks are exceeded (Johnson 1992).

Sensitivity of Human Wellbeing

Climate change directly affects human wellbeing through extreme weather events and indirectly through its effects on ecosystems, the foundation of human wellbeing. Despite a general understanding and concern, we have limited and imprecise knowledge supported by scientific evidence on how climate change affects human wellbeing (Fang Jing and Leduc 2010). Knowledge and data on human wellbeing is particularly limited in the EH. To assess the future impact of climate change on human wellbeing, it is essential to benchmark the current status of human wellbeing in this region as a baseline for future projections. The demographic, socioeconomic, and poverty status of the EH can be used to proximally reflect 'materials for a good life', which is the basic aspect of human wellbeing. These indicators for the EH are well below the level of human wellbeing thought likely to be necessary to deal with the full spectrum of adverse climate change impacts anticipated in the region. Indicators include the following:

- Poverty levels are high and many people still exist on less than a dollar a day.
- Infrastructure, including roads, transportation, electricity and water supply, education and health care services, communication, and irrigation, is underdeveloped.
- The majority of the population relies on subsistence farming and forest products for their livelihood, which are highly sensitive to weather extremes, climate variability, and water availability, and, therefore, susceptible to climate change.
- Major health indicators such as the maternal mortality rate, infant mortality rate, and life expectancy at birth are at a low level.
- Other metrics are equally unsatisfactory, e.g., there is lack of access to safe drinking water and sanitation; weak health systems; economic and income monopolies; a high prevalence of water-borne diseases and undernourishment; frequent disasters such as flash floods and landslides; and huge inequalities and social exclusion based on wealth, religion, gender, caste, and others.

All these factors make the EH more vulnerable to climate change as the capacity to adapt is inadequate. Adaptive capacity is determined by the economic, socio-political, and technological attributes that empower people with freedom of choice and action.

Explorative surveys of local people's perceptions and societal experiences in their daily interactions with nature and the surrounding environment can provide insight into climate change sensitivity and likely impacts on human wellbeing in the future. Results from such surveys carried out in North East India and Bhutan uncovered some notable aspects of people's understanding and the coping mechanisms they resort to in dealing with environmental changes. People generally agree that changes are imminent and their reasoning was plausible in the light of trends in the recent past. They talked about the changes in the weather patterns, transformations in their way of life, and apparent transitions in their immediate physical surroundings, although they did not comprehend these developments from a global warming or climate change perspective. People are concerned about the sustainability of ecosystem services, especially if they have lived through unpredictable periods of bizarre weather conditions, food insecurity, and water shortages, and witnessed land degradation, a reduction in snowfall, wholesale deforestation, and the emergence of new pests and diseases. They are able to relate these changes to loss of livelihood, high morbidity and mortality, insecurity, and socio-cultural degeneration, ultimately leading to loss of freedom and opportunity.

In order to safeguard their wellbeing and adapt to the changing climate, people have engaged in different livelihood strategies by adopting more resilient food production systems or migrating to new locations. Productivity gains have come at the cost of eroding the genetic base of farming systems and polluting the ecosystems with excessive use of chemicals. Frequently noxious species are released or escape into the wider ecosystem, invading the natural space, disturbing the ecological harmony, and disrupting the food chain. Human migration exerts enormous pressure on nature from land degradation and extracts huge socioeconomic costs in terms of resettlement and reconnection to civic services. As natural resources and ecosystem services decline with increasing human interference through industrial and infrastructural development and overexploitation, human conflict and competition for scarce resources could reach alarming proportions, which in turn will set the context for further desolation.

Water stress and scarcity due to melting glaciers, reduced snowfall, variable rainfall, rising temperatures, and high evapotranspiration will severely affect agricultural production and hydropower generation, which are the main sources of livelihood and income in this region, particularly in Bhutan and Nepal. Climate change will directly affect human health through extreme weather and indirectly through a reduction in water quality and quantity, and poor sanitation leading to higher incidences of water-related diseases. Similarly, climate change will bring with it new threats from vector-borne diseases like malaria, cholera, and dengue as their epidemiology follows the warming trend. Malnourished people with weaker livelihood bases are likely to be even more affected by higher morbidity and mortality rates. Gender inequality is likely to increase with climate change. Collecting water, fuel, and food will become more time consuming and the drudgery involved will increase due to greater resource scarcity (Stern and Taylor 2007) this burden will be disproportionately shouldered by women in the Himalayan regions. The situation will become worse when large numbers of men migrate for work.

Climate change also presents new threats to ecosystems through overexploitation for food and materials during times of food shortage and decline or loss in monetary income. Considering the high population growth rate in the region, this will put additional strain on ecosystems. In the face of reduced resources, such as water and food, social conflicts and unrest may rise or be exacerbated among nations, communities, and tribes. Water related disasters such as floods, droughts, landslides, GLOFs, and extreme weather events may increase or become more frequent due to climate change. This poses a huge threat to livelihoods and well being of the people of the region.

4 Potential Impacts of Climate Change and Implications for Biodiversity and Human Wellbeing

Introduction

A holistic perspective on global climate change has emerged out of the discernible trends: that human activities are responsible for these recent shifts and variability in the physical and biological systems. Climate change is projected to compound pressures on natural resources and the environment associated with rapid urbanisation, industrialisation, and economic development. The impacts of climate change vary across regions and communities. In general, these impacts are most severe in regions that display high vulnerability as a result of a number of factors, including poverty. From the AR4 (IPCC 2007a), it is clear that the countries most vulnerable to climate change impacts also tend to be the poorest ones, with limited capacity in terms of the instruments needed to address the situation they face (e.g, data and observations, methods and tools, and technical and institutional infrastructure capacity building). The biggest challenge for the EH is to adapt to the impacts of climate change by integrating responses to climate change and adaptation measures into strategies for poverty reduction at the local level to ensure sustainable development. This synthesis also warns that unprecedented stresses on ecosystems from the combination of climate change, associated disturbances (e.g., floods, drought, wildfire, insects, disease), and other global change drivers (e.g., land use change, pollution, fragmentation of natural systems, overexploitation of resources) may exceed the natural resilience of ecosystems. The interaction of climate impacts with rapid economic and population growth, and migration from rural to urban areas, is likely to affect development. Net carbon uptake by terrestrial ecosystems is expected to peak before mid-century, and then weaken or even reverse, thus amplifying climate change.

Mountains are susceptible to the impacts of a rapidly changing climate, and provide interesting and unique locations for the early detection and study of the signals of climatic change and the assessment of climate-related impacts on hydrological, ecological, and societal systems. Climate changes rapidly with altitude over relatively short horizontal distances, as does vegetation and hydrology (Whiteman 2000). In places where climatic change may lead to warmer and drier conditions, mountain vegetation is expected to suffer as a result of increased evapotranspiration. However, contrary to the expectations from the models, Chen et al. (2006) found that average PET trends (1961–2000) on the Tibetan Plateau were negative in all seasons and annually, with an average annual PET trend of –13.1 mm/decade. Such contradictory evidence highlights the reality that ecosystems are complex and highly interconnected, making the effects of climate change extremely difficult to predict. The loss of wetlands is equally difficult to predict. Knowledge of temperature change is particularly important for prediction because it influences activity, feeding, growth, metabolism, and reproduction.

Impacts on Ecosystems and Consequences for Biodiversity

Impacts on biodiversity are also a matter of degree between extremes of significance, as judged by humans, and the 'middle path', a notion of sustainability that ecosystems and biological processes are able to tolerate and absorb certain thresholds of climate change and human activity. As mentioned already, there may be positive as well as negative impacts of climate change. Recent warming is strongly linked to the changes observed in terrestrial biological systems, including the

Impacts on biodiversity and ecosystems: IPCC projection and consequences for human wellbeing

IPCC projection: There is a high confidence probability that the resilience of many ecosystems will be undermined by climate change, with rising CO_2 levels reducing biodiversity, damaging ecosystems, and compromising the services that they provide. Over the past three decades, the lines marking regions in which average temperatures prevail (isotherms) have been moving pole-ward at a rate of about 56 kilometres per decade. Changes in flowering seasons, migratory patterns, and the distribution of flora and fauna have been detected. Alpine plants are most at risk and are being pushed towards higher altitudes and literally off the planet. But when the pace of climate change is too rapid, or when natural barriers block migration routes, extinction looms. According to the IPCC, 20-30% of plant and animal species are likely to be at increased risk of extinction if global average temperature increases exceed 1.5-2.5°C (medium confidence).

Human wellbeing projection: At temperature increases in excess of 2°C, rates of extinction will start to increase. Environmental degradation will gather pace, with wetland and forest systems suffering rapid losses. The loss of ecosystems and biodiversity is intrinsically bad for human development and the poor, who depend most heavily on ecosystem services, will bear the brunt of the cost.

earlier timing of spring events like leaf-unfolding, bird migration, and egg-laying; and pole-ward and upward shifts in ranges of plants and animal species. The present distribution of species in high-elevation ecosystems is projected to shift to even higher elevations, although rates of vegetation change are expected to be slow and colonisation success will be constrained by the limitations of the highly dissected and steep terrain of the EH mountain range. Studies of satellite observations since the early 1980s indicate that there has been a trend towards the early 'greening' of vegetation in the spring, linked to longer thermal growing seasons due to recent warming (Dye and Tucker 2003). However, observations of such changes are difficult to use in future projections because of the complexities involved in human-nature interactions (e.g., land use change). Declining snow cover may also be at least partially responsible for the higher NDVI (normalized difference vegetation index) values associated with the greening trend (Shabanov et al. 2002). Nevertheless, the observed changes are compelling examples of how rising temperatures can affect the natural world and raise questions about how vulnerable populations will adapt to direct and indirect effects associated with climate change (IPCC 2001a).

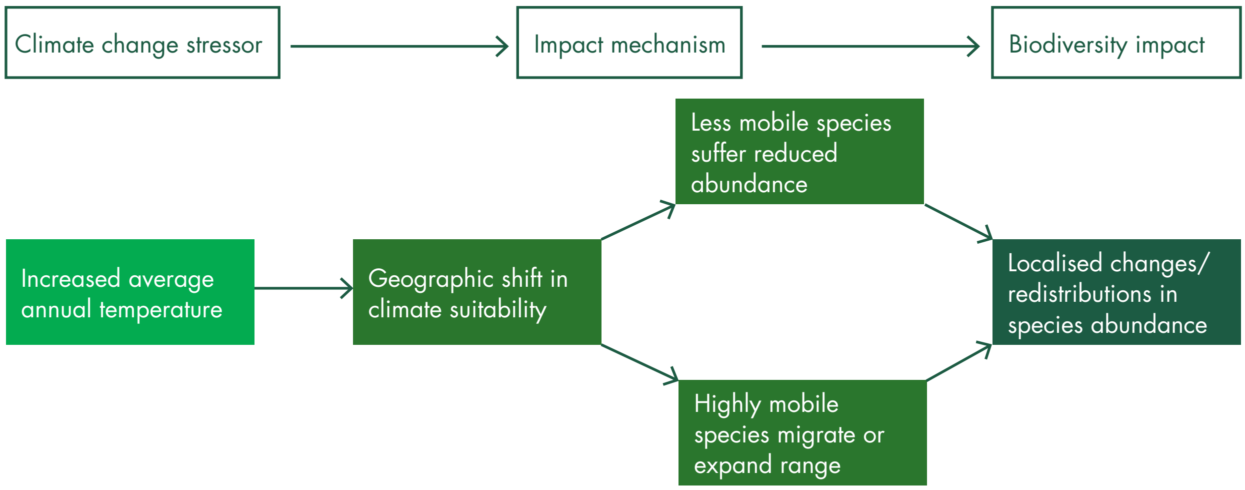
Climate change is expected to affect the boundaries of forest types and areas, primary productivity, species populations and migration, the occurrence of pests and diseases, and forest regeneration. The increase in GHGs also affects species composition and the structure of ecosystems, which, in turn, affects ecosystem functions (Schutze and Mooney 1994). The interaction between elevated CO_2 and climate change plays an important role in the overall response of net primary productivity to climate change at elevated CO_2 (Xiao et al. 1998). Climate change will have a profound effect on the future distribution, productivity, and health of forests. There may be a significant reduction in alpine and cryospheric ecosystems. Tropical zones are expected to expand to cover most of the middle mountains and inner valleys of the region.

Species responses

Species may respond to changes in climatic variables by adapting, shifting their range, changing their abundance, or disappearing altogether (Figure 9). Species will shift their geographic ranges at different rates, and some may be unsuccessful in reaching or colonising new habitats. As temperature decreases with altitude by 5-10°C/1000 m, species will respond to climate change by migrating upwards to find climatic conditions in tomorrow's climate that are similar to today's (McArthur 1972; Peters and Darling 1985). Past tree species migration rates are believed to be in the order of 4 to 200 m per century. For the EH, an average warming of 1 to 3.5°C over the next 100 years (as predicted by the IPCC-AR4) would be equivalent to an altitude shift of about 150 to 550 m (IPCC 2007a).

According to this paradigm, the expected impacts of climate change in mountains would include the loss of the coolest climatic zones at the peaks of the mountains and a linear shift in all remaining vegetation belts upslope. Because mountain tops are smaller than bases, the present belts would occupy smaller and smaller areas at higher elevations, and the population of corresponding species would decrease, becoming more vulnerable to genetic and environmental pressure (Hansen-Bristow et al. 1988). However, the migration hypothesis may not always be applicable because of the different climatic tolerance of species involved, including genetic variability between species, different longevities and survival rates, and competition from invading species.

Figure 9: **Climate change impact: Species-level range and abundance shifts**

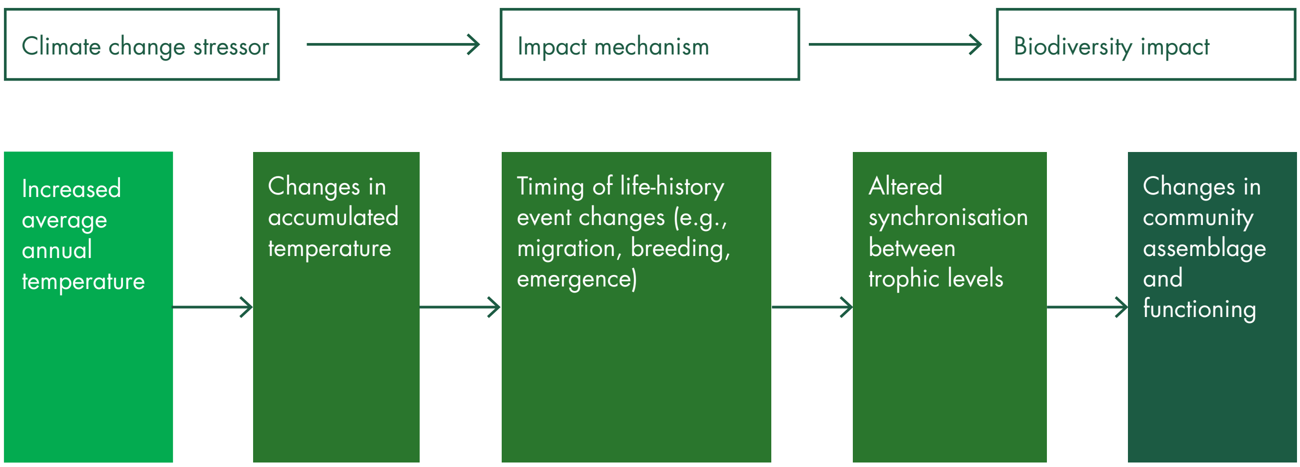


Lifecycle changes

Snow cover provides frost protection for plants in winter and water supply in spring. Vegetation communities that live in snow beds and hollows will be the most vulnerable to climate change because they will be subject to summer desiccation. As species will be affected differently by climatic changes, relationships among species will be altered. Ecosystem functions that depend upon interactions among species could be affected. Changes in phenology are expected to be the primary short-term response to climate change (Root and Hughes 2005). The lifecycle events of many plants, insects, and animals depend on 'accumulated temperature' – the amount of heat energy available over time (Figure 10). These organisms will hatch, bud, or breed earlier in the year in response to warming trends. Long-living plants that cannot migrate will see climate change occur within their lifetime, so their ability to undergo phenological adaptations will determine their individual survival.

In the animal world, these lifecycle changes are likely to disrupt communities, interfering with breeding seasons, potentially uncoupling predator-prey and competitive interactions between species, and ultimately influencing community composition (Root and Hughes 2005). Migratory species are particularly vulnerable as a discrepancy could develop between the timing of migration and the availability of food. Hence, both the structure and functioning of ecosystems could change. Rapid evolution might help species with short generation times, such as insects and annual plants, to adapt to climate change. Evolution may be slower in long-lived species, such as trees. The probability of ecosystem disruption and species extinction is positively related to the rate of climate change (IPCC 1998). If climate change is more rapid than the migration capacity of species, the probability of species extinction and disruption of ecosystems is great (Halpin 1994).

Figure 10: **Climate change impact: Lifecycle changes**



Evolutionary impacts

Changes in species abundance, distribution, and phenology suggest changes in species fitness in response to climate change. Individuals within one species may have different capacities for expressing new phenotypes (e.g., hatching or budding earlier in the year) and, as such, climate change might select individuals with greater genetic capacity for adaptation (Figure 11). New community assemblages and interactions resulting from climate change will also exert evolutionary pressure on species. Subpopulations at the warmer edges of species ranges are being extirpated, causing a loss in genetic diversity (Thomas 2005).

Adaptation pathways in the face of changing climate include the progressive replacement of currently dominant species by more thermophilous (heat-loving) species. A further mechanism is that dominant species are replaced by pioneer species from the same community that have enhanced adaptation capabilities (Halpin 1994; Pauli et al. 1998). A third possibility is that climate change may favour less dominant species, which then replace dominant species through competition (Street and Semenov 1990). These scenarios are based on the assumption that other limiting factors, such as soil type and moisture, will remain relatively unaffected by the changing environment.

Pest species may shift north or to higher elevations, and/or increase in abundance if temperatures increase. Shifts in fish species from cool and cold water species to warmer water species are likely. Species or whole ecosystems could fail to shift their range if they cannot disperse fast enough to keep pace with change, or if landscape features (such as cities) block their movement, or if new suitable habitats are simply not available. A species may fail to colonise a prospective habitat if it cannot adapt to that habitat's soil, or its level of human development, or if it cannot coexist with other species already in residence. Invasive species share a set of traits that predispose them to successfully invade pre-existing communities. These traits include a high rate of population growth, which contributes to rapid colonisation; the ability to move long distances, which contributes to the colonisation of distant habitats; tolerance of close association with humans; and tolerance of a broad range of physical conditions.

Landscape level processes

Climate change has the potential to have a profound effect on landscape-level processes, altering both the frequency and extent of major disturbance events (Figure 12). Droughts can lead to insect epidemics and major wildfires over vast areas with significant effects, and both frequency and severity can be expected to increase significantly with climate change. Disturbance processes, such as fire, may lead to some forest ecosystems being converted to grassland ecosystems. Besides direct habitat loss, the interaction between climate and fire regimes has the potential to overshadow the direct effects of climate change on the distribution and migration of forest species. Changes in disturbance regimes are, therefore, expected to be a major driver of ecosystem-level changes that may include changes in structure (e.g., dominant vegetation, age class distribution, species composition), functioning (e.g., productivity, decomposition, nutrient cycling), and distribution within and across landscapes.

Figure 11: **Climate change impacts: Evolutionary effects**

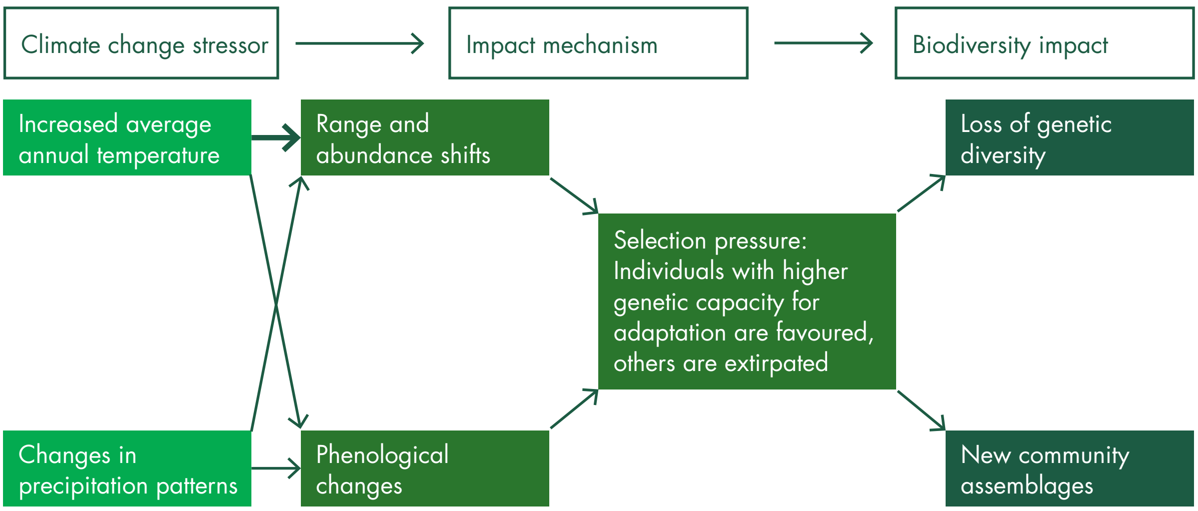
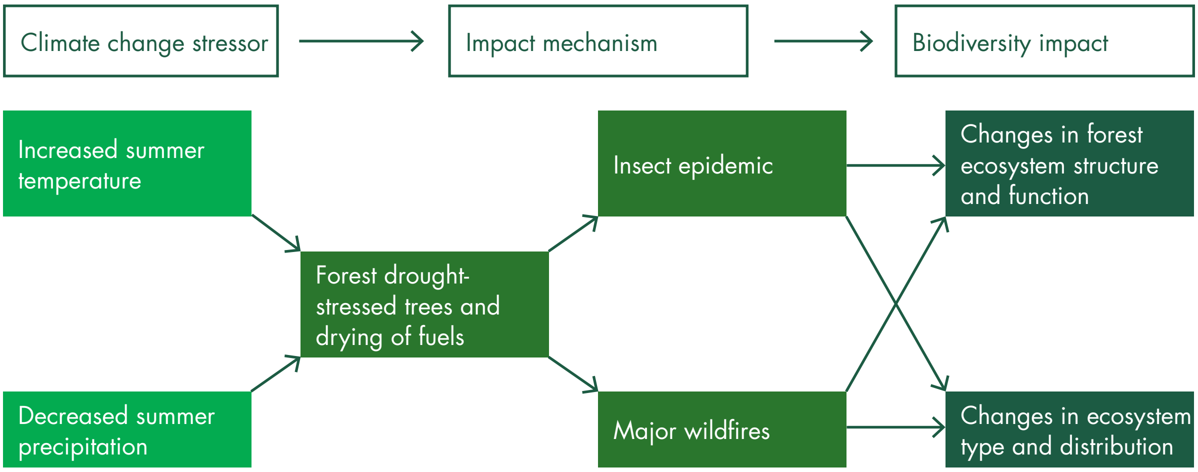


Figure 12: **Climate change impacts: Disturbance regimes and ecosystem-level change**



Observed and projected impacts and threats

Table 18 presents a list of observed and projected impacts of climate change on biodiversity in the EH. The list has been compiled based on literature, stakeholders' workshops, and a stakeholder survey. The list is not intended to be comprehensive, but rather to present an overview of impacts that have been identified in the EH. The circle coding in the table provides a broad differentiation between impacts that have been observed (or documented scientifically), versus those that are projected (or otherwise hypothesised).

Based on a broad review of impact literature, people's perception surveys, and the outcome of a series of stakeholder dialogues, sufficient evidence has been collected to postulate impact characteristics traversing systems and impact mechanisms that are synergistically coupled with other biodiversity impact mechanisms (e.g., habitat loss, invasive species). Impacts on genetic diversity are poorly studied relative to impacts at the species or ecosystem levels. Some of the highest priority threats to biodiversity in the EH from climate change are summarised in Table 19, as assessed on the basis of the information currently available for the EH (Table 18) and the broader literature on potential climate change impacts. A more detailed assessment of observed, perceived, and projected impacts of climate change on the components of mountain ecosystems is given in the separate technical reports that complement this assessment.

Impacts on Water, Wetlands and Hazards, and Consequences for Biodiversity

The EH plays a critical role in the provision of water to the Asia continental monsoon. Because of the sensitivity of mountain glaciers to temperature and precipitation, the behaviour of glaciers provides some of the clearest evidence of atmospheric warming and changes in the precipitation regime, both modulated by atmospheric circulation and flow patterns over the past decades (Haeberli and Beniston 1998; WGMS 2000). As mountains are the source of the region's rivers, the impact of climatic change on hydrology is likely to have significant repercussions, not only in the mountains themselves, but also in populated lowland regions that depend on mountain water resources for domestic, agricultural, hydropower generation, and industrial purposes. Significant shifts in climatic conditions will also have an effect on social and economic systems in the region through changes in demand, supply, and water quality. Any shortfall in water supply will enhance competition for water use for a wide range of economic, social, and environmental applications. Such competition will be sharpened as a result of larger populations downstream, leading to heightened demand for irrigation and perhaps also industrialisation, at the expense of drinking water (Noble and Gitay 1998).

Natural systems related to snow, ice, and frozen ground (including permafrost) are being affected through the enlargement and increased number of glacial lakes, increasing ground instability in permafrost regions, and

Table 18: **Observed and projected impacts of climate change on biodiversity in the Eastern Himalayas**

Biodiversity impact	System		Level			Range			
Description	**Terrestrial**	**Freshwater**	**Ecosystem**	**Species**	**Genetic**	**Local**	**Widespread**	**Impact mechanism/ hypothesis**	**Climate change driver**
Loss and fragmentation of habitat	●		●				●	Ecological shift, land use change, exploitation	Temp change
Vertical species migration and extinction	○			○		○		Ecological shifts	Temp change
Decrease in fish species (in Koshi river)		●		●		●		Less oxygen, siltation	Temp change, extreme weather events
Reduced forest biodiversity	○●		○●				○●	Ecological shift, habitat alteration, forest fire, phenological changes	Temp change, precipitation change, land use change, overexploitation
Change in ecotone and micro-environmental endemism	○		○	○		○		Ecological shifts, microclimate	Temp change
Peculiar tendencies in phenophases, in terms of synchronisation and temporal variabilities	●			●		●		Phenological changes	Temp change
Wetland degradation (Umiam Lake, Barapani in Meghalaya) (climate attribution is strongly contested)		●	●		●			Siltation	Precipitation change
Degradation of riverine island ecosystems (Majuli) and associated aquatic biodiversity (refuted, but not overlooked)		●	●		●			Flooding	Extreme weather events
Loss or degradation of natural scenic beauty	○	○	○				○	Drought, reduced snowfall	Less precipitation
Reduced agrobiodiversity	○●		○●				○●	Monoculture, inorganic chemicals, modern crop varieties, degeneration of crop wild relatives	Higher temp and more precipitation
Change in utility values of alpine and sub-alpine meadows	○		○			○		Biomass productivity, species displacement, phenological changes	Higher temp and more precipitation
Loss of species	○	○		○			○	Deforestion, land use change, land degradation	Higher temp and more precipitation
Increase in exotic, invasive, noxious weeds (mimosa in Kaziranga)	●			●		●		Species introduction and removal, land use change, tourism	Higher temp and more precipitation
Decline in other resources (forage and fodder) leading to resource conflicts	●		●				●	Reduced net primary productivity	Higher temp and less precipitation
Successional shift from wetlands to terrestrial ecosystems, and shrinkage of wetlands at low altitudes (Loktak Lake, Deepor Beel)	●○		●○			●○		Habitat alteration, drought, eutrophication	Higher temp and less precipitation
Increase in forest fires (Bhutan)	●		●			●		Forest fire, land degradation	Higher temp and extreme weather events like long dry spells
Invasion by alien or introduced species with declining competency of extant and dominance by xeric species (e.g., Mikania, Eupatorium, Lantana)	●○			●○			●○	Species introduction, land use change	Higher temp and less precipitation
Increased crop diversity and cropping pattern	○			○		○		Demographic and socio-economic change	Variable temp and variable precipitation
Drying and desertification of alpine zones			○				○	Drought, overgrazing	Higher temp and less precipitation

Cont...

Biodiversity impact	System		Level			Range			
Change in land use patterns	●		●				●	Development policy, socioeconomic change	Variable temp and precipitation
Soil fertility degradation	●		●				●	External inputs, land use intensification, desertification	Higher temp and less precipitation
High species mortality	○	○		○		○		Range shift, pollution, deforestation	Higher temp and less precipitation, less days/ hours of sunshine
More growth/biomass production in forests, variable productivity in agriculture (orange)	○●		○●			○●		Carbon enrichment, external input, reduced grazing	Increased CO_2 level, higher temp
Net methane emission from wetlands (Thoubal, Vishnupur)		○●	○●			○●		Resource use, drainage, eutrophication, flow obstruction	Increased CO_2 level, higher temp
Increased degradation and destruction of peatlands (bog, marshland, swamps, bayou)		○	○		○			Land conversion, drainage, removal of ground cover	Higher temp and less precipitation
Land use change that increases soil degradation	●		●				●	Overpopulation, unsustainable agriculture	Variable temp and variable precipitation

● Observed/documented response; ○ Projected/hypothesised response

Source: ICIMOD 2009

Table 19: **Summary of priority climate change threats to biodiversity in the EH**

Species at risk	Although there could be some benefits for at risk species, in general, there is significant concern for species at risk that are already threatened by small population size, loss of unique habitats, and low reproduction/ dispersal rates (among others). Any potential for climate change to further exacerbate these existing causes could greatly increase the risk of extinction.
Aquatic habitats	Extended summer low flow periods are expected in rainfed streams. This will further increase water temperature, favouring warm water species and altering community structure and functioning. Conversely, in snowmelt and glacier-fed streams, the magnitude and duration of summer floods is expected to increase. In either case, significant impacts on aquatic habitats are expected.
Wetlands	Wetlands are particularly vulnerable to climate change. As physiographically limited systems, they are unable to migrate and, hence, are vulnerable to changes in hydrology, nutrient inputs, and others.
Alpine ecosystems	Given their restricted geographic area and narrow elevation range, alpine ecosystems are particularly vulnerable to climate change. Climate and vegetation change rapidly with altitude over relatively short distances in mountainous terrain. As a result, alpine ecosystems are particularly vulnerable to encroachment by lower elevation ecosystems.
Forest and grassland ecosystems	The current pine bark beetle epidemic is a matter of serious concern. Ongoing concerns include the increased potential for major widespread wildfires and the subsequent potential for transformations in disturbed ecosystems, such as colonisation by invasive species and resultant new species assemblages. Grassland ecosystems may expand in range, yet face threats in terms of lost species diversity.
Invasive species	Climate change may expedite the colonisation of some areas by invasive species in both terrestrial and freshwater realms. Increased frequency and magnitude of forest disturbances will create openings vulnerable to colonisation by invasive plants.
Protected area ecosystems	Protected areas are widely acknowledged as one of the most important management instruments for biodiversity conservation. In the EH, protected area systems are some of the most intricate and complex, maintaining a delicate balance between conservation and sustainable use. The potential for major, long-term ecosystem shifts under a changing climate suggests a need to re-evaluate the protection of representative ecosystems with a stronger focus on the landscape approach as it is based on broad topographical features that do not shift with climate change.

Impacts on water, hydrology, wetlands and hazards: IPCC projection and consequences for human wellbeing

IPCC projection: It is very likely that mountain glaciers and snow cover will continue to retreat. With rising temperatures, changes in runoff patterns and increased water evaporation will impact on the distribution of water and on the timing of flows. It is likely that tropical cyclones will become more intense as oceans warm, with higher peak speeds and heavier precipitation. Droughts and floods will become more frequent and widespread.

Human wellbeing projection: There is an imminent prospect of increased water stress. Water supply stored in glaciers and snow cover will decline, groundwater levels will fall rapidly (threshold = 1000 cubic metres per capita per annum). The thousands of glaciers located across the 2,400 kilometres of the extended Himalayan range are at the epicentre of an emerging crisis. The largest mass of ice outside the polar caps is shrinking. Avalanches, floods, and flash floods, including GLOFs, pose special risks to densely populated mountain regions. As glacial water stores are reduced, water flows will diminish. The Ganges could lose two-thirds of its July to September flow, causing water shortages for over 500 million people and one-third of India's irrigated land area. Projections for the Brahmaputra indicate reduction in flows of between 14 and 20% by 2050.

Extreme and unpredictable weather events bring short-term human insecurity and destroy long-term efforts aimed at raising productivity, improving health, and developing education, perpetuating the poverty trap. Climate change is one of the forces that will influence the profile of risk exposure in the decades ahead. However, climate change will reconfigure patterns of risk and vulnerability. The combination of increasing climate hazards and declining resilience is likely to prove a lethal mix for human development. Rainfed production may suffer from drought as length of growing period is determined by water availability. Settlements located on mountainsides are vulnerable to flooding and landslides.

rock avalanches in mountain regions. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st Century, reducing water availability, hydropower potential, and changing the seasonality of flows in basins supplied by meltwater from snow and ice. For example, during the 20th Century, glaciers and ice caps in the EH experienced widespread losses, which are likely to have major consequences for water supply in several adjoining areas. The mountain hydrology is being affected in terms of increased runoff and earlier spring peak discharge into many glacier-fed and snow-fed rivers. Runoff is projected to increase up till the 2030s time range and gradually reduce thereafter, contrary to what the IPCC has predicted for the region. In Nepal, a preliminary analysis of river discharge some years ago showed decreasing trends for the Karnali and Sapta Koshi rivers, but an increasing trend for the Narayani river (DHM 1996). Increased temperatures will further affect the physical, chemical, and biological properties of wetlands, freshwater lakes, and rivers, with predominantly adverse impacts on their thermal structures, freshwater species, community composition, and water quality. Winter precipitation in the form of snowfall has declined over the years and the area under snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Drought-affected areas are projected to increase in extent, with large increases in irrigation water demand.

The beneficial impact of increased annual runoff in some areas is likely to be tempered by the negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality, and flood risk. Available research suggests a significant future increase in heavy rainfall events will result in increased flood risk to society, physical infrastructure, and water quality. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. Shrestha et al. (2003) suggest that the number of flood days and consecutive days of flood events have been increasing in Nepal. Increases in glacier melting and likely increases in runoff will heighten the risk of glacial lake outburst floods. According to Qin Dahe (1999), there are 2,968 glaciers in the EH with a total area of 4,160 km^2 and a total ice volume of 415 km^3. Retreat of glacier fronts and negative mass balances characterise most glaciers in the Eastern Himalayas (since around 1900 with only brief interruptions). Himalayan glaciers are retreating at an average rate of 18 to

20 m/yr (PC-GOI 2006). In Nepal, the Department of Hydrology and Meteorology (DHM 2004) found that almost 20% of the present glaciated area above 5000 m in altitude is likely to become snow and glacier free with an increase in air temperature of 1°C. A rise of 3 to 4°C would result in the loss of 58 to 70% of snow and glaciated areas accompanied by an increased threat of GLOFs.

Impact on surface water availability

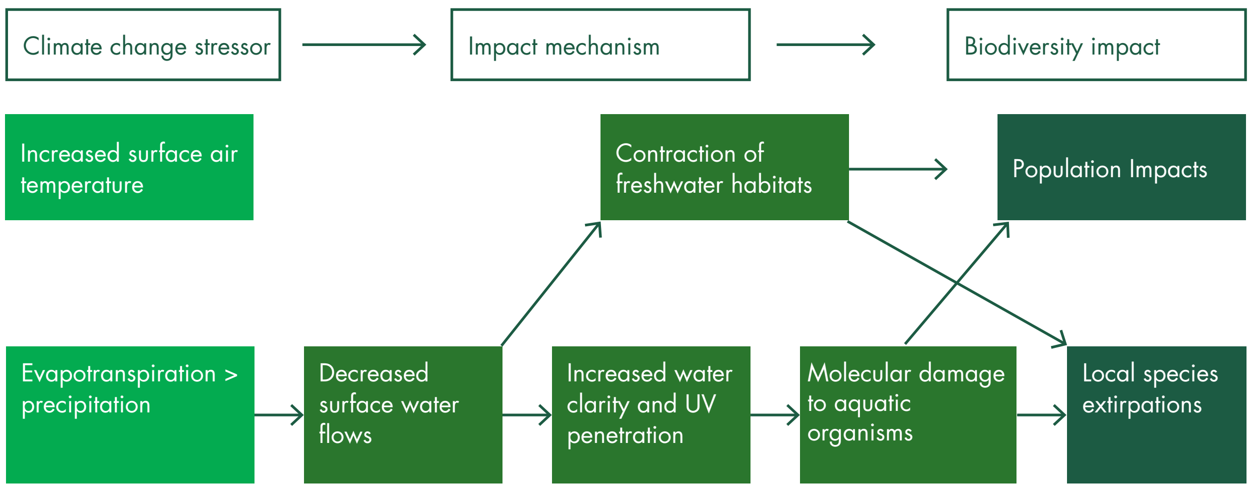
Water availability, in terms of both temporal and spatial distribution, is expected to be highly vulnerable to climate change. Growing populations and the concentration of the population in urban areas will exert increasing pressure on water availability and water quality. Some areas are expected to experience increases in water availability; other areas will have reduced water resources. The majority of the perennial rivers in the EH receive water from snow and glaciers. The contribution of snow to the runoff of major rivers in the EH is about 10% (Sharma 1993), in contrast to more than 60% in the western Himalayas (Vohra 1981). Because the melting season for snow coincides with the summer monsoon season, any intensification of the monsoon is likely to contribute to flood disasters in the catchments in the EH, although the impact will be less than in the western Himalayas. An increase in surface runoff during autumn and a decrease in spring are projected for the EH. The increase in surface temperature will contribute to a rise in the snow line, which in turn will increase the risk of flooding during the wet season as less precipitation is stored in the form of snow.

The supply of water in the EH is limited and governed by the renewal processes associated with the hydrological cycle (Figure 13). A warming climate will generally enhance the hydrological cycle resulting in higher rates of evaporation and a greater proportion of liquid precipitation (more rain and less snow). The potential changes in precipitation (amount and seasonality) will affect soil moisture, groundwater reserves, and the frequency of flood and drought episodes. Hydrological systems are also controlled by soil moisture, which largely determines the distribution of ecosystems, groundwater recharge, and runoff; the latter two factors sustain river flow and can lead to floods. However, the impacts of these on freshwater biodiversity are uncertain. Given these possibilities, different impacts of these changes to the water cycle will have different consequences in different watersheds.

When summer evapotranspiration is greater than precipitation, surface water flow will decrease in freshwater systems that are not glacier-fed, resulting in shrinkage and desiccation. This will cause small ponds and wetlands that are surface-water fed to contract. A contraction in these water bodies will reduce freshwater habitats, which in turn will reduce freshwater biodiversity through the contraction of habitats, acidification of lakes, and molecular damage associated with UV exposure. Reduced surface water flows will reduce the amount of available cations and thus the buffering capacity of softwater lakes, accelerating acidification and impacting negatively on organisms that cannot tolerate reductions in pH. The clear water of acidic lakes offers less protection against damaging UV rays.

The seasonal character and amount of runoff in the EH is closely linked to its wetland ecosystems and the cryospheric processes of snow, ice, and glaciers. Glacier melt influences discharge rates and timing in the rivers

Figure 13: **Climate change impact: Hydrological cycle change to reduce surface water availability**



that originate in the mountains. The timing of peak runoff, associated with the monsoon in many EH river basins, may change in the future. Shifts in the timing and intensity of the monsoon, and the manner in which the Himalayan range intercepts the available precipitable water content in the atmosphere, will have major impacts on the timing and amount of runoff in river basins such as the Ganges, the Brahmaputra, and the Irrawaddy. For every 1°C increase in temperature, the snowline will rise by about 135 m. Shifts in snowpack duration and amount as a consequence of sustained changes in climate will be crucial factors in water availability in hydrological basins. As glaciers melt rapidly, they will provide enhanced runoff, but as the ice mass diminishes, the runoff will wane. Availability of water from snow-fed rivers may increase in the short term, but will decrease in the long term.

When evapotranspiration is less than precipitation, water flow will increase. Increased glacial runoff and the thawing of permafrost due to warming will add to increases in flow in glacier-fed systems (for a period of decades, until this runoff eventually subsides). Increased water flow could change stream channel morphology by causing erosion along the banks and depositing sediments elsewhere. Such changes in channel morphology have direct links to freshwater species' lifecycles and habitat requirements (e.g., fish spawning and rearing), which in turn can have direct population-level impacts (Figure 14).

Impacts on freshwater ecosystems

There is growing concern that climate change may accelerate the damage to wetlands and freshwater ecosystems such as lakes, marshes, and rivers. The response of lakes and streams to climate change will involve complex interactions between the effects of climate on runoff, flow volume, hydrology, catchments, and in-lake processes. Climate change is expected to increase the temperature of lakes, streams, and other water bodies. Increases in water temperature may lower dissolved oxygen concentrations, particularly in summer low-flow periods (IPCC 1998). This will be detrimental to cold-water species in two ways: firstly, a direct temperature increase will reduce their survival or potentially extirpate species from asphyxiation and extremes beyond their narrow temperature range. Secondly, particularly in smaller lakes, warmer temperatures will generally occur at the surface layer enhancing production as most aquatic organisms are cold-blooded. This increase in production can quickly lead to eutrophication, increasing biological oxygen demand and causing the lower, cooler layer to become anoxic, potentially suffocating cool-water species. Larger lakes, however, may be able to maintain their temperature gradients despite some warming of surface layers. Such lakes may see increases in biodiversity if they are large enough to buffer the temperature effects, and cool water species could actually benefit from increased production (Figure 15).

In lakes and streams, warming will have the greatest biological effects at high altitudes – where biological productivity will increase and lead to the expansion of cool-water species' ranges – and at the low-altitude boundaries of cold- and cool-water species ranges, where extinctions would be greatest. Altered precipitation and temperature patterns will affect the seasonal pattern and variability of water levels in wetlands, potentially affecting valued aspects of their functioning, such as flood protection, carbon storage, water cleansing, and waterfowl/wildlife habitat (IPCC 1998). The geographical distribution of wetlands is likely to shift

Figure 14: **Climate change impact: Hydrological cycle change to increase surface water availability**

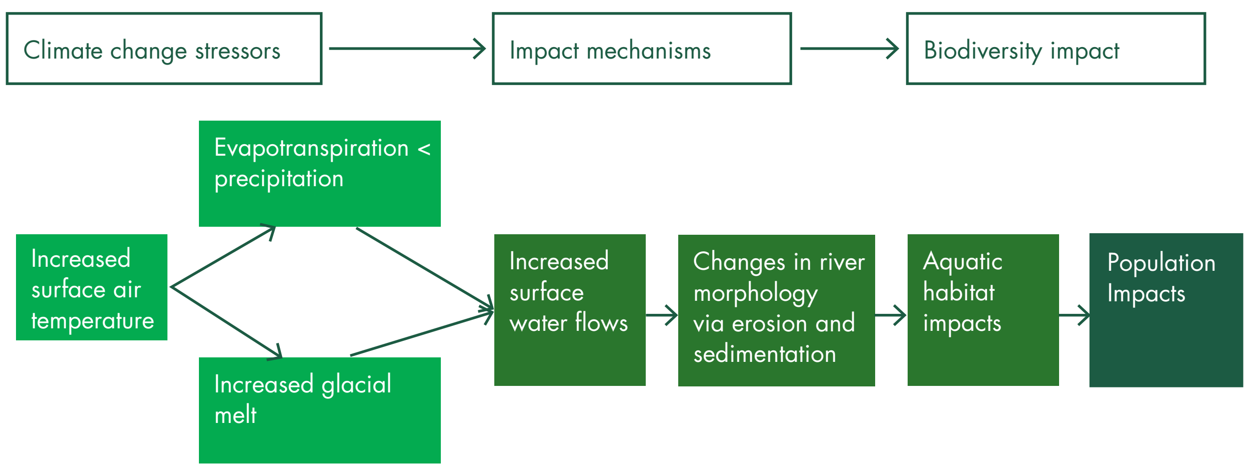


Figure 15: **Climate change impact: Changes in lake productivity**

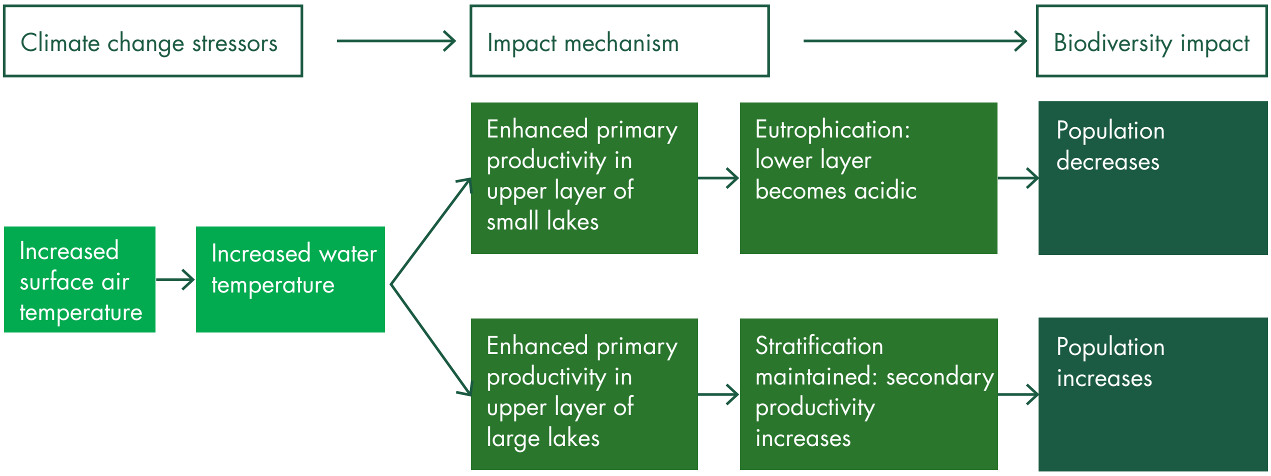
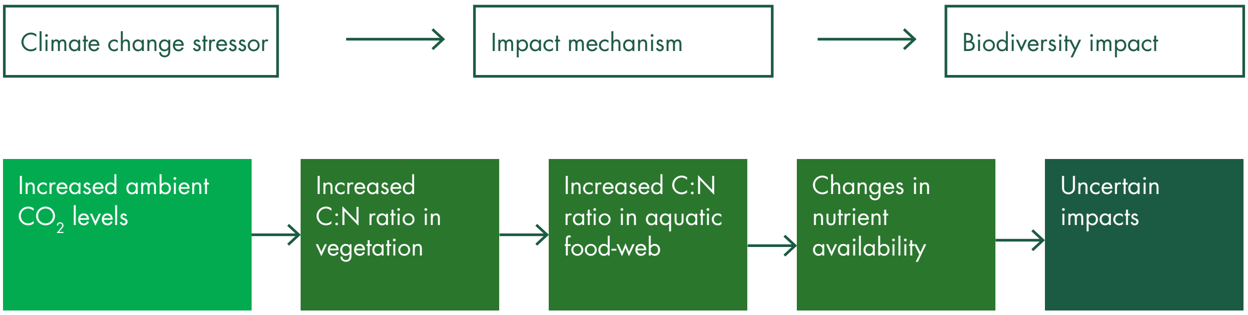


Figure 16: **Climate change impact: Changes in food-web dynamics**



with changes in temperature and precipitation, with uncertain implications for net greenhouse gas emissions from wetlands. Changes in these ecosystems could have major negative effects on freshwater supplies, fisheries, biodiversity, and tourism. Inputs of nutrients and other pollutants into aquatic habitats will vary with rainfall and other characteristics of the watershed.

One of the ways that climate change could affect freshwater biodiversity is by altering the carbon to nitrogen (C:N) ratio in riparian vegetation (Allan et al. 2005) (Figure 16). Increased ambient CO_2 generally increases the carbon to nitrogen ratio in plants. Plant litter provides important nutrient input to water bodies with corresponding increases in carbon in their nutrient pools. This change in nutrient quality could lead to corresponding changes in biological assemblages, enhancing organisms that use carbon efficiently, while suppressing those that depend on larger nitrogen inputs. Such changes in aquatic assemblages are highly uncertain, but would likely be noticeable throughout the entire food-web.

Impacts on Human Wellbeing

Rising prosperity and climate security are not conflicting objectives. Climate change is providing us with a reminder of the symbiotic relationship between human culture and ecological systems. This relationship is very evident in the EH, where some of the world's most fragile ecosystems are being affected by rapid warming. Indigenous people have become sentinels for a world undergoing climate change and the EH, in effect, a global climate change barometer. The livelihoods of subsistence farmers and pastoral peoples, who make up a large portion of the rural populations, could be negatively affected by such changes.

Livelihoods

A major area of serious impacts is in the field of agricultural production. Agriculture is the direct or indirect source of livelihood for over 70% of the population in the EH and is a substantial contributor to national incomes. Agriculture is highly sensitive to climate change and is expected to impact on the region differently, with some

Impacts on livelihoods and health: IPCC projections and consequences for human wellbeing

IPCC projection: There will very likely be decreases in precipitation. Warming in the EH is likely to be above the global average, and is expected to further reduce water availability through increased frequency of droughts, increased evaporation, and changes in patterns of rainfall and runoff.

Climate change will affect human health through complex systems involving changes in temperature, exposure to extreme events, access to nutrition, air quality, and other vectors. Small health effects can be expected with very high confidence to progressively increase in the EH, with the most adverse effects on low-income groups.

Human wellbeing projection: Major losses in agricultural production leading to increased malnutrition and reduced opportunities for poverty reduction are expected. Overall, climate change will lower incomes and reduce the opportunities for vulnerable populations. By the 2080s, agricultural potential could fall by 9%.

Ill health is one of the most powerful forces holding back the human development potential of poor households. Climate change will intensify this problem. Rainfall, temperature, humidity, and flooding are variables that most influence the transmission of malaria, cholera, diarrhoea, kala-azar, and dengue fever; climate change will affect all of these.

places projected to experience a decline in potentially good agricultural land, while others will benefit from substantial increases in suitable areas and production potentials (Fischer et al. 2002a). Management of climate hazards and climate change impacts in the agricultural sector and rural communities will be critical for success. The main direct effects of climate change 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 concentrations (which may have a beneficial effect on the growth of many crop types). Watershed responses to climate change are complex in terms of the simulated impacts of elevated concentrations of carbon dioxide and temperature and precipitation changes upon simulated fluxes of energy, water, carbon, and nutrients. The positive effects of climate change – such as longer growing seasons, lower natural winter mortality, and faster growth rates at higher altitudes – may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships. Indirect effects will include potentially detrimental changes in diseases, pests, and weeds, the effects of which have not yet been quantified. The extent of agricultural pollution will, thus, depend upon both human responses to climate change and changes in runoff associated with altered precipitation patterns.

Several studies in the past have shown that the production of rice, corn, and wheat has declined due to increasing water stress arising partly from increasing temperature, the increasing frequency of El Niño, and a reduction in the number of rainy days (Agarwal et al. 2000; Jin et al. 2001; Fischer et al. 2002b; Tao et al. 2004).

Climatic changes are predicted to reduce the livelihood assets of poor people, alter the path and rate of national economic growth, and undermine regional food security due to changes in natural systems and infrastructure impacts. Malnutrition, for example, will be further exacerbated due to disruptions to the growing conditions and environmental stresses at critical phenological stages. The flowering and fruiting phenology of many species will alter. Late snowfall could trigger the relative immobilisation of bees due to low temperatures, indirectly affecting the processes of pollination. As its cryospheric water towers are depleted, the EH is expected to experience excess runoff until the middle of this century, with meltwater flow declining thereafter. Extremes in floods and droughts through much of the century may destroy the food production base of the region (Bruinsma 2003). The food security and wellbeing of its people could suffer as a consequence of greater exposure to water-related hazards.

Fischer et al. (2002a) using agro-ecological zone (AEZ) methodology, quantified regional impacts and geographical shifts in agricultural land and productivity potentials, and the implications for food security resulting from climate change and variability. The analysis indicated likely increases in general in crop yield potential for temperature increases of 1 to 3°C, depending on crop. However, in specific cases, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger. Accordingly, a temperature increase above 1.5 to 2.5°C is expected to lead to a decline in the agricultural productivity of crops such as rice, maize, and wheat. In a study by the International Rice Research Institute, the yield of rice was observed to decrease by 10% for every 1°C rise in growing-season minimum temperature (Peng et al. 2004). In all likelihood, the wheat crop in the EH is already being adversely affected by climate change, as the area under wheat cultivation has been declining over the years. The regional aggregation of results, based on the HadCM3-A1FI 2080s scenario, showed a substantial decrease in wheat production potential in South Asia (20-75%), a distinct downward trend in the production potential of rainfed sugar crops (6-38%), and a loss of 23% to a gain of 20% for roots and tubers depending on location.

Higher temperatures during flowering may counter CO_2 effects (which lead to higher yields) by reducing grain number, size, and quality (Caldwell et al. 2005). Increased water demand under warming may also reduce CO_2 effects. Studies concentrated on the region have revealed that the net effect of temperature and carbon fertilisation is negative on rice yield (Karim et al. 1996). Yields of rainfed wheat grown at 450 ppm CO_2 increased up to 0.8°C warming, then declined beyond 1.5°C warming; additional irrigation was needed to counterbalance these negative effects (Xiao et al. 2005). Net cereal production in the region is projected to decline at least between 4 to 10% by the end of this century under the most conservative climate change scenario (Lal 2005). India could lose 125 million tons, equivalent to 18% of its rainfed cereal production; in contrast, China's rainfed cereal production potential of 360 million tons could increase by 15%.

Upland crop production, practised close to the margins of viable production, can be highly sensitive to variations in climate. The upward shift in thermal regimes due to warming will result in upward shifts of agricultural zones to higher elevations. For example, the buckwheat-barley belt will give way to rice cultivation, a trend already observed in Bumthang Dzongkhag in Bhutan at an altitude of more than 3000 masl. A temperature increase of 2°C would theoretically shift rice cultivation to even higher elevations, but here landforms are mainly steep, craggy slopes, appropriate only for protection forests. Warming may have positive impacts on some crop yields in some regions, but only if moisture is not a constraint. However, increases in the occurrence of extreme events or pests may offset any potential benefits.

Climate change is likely to represent an additional stress in areas experiencing rapid social change, as in many of the EH rangelands. Likewise, rangeland and pastoral production systems are likely to be affected by a decline in forage quality and quantity, heat stress, and diseases like foot and mouth in livestock. Grassland productivity is expected to decline by as much as 40 to 90% for an increase in temperature of 2 to 3°C combined with reduced precipitation (Smith et al. 1996). Fisheries and fish production are also sensitive to changes in climate and are currently at risk from overfishing, diminishing spawning areas, and extensive pollution. Inland freshwater fisheries at higher elevations are likely to be adversely affected by lower availability of oxygen due to a rise in surface air temperatures. In the plains, the timing and amount of precipitation could also affect the migration of fish species from rivers to the floodplains for spawning, dispersal, and growth (Bruinsma 2003). Climate change has the potential to substantially alter fish breeding habitats, the food supply for fish, and, ultimately, the abundance of freshwater fish populations (IPCC 2001a). Finally, both crops and livestock will be affected by increased incidence of alien/invasive pests and diseases.

Health

It is extremely difficult to make any projections about the extent and direction of the potential impacts of climate variability and change on human health with any confidence, because of the many confounding and poorly-understood factors associated with potential health problems. Equally, the complex interactions between climate stresses on the ecology of infectious diseases and other factors will determine how effectively prospective problems can be dealt with. The sensitivity of human health to various aspects of weather and climate, differences in the vulnerability of different socioeconomic, demographic and geographic segments of the population, movement of disease vectors, and health sector reforms are some of the factors that determine exposure, transmission, infection results, treatment, and prognosis. Forecasting climate change impacts on health is complex, because populations have different susceptibilities to disease and modelling health impacts is, therefore, that much more difficult. Consequently, there are very few studies that have attempted to look at the effects of climate change on health in the region. Data on health surveillance in the EH are not readily available, making predictions and comparisons difficult. These inadequacies notwithstanding, climate influence on human health is certain, and it is likely that newly affected populations will initially experience higher fatality rates.

Climate change will have a wide range of health impacts all across the EH through, for example, increases in malnutrition due to the failure of food security strategies, stress, disease, and injury due to extreme weather events (Epstein et al. 1995); increased burden of diarrhoeal diseases from deteriorating water quality; altered spatial distribution of some infectious diseases; and increased frequency of cardio-respiratory diseases from high concentrations of air pollutants such as nitrogen dioxide (NO_2), lower tropospheric and ground-level ozone, and air-borne particulates in large urban areas. A reduction in winter-time deaths is anticipated; however, human health is likely to suffer chronically from impacts related to heat stress (Bouchama et al. 1991; Ando 1998). Overall, climate change is expected to result in negative health effects associated with rising temperatures. Combined exposure to higher temperatures and air pollutants appears to be a critical risk factor for health during the summer months (Piver et al. 1999).

Endemic morbidity and mortality due to diseases primarily associated with floods and droughts are expected to rise with projected changes in the hydrological cycle. In the lowlands, hygrothermal stresses (warmer and wetter conditions) will also influence the epidemiology and increase the incidence of heat-related and vector-borne infectious diseases with increases in transmission windows (Martens et al. 1999). Malaria, schistosomiasis, and dengue are very sensitive to climate and are likely to spread into new regions on the margins of presently endemic areas because of climate change. Vectors require specific ecosystems for survival and reproduction; epidemics of these diseases can occur when their natural ecology is disturbed by environmental changes, including changes in climate (McMichael et al. 2001). With a rise in surface temperature and changes in rainfall patterns, the distribution of vector mosquito species may change (Patz and Martens 1996; Reiter 1998). Temperature can directly influence the breeding of malaria protozoa and suitable climate conditions can intensify the invasiveness of mosquitoes (Tong et al. 2000). Another concern is that changes in climate may allow more virulent strains of disease or more efficient vectors to emerge or be introduced to new areas.

Changes in temperature and precipitation could also expand vector-borne diseases into high altitude locations that hitherto have been uninfected. Expanding the geographic range of vectors and pathogens into new areas, increasing the area of suitable habitat and number of disease vectors in already endemic areas, and extending transmission seasons could expose more people to vector-borne diseases. Studies carried out in Nepal indicate that the present subtropical and warm temperate regions are particularly vulnerable to malaria and kala-azar. Climate change-attributable water-borne diseases including cholera, diarrhoea, salmonellosis, and giardiasis are prevalent in Bhutan, India, Myanmar, and Nepal. The relative risk of these conditions in 2030 is expected to increase as a result of elevated temperatures and increased flooding (Patz et al. 2005).

Other components of human wellbeing

Climate change is also poised to have an adverse impact on other components of human wellbeing, unless policies, legislation, and institutions are put in place to make development sectors more resilient to climatic perturbations. For years, too many viewed global warming simply as an environmental or economic issue. We now need to consider it as a security concern. The adverse impacts of climate change will place additional stress on socioeconomic and physical systems. These pressures may induce changes in demographic processes. Demographic trends, including the stability and size of populations, will be influenced directly through the impacts of climate change on human health and indirectly through the impacts of climate change on food security, human settlements, and the viability of natural resource-based economic activity. If the incidence and magnitude of extreme events such as droughts and floods increase, there could be large-scale demographic responses like migration. The annual rate of growth in migration has been disturbing in the countries of the EH, and the number of internally displaced people is expected to rise. Motivations for migration are diverse, with much of the rural-to-urban migration taking place as a result of increased economic opportunities and access to social services in urban centres. The situation is exacerbated by regular floods and droughts affecting the livelihoods of the landless and poor farmers in the region. Climate change will act in concert with other complex social, cultural, and economic motivations to spiral migration (Pebley 1998; Conway et al. 2000; Kates 2000).

Recreation is one of many cultural ecosystem services (MEA 2003). A rise in the elevation of the snow line will impact on winter tourism and change the seasonality of mountain runoff. In socioeconomic terms, mountain landscapes attract large numbers of people in search of opportunities for recreation and tourism. However, the environmental stress imposed by growing numbers of tourists is placing an increasingly heavy burden on mountain resources (Godde et al. 2000) and local communities. Tourism is, thus, both a significant economic driver for many mountain communities, but also an industry capable of adversely affecting the environmental quality of mountains and uplands.

5 Responses to Climate Change

Stakeholder Perceptions of Climate Change

The questionnaire surveys carried out in the North East states of India and Bhutan as part of this assessment came up with some enriching insights into what ordianry people perceive as climate change and the perceived impacts on their livelihoods and livelihood strategies. Although perceptions were varied depending on place, ethnicity, culture, and socioeconomic background, there was a clear idea among participants of the atypical changes in the environment. Most of the participants immediately talked about changes in weather patterns, shortages of water for irrigation and household use, increasing uncertainty in rainfall, and the emergence of new, and increase in the incidence of existing, pests and diseases in humans, animals, and plants. Such changes are evidenced by cases like the soya bean failure in Manipur due to excessive rain in the 2004/05 growing season; the decline in the number of indigenous fish with the introduction of brown trout in Bhutan; wild mushrooms growing in unexpected places; and increasing incidence of wild forest fires. On the positive side, there are reports of more areas becoming suitable for the cultivation of staple cereals, increases in the productivity of oranges in Helipong village in Tuensang, and improvements in apple quality in Bhutan in places where previously low temperatures in late summer cut short the fruit development stage. People are mostly concerned about the adverse changes that may disrupt the flow of ecosystem services that sustain rural communities ensuring food security, curing illness, and providing cash income and spiritual comfort by being at peace with nature.

Many communities have adapted and continue to adapt to environmental changes. In food production, they maintain a portfolio of crop species and varieties to adjust the cropping pattern and crop calendar to the prevailing and anticipated changes in the growing environment. In extreme cases, people migrate to more benign environments and reconnect with new sets of ecosystem services.

Awareness of climate change is fairly high in terms of relating natural hazards to perturbations in the environment as a result of anthropogenic interventions and disturbances linked to the indiscriminate use of natural resources. The participants' understanding of the adaptation and mitigation aspects of dealing with such environmental threats is, at best, tenuous as their experiences with problem resolution are not always limited to climate considerations. This was expected as coping mechanisms in terms of adjustments and interventions cannot be elucidated meaningfully from the climate change perspective alone, because most impacts we attribute to climate change are indeed consequences of several interacting stresses. People have always responded to changes in the environment and, in the process, have accumulated a vast amount of indigenous and appropriate knowledge and technologies for minimising adverse impacts while taking advantage of new opportunities.

Deductions from people's perceptions, however, are limited to a time scale within the range of human memory, while climate change impacts may become evident only after hundreds of years. In documenting people's perceptions, it is important to be mindful of the accuracy of the information that is provided and reasons why some information cannot be provided. Of course, perceptions are likely to be biased toward the response of agricultural crops or components of ecosystems that impinge on livelihoods or that are conspicuous enough to be considered. A verification means must be integrated into the information collection system. Perceptions are mostly associated with climate variability, rather than change.

Specific and relevant to the EH, a series of consultative workshops with stakeholders, partners, and government actors identified several impacts attributed partially or wholly to climate change based on informed perceptions and investigative research on aspects confined to or of relevance to the EH. Examples of the impacts of climate change are listed in Table 20, without taking into account any changes or developments in adaptive capacity or mitigation measures. The impacts listed are not exhaustive for the region, but merely restricted to the ecosystem resources and services within the scope of the project intervention.

Table 20: **Perceptions and projected impacts of climate change in the Eastern Himalayas identified in stakeholder consultations and case studies**

Climate change stress	Change types	Perceptions and impacts
Higher Temperature	• Ecological shifts • Biomass productivity • Habitat alteration • Forest fires • Biodiversity • Species composition • Glacial retreat • Human health • Phenological changes	• Loss of agricultural productivity with shortening of growing season (maturity period) • Success of C_3 plants under agriculture, forest, pastureland, rangeland, horticulture (vegetables) at higher elevations; increased productivity of 'Phumdis'/wetlands • Loss and fragmentation of habitats • Vertical species migration and extinction • Decrease in fish species (in Koshi river) • Reduced forest biodiversity • Changes in ecotones and micro-environmental endemism • Reduced availability of medicinal plants for traditional health systems • Increase in vector-borne diseases (malaria, dengue) • Formation and expansion of glacial lakes and wetlands at high altitude • More liquid precipitation at higher altitude • Peculiar tendencies in phenophases in terms of synchronisation and temporal variabilities
More precipitation	• Siltation • Drainage • Flooding • Human health • Fire incidence	• Decrease in controlled and prescribed burning under shifting cultivation and other forest use areas (North East India) • Wetland degradation (Umiam Lake, Barapani in Meghalaya) (climate attribution is strongly contested) • Degradation of riverine island ecosystems (Majuli) and associated aquatic biodiversity (refuted, but not overlooked) • Widening of river basins (Brahmaputra breadth widened from 1.8km to 20km near Kamakhyaa Temple) eroding agricultural land • Increase in water-borne diseases (kala-azar, cholera, diarrhoea) • Riverbank erosion • Flood-water related sedimentation • Increase in landslides and landslide dam outburst floods • Flood-water inundation (Dibrugarh and Dhubri) • Shallow water table pollution
Less precipitation	• Snowfall • Drying • Drought	• Reduced, delayed, and unseasonal snowfall affecting winter crops • Reduced forage availability resulting in change from dzo (yak/cattle cross) to horses as pack animals • Loss or degradation of natural scenic beauty • Drying up of water spouts and reduced flow in streams/springs (in Mizoram) • Frequent incidences of dry spells and agricultural drought • Lower humidity and less cloud at high altitudes • Shift in rainfall arrival from March to April • Increasing salinity from groundwater pumping
Higher temperature, more precipitation	• Biomass productivity • Biodiversity • Species composition • Flooding	• Increased pest infestation and disease outbreaks • Decline in orange yield (North East India) • Increased agricultural productivity (in Helipong in Tuensang) • Reduced agrobiodiversity • Change in utility values of alpine and sub-alpine meadows • Loss of species • Seasonal/interannual change in flow patterns • Soil erosion, especially topsoil • More landslides • Risk of snow avalanches • High rate of siltation with increased sediment • Increase in exotic, invasive, noxious weeds (mimosa in Kaziranga)

Climate change stress	Change types	Perceptions and impacts
Higher temperature and less precipitation	• Biomass productivity • Forest fires • Habitat alteration • Invasion • Biodiversity • Drought • Desertification • Eutrophication	• Decline in snowfall period, depth, and persistence • Decline in other resources (forage and fodder) leading to resource conflicts • Successional shift from wetlands to terrestrial ecosystems and shrinkage of wetlands at low altitudes (Loktak Lake, Deepor Beel) • Increase in forest fires (in Bhutan) • Invasion by alien or introduced species with declining competency of extant and dominance by xeric species (e.g., Mikania, Eupatorium, Lantana) • Increased crop diversity and changes in cropping patterns • Drying and desertification of alpine zones • Increased flow in summer/decreased flow in winter • Change in land use patterns • Soil fertility degradation • Increased evapotranspiration and reduced moisture content • Less infiltration affecting groundwater recharge • Decrease in river discharge • Nutrients in the floodplains increase productivity
Higher temperature and more or less precipitation with more extremes and hazards	• Human health • Food security • Livelihood • Socioeconomic upheaval	• High species mortality • Human migration due to extreme hydrological events and seasonal displacement • Increase in instances of cloudburst • Risk to hydropower plants, irrigation infrastructures, drainage systems, and municipal and industrial water supplies • Unpredictable water availability, environmental pollution (acidic rain in Manipur), and decline in water quality and quantity • Unpredictable rain with impacts on harvesting and cropping patterns • Increased GLOF potential • Erratic season transitions • Rural-to-urban and male out-migration • Labour shortages for agriculture • Reduced livelihood options • Heavy loss of life and property
Elevated GHG concentration (CO_2)	• NDVI • Methane emission • CO_2 source	• More growth/biomass production in forests, variable productivity in agriculture (oranges) • Net methane emission from wetlands (Thoubal, Vishnupur) • Increased degradation and destruction of peatland (bog, marshland, swamps, bayous) • Land use change that increases soil degradation

Vulnerability of Biodiversity to Climatic Threats

A detailed assessment was carried out to explore the vulnerability of mountain ecosystems to climate by investigating their exposure level to climate variability and potential change in the immediate future, the sensitivity of the components of mountain ecosystems, and the adaptive capacity of the coupled human-environment system. Some of the highlights of the research process, results, and conclusions drawn from the study are presented here.

Concepts of vulnerability

Reviews of the interpretations of ‘vulnerability’ in climate change research have generally identified two different vulnerability concepts. O’Brien et al. (2004a) made a distinction between an ‘end-point’ (top-down) and a ‘starting-point’ (bottom-up) interpretation of vulnerability. Vulnerability according to the end-point interpretation represents the net impacts of climate change taking into account feasible adaptations. This positivist concept is most relevant for the development of mitigation policies and for the prioritisation of international assistance. The Assessments of Impacts and Adaptations to Climate Change (AIACC) studies investigated vulnerabilities to climate impacts of a variety of natural resources, including ecosystems and biodiversity, and identified nine key messages for adaptation: (i) adapt now, (ii) create conditions to enable adaptation, (iii) integrate adaptation with development, (iv) increase awareness and knowledge, (v) strengthen institutions, (vi) protect natural resources, (vii) provide financial assistance, (viii) involve those at risk, and (ix) use place specific strategies (AIACC 2007).

Vulnerability according to the starting-point interpretation takes a different approach using modelling and scenario analysis to investigate climate change impacts. This interpretation assumes that addressing vulnerability to current climate variability will also reduce vulnerability to future climate change. This approach incorporates human and economic dimensions of local communities, particularly livelihood aspects and inter-sectoral relationships. Climate drivers are treated as important, but with a weaker attribution to future climate change; while drivers related to demographic, social, economic, and governance processes are given sufficient attention. This interpretation is largely consistent with the social constructivist framework and primarily addresses the needs of adaptation policy. An example of this approach is the UNFCCC's National Adaptation Programmes of Action (NAPAs) for Least Developed Countries (LDCs) to prioritise their urgent adaptation needs. The NAPAs examine vulnerabilities to current climate variations and extremes, building upon existing coping strategies at the grassroots level, for insights into vulnerability to future climate change. The involvement of different stakeholders is an integral part of this assessment process to identify interventions that might reduce vulnerability most effectively.

Information requirements

Assessing the impacts of and vulnerability to climate change and identifying adaptation needs requires good quality information. This information includes climate data, such as temperature, rainfall, and the frequency of extreme events, and non-climatic data, such as the current situation on the ground for different sectors including water resources, climatic hazards, agriculture and food security, livelihoods and human health, terrestrial ecosystems, and biodiversity. Lack of reliable data has invariably been cited as a major constraint in developing any meaningful insight into climate change in the EH. In addition, limited, highly regulated, and sometimes no, access to existing data is frustrating efforts to improve the situation of data paucity. The situation is no less challenging for vulnerability assessment at the coupled human-ecosystem level, and especially when trying to separate the potential impact of climate change from a myriad of real and interacting stresses. Equally important, and very much lacking at present, is the need for accurate socioeconomic data. This data needs to come from across sectors and is an important complement to existing climate-only assessments, particularly given that poverty has been recognised as a major factor in vulnerability.

Sources of vulnerability

It may be argued that the environmental vulnerability of the EH is an established reality, and further treatment of the issue is unwarranted. However, one cannot discount differentials in the degree of exposure, level of sensitivity, and adaptive capacity within the region, depending on the biophysical and geographic setting, accumulated social capital, and economic status. The region is also the focus of growing concern over biodiversity loss and ecosystem destruction, with all major causal drivers in unsettled flux from unprecedented socioeconomic change. There is an emerging consensus that the vulnerability of biodiversity in the mountain ecosystems reflects the vulnerability of coupled human-environment systems in the region to perturbations, stresses, and stressors. Mountain ecosystems are valued for their services (MEA 2003), which are quantifiable, making them obvious candidates as vulnerability indicators for sectors like human wellbeing, biodiversity, and water resources. The in depth inquiry into the current scientific understanding of vulnerability carried out for this report revealed subtle differences in what sets apart the two terms: 'biodiversity' and 'ecosystems.' For the purpose of this report, the treatment of biodiversity is limited to qualifying, and quantifying wherever possible, the structure, function, and services of ecosystems at different levels of aggregation. As a central element of sustainablility, biodiversity will be assessed as an inherent index of the natural vulnerability of mountain ecosystems.

Using this approach, poverty and biodiversity have emerged as sources of vulnerability, predicated on the synergy between human and biophysical subsystems of mountain ecosystems. Biodiversity is still valid as a measure of ecosystem resilience, and poverty metrics are still relevant for evaluating the autonomous and adaptive capacity of human systems. An attempt has been made to explore the biodiversity-poverty nexus in profiling the vulnerability of mountain ecosystems to the adverse impacts of climate change stresses. The following analytical framework gives an assessment of current vulnerability and its trajectory into plausible futures with climate change.

Assessment framework and indicators

Vulnerability is a function of context and exposure, and therefore, cannot be generalised. Functional vulnerability, which includes natural resilience, is the baseline measure to be assessed in formulating and implementing external adaptations. For the purpose of this report, the IPCC concept was adopted in developing and applying a vulnerability assessment framework for the mountain ecosystems in the EH (Figure 17). Within this implementation framework, the impacts of climate change on natural and managed ecosystems were assessed, integrating feedback mechanisms within the human-ecosystem-climate continuum. Finally, practical measures of vulnerability were defined. Integrating information across these factors into a unified vulnerability indicator is one of the challenges this report attempts to address in the process of characterising vulnerability.

A variety of exposure, sensitivity, and adaptive capacity indicators were used in the assessment of current vulnerability in the EH. Baselines for ecosystems and biodiversity were fixed with GIS-implemented spatial datasets prepared by several organisations under various initiatives inventorying biophysical resources on global, regional, and national scales. The rationale for such baselines is the need to focus on existing conditions in order to assess the capacity to deal with the actuality or eventuality of potentially adverse impacts in the future. The indicators are organised around the sources of vulnerability identified for focused assessment under the project based on the state and evolution of ecosystem sectors – water resources, ecosystem biodiversity, and human wellbeing. Besides their functional relationship with the three dimensions of vulnerability as understood by the IPCC, ie., exposure, sensitivity, and adaptive capacity, the indicators can also be grouped into five different sources of vulnerability as shown in Table 21. The rationale for including these sources in a vulnerability index is outlined in the following paragraphs.

Figure 17: **IPCC framework for vulnerability assessment**

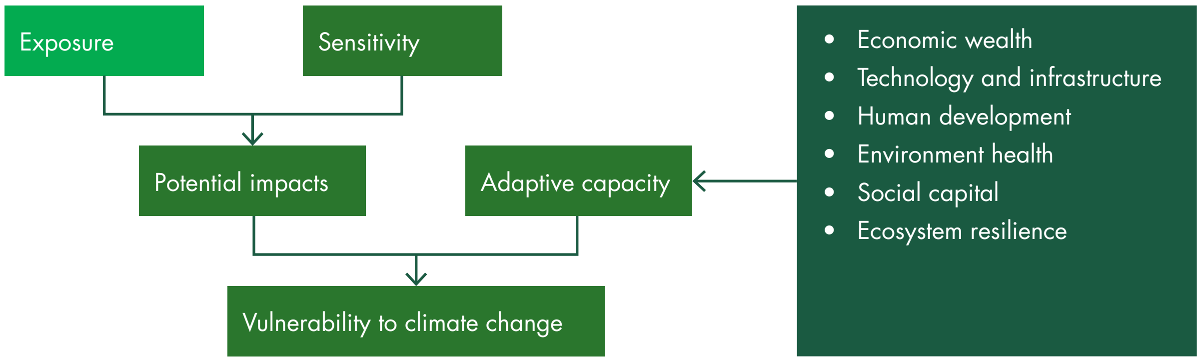


Table 21: **Sources and indicators of vulnerability**

	Indicators of vulnerability grouped under the IPCC dimensions		
Source of vulnerability	**Exposure**	**Sensitivity**	**Adaptive capacity**
Climatic	• Temperature mean and variance change • Precipitation mean and variance change		
Demography		• Infant mortality rate • % underweight children below age 5 • % urban population	• Population density • Literacy rate
Food and water		• Pop. with access to sanitation/safe drinking water • Human appropriation of net primary prod. (NPP) • % land managed • Water use	• Cereal production/ area
Occupation			• Economic activity rate • Dependency ratio
Environment		• Human influence index • Species under IUCN categories, VU, EN and CR • Carbon storage • Renewable water supply and inflow	• % tree cover

Note: VU - vulnerable; EN = endangered; CR = critically endangered

Key biophysical vulnerabilities to climate change, variability, and extreme events vary widely across the region due to differences in physical, social, and economic circumstances. An attempt is made in this assessment to identify socioeconomic and environmental conditions that adversely affect the ability of human populations to adapt to climate change, climate variability, and extreme weather events, while focusing on mountain ecosystem sectors and components like biodiversity, water resources and hazards, wetlands, and human wellbeing (including livelihood and health). The National Communications to the UNFCCC and NAPAs of EH countries reveal that the key biophysical vulnerability contexts are livelihoods and food security, water resources, natural ecosystems and biodiversity, hazards and natural disasters, and human health.

Climate variability and change directly increase the vulnerability of people through flooding, drought, changes in average temperatures, temperature extremes, and extreme weather events. Variability in precipitation affects crop production directly, as well as through impacts on soil, pest and disease outbreaks, and other mechanisms. Trends and variance in temperature and precipitation based on historic data are crucial to vulnerability. Large seasonal and inter-annual variability heightens the vulnerability of an impact entity.

The demographic determinants of vulnerability are captured by five indicators: population density, urban population, literacy rate, infant mortality rate, and underweight children. Rates of mortality and underweight children depend on quality of life and are the most relatable metrics of human wellbeing embodying the combined influence of multiple factors. Literacy implies the quality of human capital and is significant in defining socioeconomic vulnerability. Population (number and density) is a reliable measure of vulnerability as well as adaptive capacity. A population that is literate is more likely to be resilient due to their ability to draw on alternative entitlements in the face of shock.

Food and water are part of livelihood security. Five indicators are identified to represent the food and water situation in the region, with four providing a holistic look at the sector sensitivity from an ecosystem services perspective and one as a measure of the adaptive capacity of the people to deal with food and water risks. These indicators are: cereal production; population with access to sanitation and safe drinking water; access to water for other uses; human appropriation of net primary production; and percentage of land managed. Cereal production captures the state of development in the agriculture sector and the access of farmers to production inputs. People's access to sanitation and drinking water, and water use situations shed light on human health standards and the state of water resources in terms of demand and supply. Human appropriation of net primary production presents a composite picture of food security, resource degradation, and population pressure in the ecosystems.

The composition of the labour force (occupational structure) reflects the social and economic resources available for adaptation. The two indicators used as proxies are the economic activity rate and the dependency ratio, which reflect labour productivity, risk level to natural hazards, and the social cost of dependencies. A highly productive labour force indicates high institutional strength and stable public infrastructure, and reduced social vulnerability. Hence, a stable and diverse occupational structure means that the labour force is utilised optimally. The absence of infrastructure services seriously increases vulnerability levels and reduces adaptive capacity.

Indicators of the vulnerability of the environment, ecosystems, and biodiversity are measured by the human influence index, which represents human-induced disturbances in ecosystems; the proportion of species listed as vulnerable (VU), endangered (EN), and critical (CR) as an indicator of the biodiversity vulnerability of an ecosystem; carbon storage and renewable water flows as regulating services with an inverse relationship to vulnerability; and the percentage of tree cover as an indicator of an ecosystem's natural adaptive capacity, assuming that less fragmented forests have higher resilience to external stresses.

The data required for the analysis were obtained from diverse sources and in a variety of formats, which were then transformed into spatial data layers for processing in a common GIS environment. Table 22 describes the data sources and format, and the indicators derived from them. Each indicator is dimensioned into component indices of comparable scale and further aggregated to construct the composit indices for the project focal areas of the mountain ecosystems. A higher index value represents higher vulnerability of the impact entity. The sectoral profiles of vulnerability to climate change were constructed under the assumption that the selected proxy indicators adequately describe the fundamental attributes of human ecology and the sociopolitical economy of the region, and that climate exerts a significant influence on their present state and transformation in the future. Finally, the composite indices of biodiversity, human wellbeing, water, and environment and ecosystem services were integrated into a vulnerability index of mountain ecosystems through clustering and principle component analysis.

Table 22: **Data used to describe indicators for producing indices of the three dimensions of vulnerability (exposure, sensitivity and adaptive capacity)**

Dimensions of vulnerability	Indicator	Source	Unit	Format
Exposure				
	Change in temperature	WorldClim	°C	Raster grid
	Change in precipitation	WorldClim	% of base	Raster grid
	Temperature and precipitation variability	WorldClim	% of base	Raster grid
Sensitivity				
Biodiversity	IUCN threatened species richness	WildFinder database (WWF 2006a)	count	MS Access
	Human influence index	LWP-2 (WCS and CIESIN 2005)		Raster grid
	Urban population fraction	Various national level population and census data	% of total population	Tabular
	Human appropriation of net primary production	HANPP (Imhoff et al. 2004; CIESIN 2004)	tons/km²/year	Raster grid
Human wellbeing	Sanitation facilities	Diverse national socioeconomic data	% of total population	Tabular
	Safe drinking water	Diverse national socioeconomic data	% of total population	Tabular
	Infant mortality rate	CIESIN (2005)	deaths/10,000 live births	Ascii grid
	% underweight under age 5	CIESIN (2005)	% of under 5 count of children	Ascii grid
Water systems	Annual precipitation	ATLAS data, IWMI	mm	Asci grid
	Annual evapotranspiration	ATLAS data, IWMI	mm	Asci grid
	Moisture availability index	ATLAS data, IWMI		Asci grid
	Global map of irrigation area	Land and Water Digital Media Series 34 (Bruinsma 2003)	ha/grid cell	Ascii raster
	Global composite runoff	UNH-GRDC Composite Runoff Fields v1.0 (Fetke et al. 2000)		Arcview grid
	Global weltands, lakes and reservoirs	GLWD Ver 3 (Lehner and Doll 2004)	coverage	Polygon feature
Ecosystems	Percentage tree cover	PAGE (Matthews et al. 2000), WRI	%	Raster grid
	Carbon store in soil and above- and below-ground live vegetation	PAGE (Matthews et al. 2000), WRI	t/hectare	Raster grid
	Area of managed land	Ecoregions Data (WWF 2006b)	km²	Excel sheet
Adaptive capacity				
Economy	Cereal production/capita	From sub-national socioeconomic data	kg/capita	Excel sheet
	Economic activity rate	From sub-national socioeconomic data	%	Excel sheet
Human development	Literacy rate	From sub-national socioeconomic data	%	Excel sheet
	Dependency ratio	From sub-national socioeconomic data	%	Excel sheet
Environment	Population density	GPW Version 3-alpha (CIESIN/CIAT 2005)	person/km²	Ascii grid
	Percentage tree cover	PAGE (Matthews et al. 2000)	%	Raster grid

Note: IWMI = International Water Management Institute, Sri Lanka

Vulnerability in the EH

An overall depiction of vulnerability averaged across ecosystem elements uncovered large areas in the EH that would likely be impacted by adverse exposure to climate change stresses. Figure 18a shows the collective relative vulnerability integrated across components of mountain ecosystems and dimensions of susceptibility to climate change impacts. The most vulnerable areas are the whole stretch of the Brahmaputra valley, segments of the lower Gangetic plain falling within the EH, the Terai-Duar tract from Nepal to eastern Bhutan, and the vicinity of Loktat lake in Manipur. Population pressure and devastation of natural biodiversity are the main factors that make these places highly sensitive to climate change. Although agriculturally the most productive area in the region, the people suffer from low per capita human development assets, and from regular disturbances from natural hazards like floods and disease epidemics. Biodiversity is at enormous risk of being degraded further as resource extraction is intensified to cope with the threats to food security and in improvised strategies for relief and recovery following each disastrous event.

In these areas of high vulnerability, the resilience of ecosystems is stretched to the limits, and the adaptive capacity of the resident population is also being eroded in their daily struggle to break out of the poverty trap. These are also potential sites for carbon emissions, offsetting the gains in sequestration offered by the forests in the adjacent mountain areas. Besides intensive agriculture, this stretch of land is also the site of much of the industrial activity in the region, with dense urban settlements and various resource use infrastructure. it is overcrowded with roads. This accounts for the high human influence index associated with high energy consumption and intense disturbance to ecosystems. The carbon balance in terms of the human appropriation of net primary production is already negative in this part of the region.

The least vulnerable places are in Bhutan, the Zhongdian of China, the Chin and Kachin states of Myanmar, Mizoram, and pockets in Sikkim and Nepal. Low vulnerability scores in places could be largely attributed to the values assigned to human pressure, biodiversity, and forest cover. Factor weightings could have reduced the bias and improved the overall interpretation, but identifying reliable weights would add a whole new methodological dimension to this assessment. Nonetheless, weighting indicators could be considered for similar studies in the future. The spatial descriptions of these sectoral and system vulnerabilities are illustrated in Figure 18b.

From all the vulnerability analyses, one common aspect that stood out was the consistent projection of vulnerability for the Terai belt in south-east Nepal extending between the districts of Parsa and Jhapa. This might be considered a hotspot of vulnerability in the EH. There are several possible reasons for this outcome ranging from intense human pressure, low socioeconomic services, few productive livelihood assets, poor health and chronic disease outbreaks, land degradation, and deforestation, the impacts of which are further aggravated by extremes of weather and climatic variability including recurrent floods. Other important locations of vulnerability are the Brahmaputra valley, the lower Gangetic plain of North East India, and a few highly localised sites that may be a true manifestation resulting from the complex physiography and diversity in nature and society, or artifacts from raster data integration. Other factors that could predispose areas to vulnerability include the following:

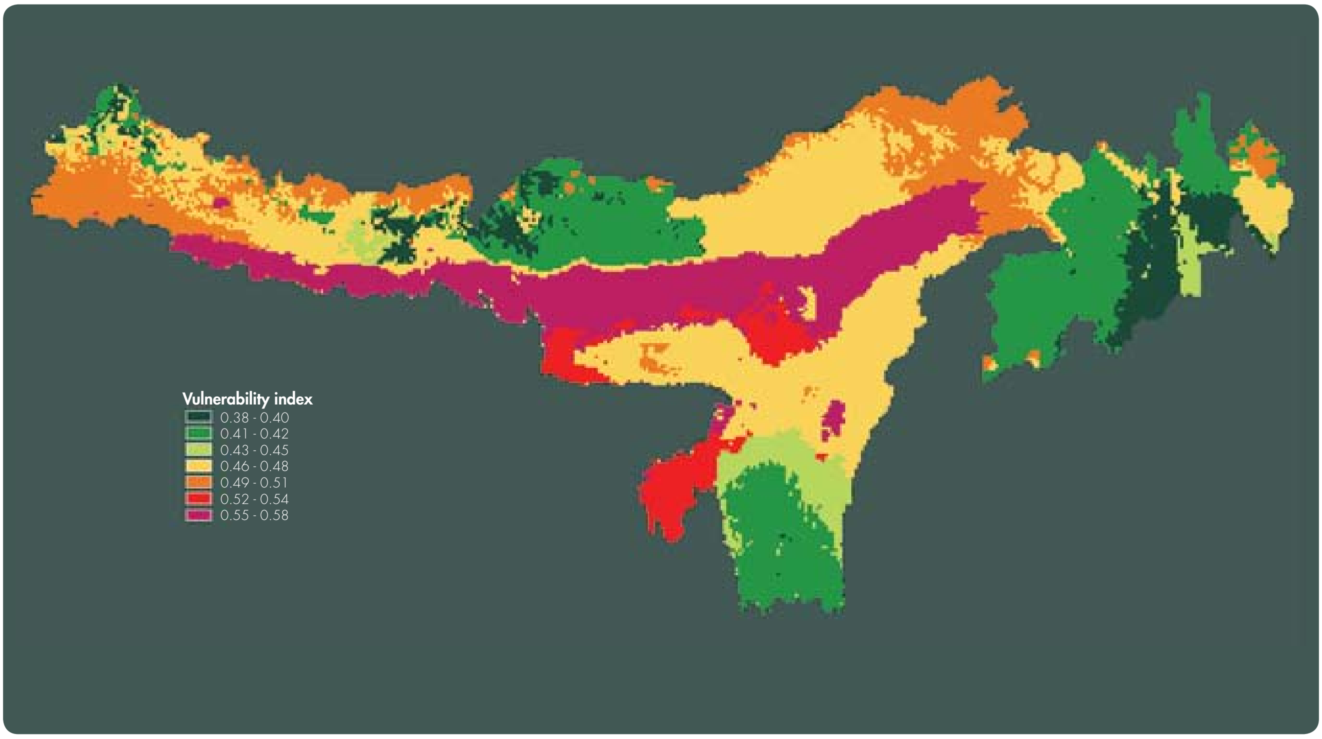
- Poverty and low human development, which make the poor intrinsically vulnerable because they have fewer resources with which to manage risks. There is a two-way interaction between climate-related vulnerability, poverty, and human development.
- Disparity in human development – inequality within countries is another marker for vulnerability to climate shocks. Gender inequalities intersect with climate risks and vulnerabilities. Women's historic disadvantages, such as their limited access to resources, restricted rights, and muted voice in shaping decisions, make them highly vulnerable to climate change.
- Lack of climate-defence infrastructure that could serve as a buffer between risk and vulnerability; for example, flood defence systems, water infrastructure, early warning systems, and so forth.
- Limited access to insurance against climate related losses. There is an inverse relationship between vulnerability, which is concentrated in poor areas, and insurance, which is concentrated in more affluent, urban places.

Vulnerability of protected areas

An attempt was made to assess the vulnerability of the existing protected area network (PAs) under a changing climate by overlaying PAs onto the map of vulnerability (Figure 19) and ranking according to their degree of vulnerability (Annex 1). Ranks are based on the sum of the vulnerability metrics that each protected area system covers. The vulnerability characteristics are guidelines only and, in some cases, will require refinement in order to form the basis for a quantitative, or even qualitative,

Figure 18: **Relative magnitude and spatial characteristic of vulnerability to climate change impacts in the Eastern Himalayas**

a) Collective vulnerability, i.e., vulnerability integrated across different components of mountain ecosystems and dimensions of susceptibility to climate change impacts



b) Relative vulnerability of biodiversity, water, ecosystems, and human wellbeing to climate change impacts

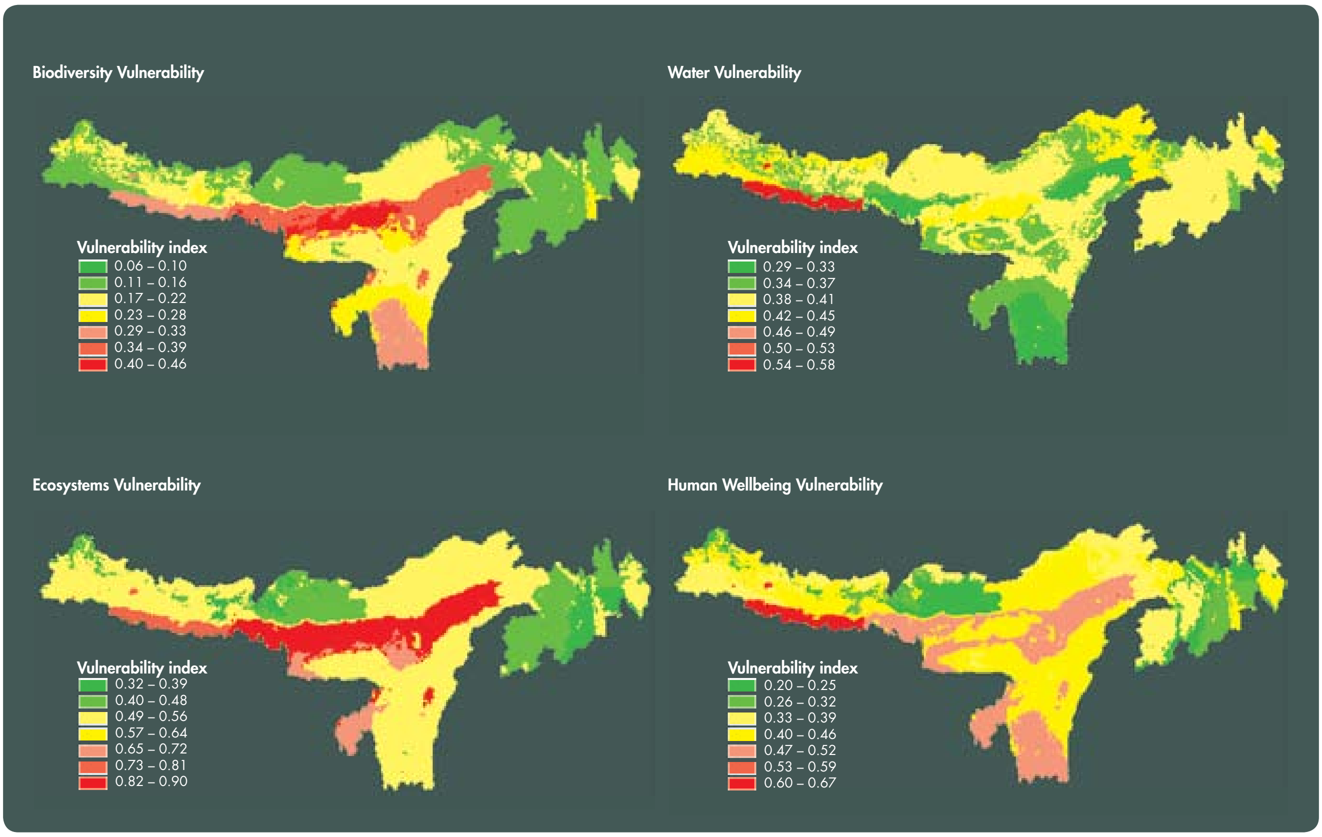
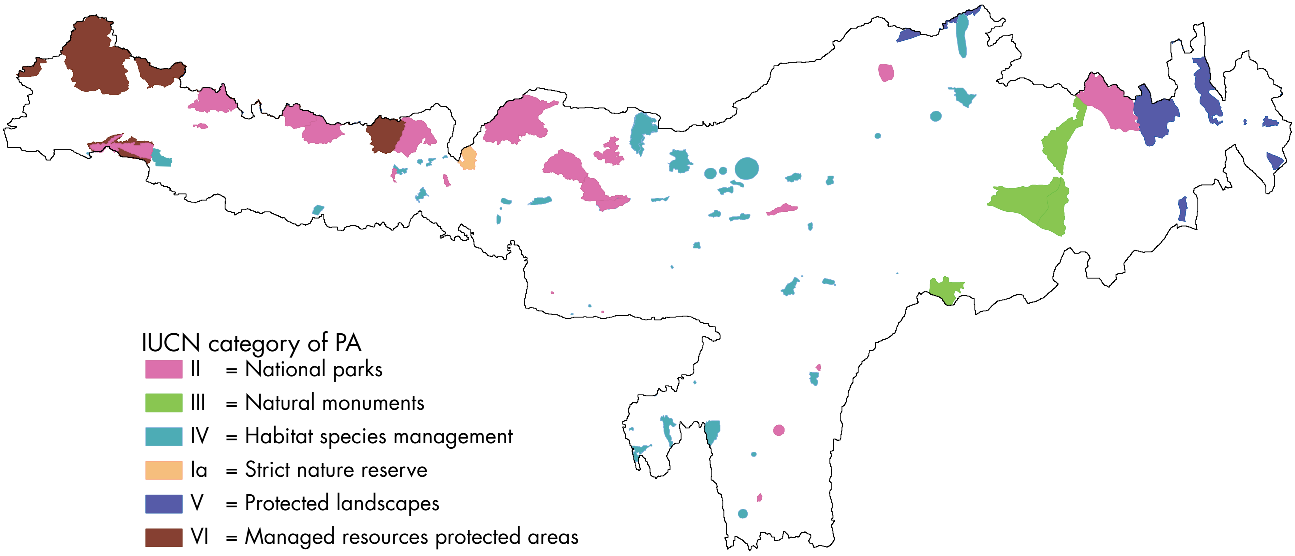
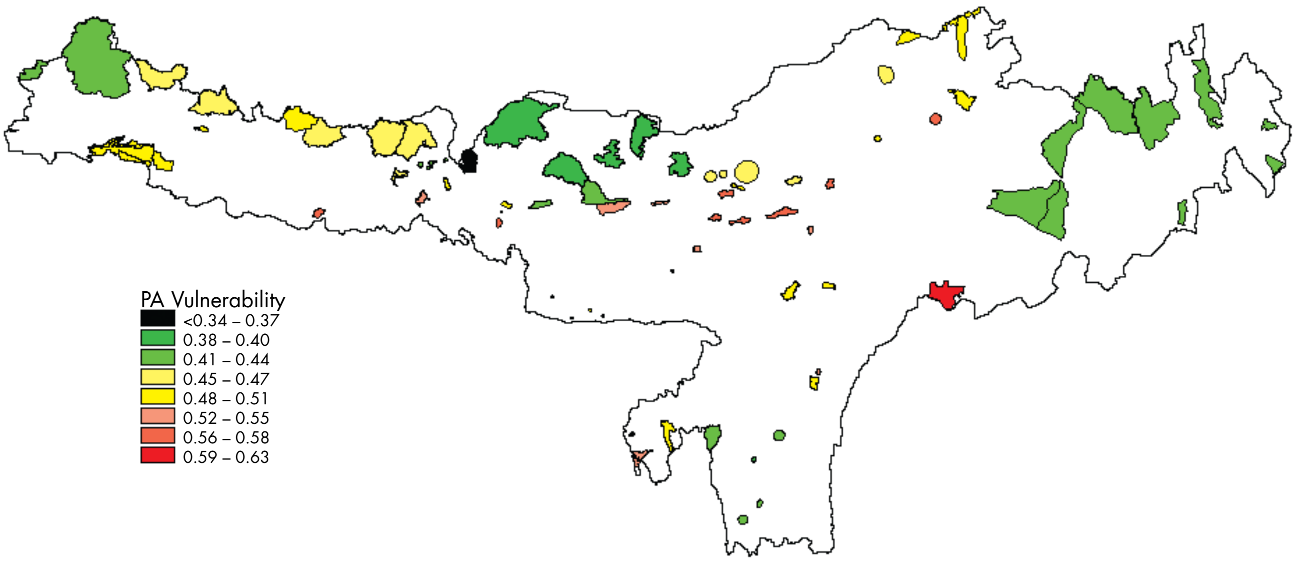


Figure 19: **Protected area (PA) coverage and vulnerability in the Eastern Himalayas**

a) Protected areas



b) Vulnerability of protected areas



ranking scheme. Some characteristics of protected areas that predispose them to climate change vulnerability have been summarised by Malcolm and Markham (1997) as follows:

- Presence of sensitive ecosystem types and species near the edges of their historical, geographically limited distributions
- Topographic and geomorphological feature like size and perimeter to area ratio
- Presence of natural communities that depend on one or a few key processes or species, isolation from other examples of component communities
- Human-induced fragmentation of populations and ecosystems, and other existing anthropogenic pressures within and close to borders

There are 91 protected area systems in the EH listed in the World Database on Protected Areas ranging from areas as small as 2 hectares (Baghmara Pitcher Plant Sanctuary) to as large as 3,400,000 hectares (Qomolangma Nature Preserve) (Figure 20a). They cover the full range of IUCN categories, but only one has been designated as a Strict Nature Reserve (Toorsa, Bhutan, Category Ia). Htamanthi Wildlife Sanctuary in Myanmar is assessed to be the most vulnerable, while other big national parks like Kaziranga, Manas, and Koshi Tappu Wildlife Reserve are potentially vulnerable to climate change (Figure 19b). These conservation areas and other smaller ones are considered to be vulnerable as they are located within the most vulnerable parts of the EH. Increasing pressure for land and other natural resources from a burgeoning population make these areas susceptible to habitat fragmentation and species extirpation through illegal poaching, hunting, and overexploitation. Furthermore, they are isolated islands of wild habitats with no prospect for habitat expansion or corridor links to extend range or for genetic enrichment. Many of them are too small to remain viable and withstand the pervasive effects of climate change. Three sites in India, one in Bangladesh, and three in China could not be ranked for their vulnerability, as the index could not be computed.

Vulnerability of ecosystems

Mountains exhibit high biodiversity, often with sharp transitions in vegetation sequences, subsequently ascending into barren land, snow, and ice. In addition, mountain ecosystems are often endemic, because many species remain isolated at high elevations compared to lowland vegetation communities that can occupy climatic niches spread over wider latitudinal belts. The response of ecosystems in mountain regions will be most important at ecoclines (gradual ecosystem boundaries), or ecotones (where step-like changes in vegetation types occur). Guisan et al. (1995) noted that ecological changes at ecoclines or ecotones will be amplified because changes within adjacent ecosystems are juxtaposed. In steep and rugged topography, ecotones and ecoclines increase in quantity but decrease in area, and tend to become more fragmented as local site conditions determine the nature of individual ecosystems. McNeely (1990) suggested that the most vulnerable species at the interface between two ecosystems will be those that are genetically poorly adapted to rapid climate change. Those that reproduce slowly and disperse poorly and those that are isolated or highly specialised will, therefore, be highly sensitive to seemingly minor stresses.

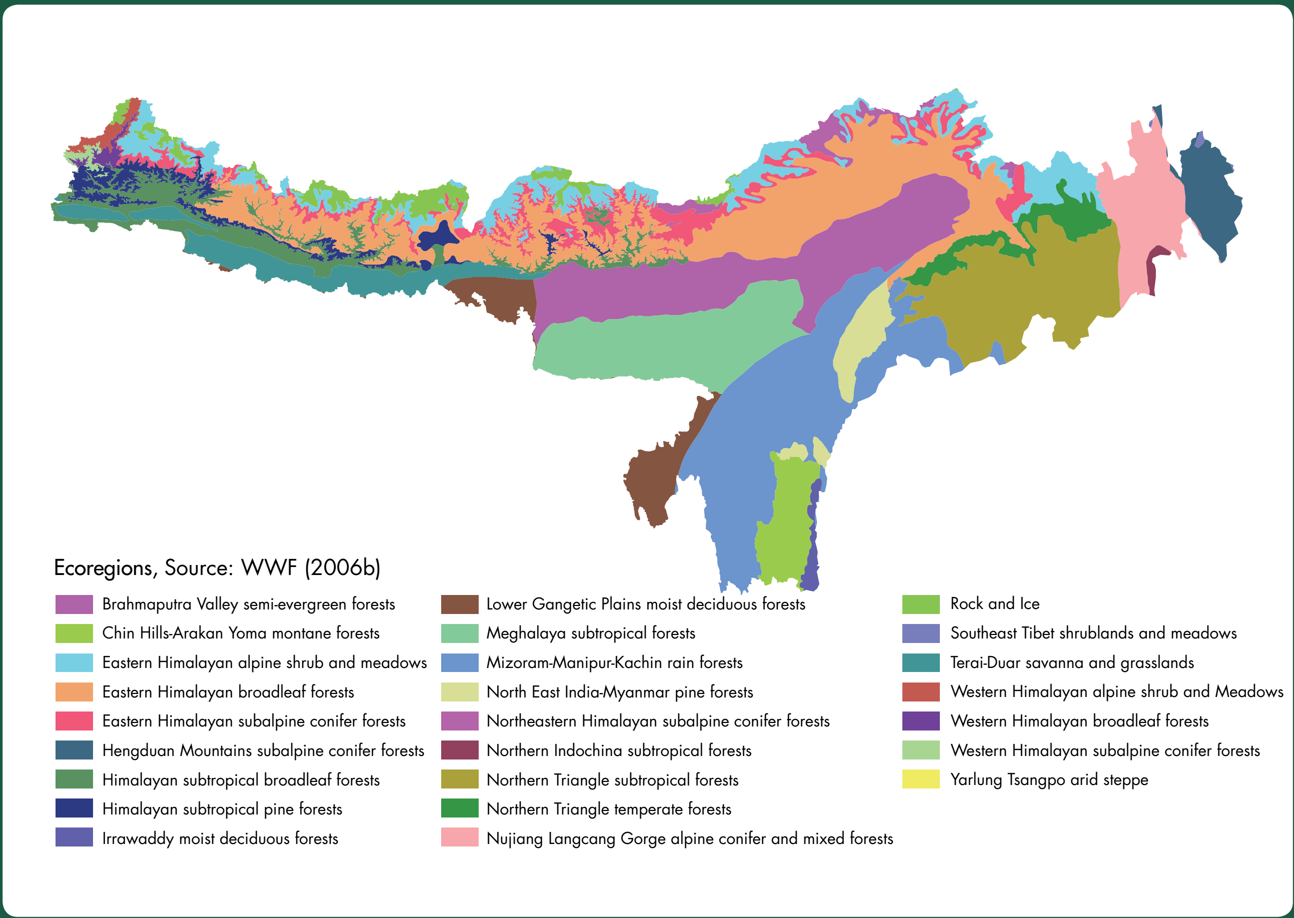
The Terrestrial Ecoregions of the World Version 2.0 (WWF 2004; Olson et al. 2001) map depicts 825 terrestrial ecoregions worldwide. Ecoregions are relatively large units of land containing distinct assemblages of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land use change. This comprehensive global map provides a useful framework and units for biological analysis and for conservation planning and action, like comparison among units and the identification of representative habitats and species assemblages, identification of areas of outstanding biodiversity and conservation priority, assessment of gaps in conservation efforts worldwide, and for communicating the global distribution of natural communities on Earth. These units are nested within two higher-order classifications: biomes (14) and biogeographic realms (8). Ecoregions have increasingly been adopted by research scientists, conservation organisations, and donors as a framework for analysing biodiversity patterns, assessing conservation priorities, and directing effort and support.

Using this map, we identified 25 ecoregions within 2 realms and 7 biomes in the EH as shown in Figure 20a. Six of these are entirely located in the region, while one ecoregional unit specific to the HKH region has less than 1% representation in the EH (the Yarlung Tsangpo arid steppe).

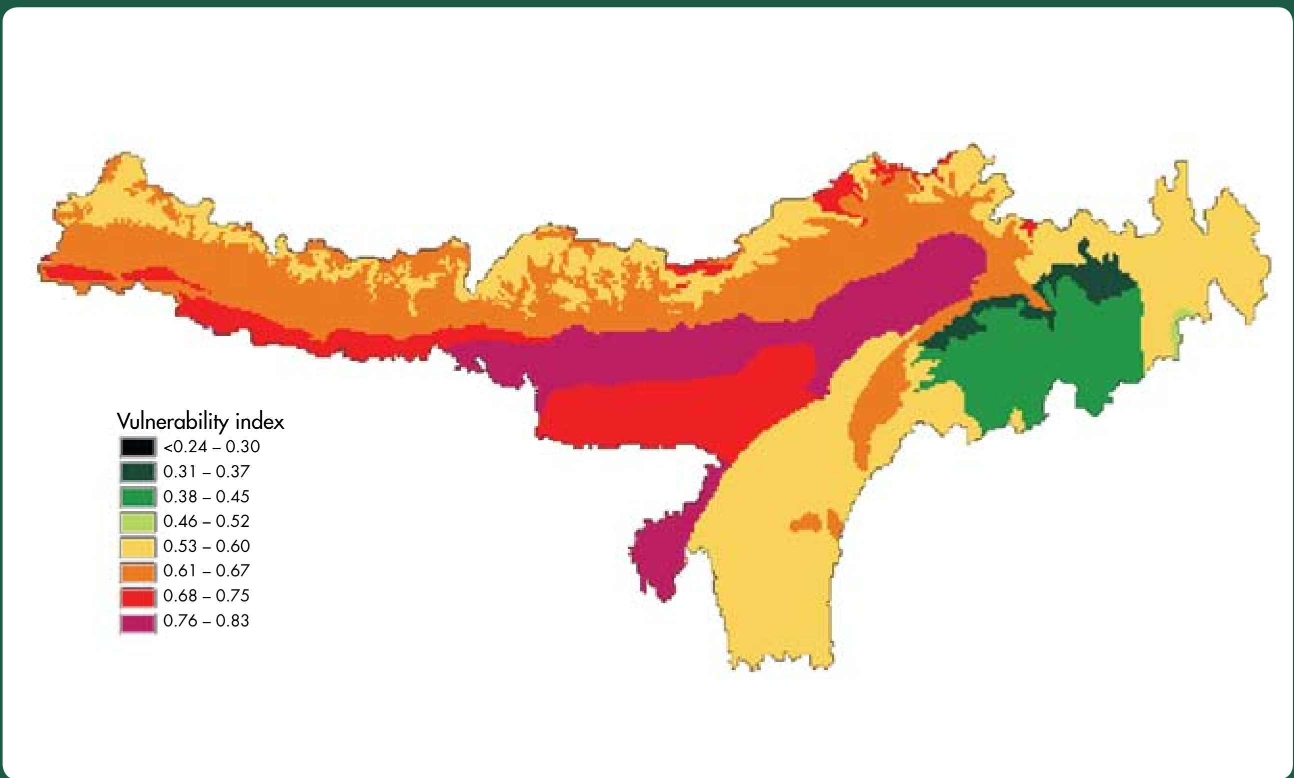
Mountain ecosystems are being continuously threatened by global change, including climate change. Management practices and the underlying socioeconomic changes have pushed the ecological resilience of mountains to their limits. Land use is the major driving force that could result in near complete loss of alpine vegetation by the end of the current century. Natural ecosystems are being continuously replaced or modified

Figure 20: **Ecoregions of the Eastern Himalayas and their relative vulnerability to climate change**

a) Ecoregions



b) Vulnerability of individual ecoregions



by agricultural systems. Thus it is important that ecosystem vulnerability is assessed within this context.

A modest attempt was made to characterise ecosystem vulnerability by implementing a quantitative approach anchored in the conceptual framework put forward by the IPCC. There are several other schools of thought in advancing the theoretical construct of vulnerability, but the most compelling ones are those that understand vulnerability as being the start-point characteristic of an ecosystem that predisposes it to future threats arising out of changes in the factors that influence the ecosystem condition. The approach taken in this assessment was essentially a compromise, drawing on the functional aspects of these perspectives. While hypothesising the process of quantification, it is almost impossible to think of vulnerability exclusively in the context of climate change and disregard other drivers of change that may impose stresses, directly or in concert with it.

The vulnerability level of ecoregions was assessed in the context of climate exposure, the sensitivity of their component ecosystems, habitats, and species, and their natural resilience, coupled with the coping capacity of the human population dependent on their goods and services for wellbeing. Appropriate variables and indicators were used to develop metrics for climate exposure, system sensitivity, and adaptive capacity which were calculated as dimension indices and then integrated into a vulnerability index. The map of the ecoregions was superimposed on the raster interpretation of vulnerability, and the pixel-level values enclosed within each ecoregion were averaged to obtain the mean index of vulnerability. The index values were then ranked to understand the relative fitness of ecoregions to withstand the adverse impacts of climate change. The results are given in Annex 2 and displayed visually in Figure 20b.

The Brahmaputra valley semi-evergreen forests were identified as the most vulnerable of the 25 ecoregions in the EH. The least vulnerable are the Northern triangle and Indochinese forests. The vulnerability index for the Yarlung Tsangpo arid steppe could not be assessed as <1% of its area is in the EH and probably below sub-pixel level. Other vulnerable areas are the lower Gangetic plains moist deciduous forests, Meghalaya subtropical forests, Terai-Duar savanna and grasslands, and Northeastern Himalayan sub-alpine conifer forests.

The overarching threats to the vulnerable ecoregions' natural habitats stem from forest clearing and livestock grazing. But settlements and agriculture go back thousands of years and have already taken a heavy toll on the natural habitat and biodiversity. Vast areas of original habitat were taken over by large tea plantations. The Naxalite insurgency in the Brahmaputra valley prevents effective government administration of conservation areas (protected areas and reserve forests). The movement is also funded to some extent by poaching and wildlife and timber trade. The dense human population is still growing rapidly. The urbanisation, industrialisation, and agriculture associated with this population growth and its resource and economic needs pose serious threats to the remaining forest fragments. The small, protected areas are vulnerable to this tidal wave of human growth and are inadequate to conserve biodiversity. Finding additional habitats for protection will be challenging. Therefore, existing protected areas should be effectively managed and protected, and restoring critical habitats should be considered where necessary. Deforestation is a huge factor, especially when it results from jhum (shifting cultivation) in and around the remaining blocks of forests. However, when allowed to be carried out in traditional fashion, jhum maintains forests and does not lead to deforestation (Kerkhoff and Sharma 2006). Hunting for tigers and elephants is rife. Mining for coal and limestone along the migratory routes of elephants threatens their traditional movement, resulting in the escalation of human-elephant conflicts, which are already intense. Many of these lands have been leased by tribal landholders to private mining companies.

The Terai is Nepal's main area for logging and wood industries. Sawmilling is the largest wood-based industry, with private sawmills spread over most of the Terai districts. Fuelwood production is also important, most consumed within the country and the rest exported to India. In addition to recorded log production, some unauthorised cutting for export also takes place. Growing population pressure in the hills has led to migration to, and settlement in, the Terai, both spontaneously and through government-sponsored resettlement programmes. The southern parts of the Terai are, therefore, densely populated, and most of the area is under cultivation, although northern regions have a lower population density. Water diversion, especially for irrigation, poses another significant threat. Poaching and overgrazing are also a problem. Much of the savanna grassland may have been created by burning by pastoralists and other human intervention.

Vulnerability of administrative areas

To assess the relative vulnerability of countries in the region, the vulnerability outcome was projected on to an administrative map to produce area-averaged vulnerability index figures for every sub-national unit. This offers a glimpse into the socio-political contours of vulnerability and the forces that are in effect to impact some units more than others. Once again, units were ranked according to their vulnerability scores focusing on the assessment of potential entry points for adaptation activities and the identification of institutional partners for implementation. These units are listed in the Annex 3 along with a few important characteristics and the scaled dimensions of vulnerability with scores and ranks.

Implications of the vulnerability analysis

There were significant inverse spatial correlations between many of the indicators used to describe ecosystem sensitivity and resilience, and human adaptive capacity in the demographic and socioeconomic aspects, which suggest that sensitivity or susceptibility and adaptive capacity or resilience describe one basic attribute of an ecosystem and in essence mean one and the same. Therefore, the relevance of defining sensitivity as one of the dimensions of vulnerability is questionable, while exposure is often indistinguishable from impact. Instead, it is proposed to redefine these dimensions as stress, potential impact, adaptive capacity, and threat. Further, there is sufficient justification to conclude that a social vulnerability-based approach within a social constructivist framework is the preferred strategy for vulnerability assessment, bearing in mind the key objective of addressing the needs of adaptation policies and actions.

The vulnerability profile described for the mountain ecosystems of the EH illustrates the inequality that pervades the human ecology and political economy of the region. There are contradictions as well as conformity with the mainstream perception that poverty leads to ecological vandalism and resource degradation. Evidence accumulated through this study also suggests otherwise: that the poor understand the need to safeguard the ecosystem structure and functions as a proximate source of wellbeing. Resilient ecosystems are often found overlapping with places where the poor live. Equally, the most vulnerable areas are those where the poor are concentrated, like the Brahmaputra valley, the Terai-Duar belt, and the lower Gangetic plain of West Bengal. High population density and insufficient attention to the enhancement of human social capital are major factors that magnify vulnerability of not only the human adaptive capacity, but also the ecosystem's ability to sustain the flow of goods and services. Equally, some of the metrics selected as proxy indicators for quantifying ecosystem attributes might have introduced unanticipated skews in the estimation process and confounded the results, especially if a particular measure has a greater value range compared to others. The indicators associated with the evaluation of biodiversity, ecosystems, and environment components may have caused such results, and are most likely the reason for the low vulnerability index for Bhutan, Zhongdian in China, and Kachin in Myanmar. Discrete indication of somewhat higher vulnerability in the high mountain areas was most likely due to high exposure levels to climate variability and change.

The vulnerability analysis was linked to existing natural and human wellbeing strategies, ecosystem services, and biodiversity endowments to identify points of intervention where the ability of ecosystems and people to adapt and build resilience could be strengthened through a process of autonomous and planned adjustment. The work on climate change vulnerability assessment was conducted in the context of mountain ecosystems of the EH to inform adaptations for sustained ecosystem services in biodiversity conservation, protected area management, water resources security, and human wellbeing. It directly addresses the information needs of adaptation decision-makers and contributes to policy-making by providing specific recommendations to planners and policy-makers on the enhancement of adaptive capacity and the implementation of adaptation policies. This entails integrating risk reduction measures into the development of plans, programmes, and policies. Such understanding helps to prioritise the allocation of resources for adaptation measures. The identification of limits to adaptation for valued systems provides important information for the determination of critical levels of climate change. The diverse groups of stakeholders with interests and concerns in mountain ecosystem services in the EH are expected to make use of the information on vulnerability for prioritising adaptation measures and research areas.

Response, Adaptation and Mitigation

Sometimes climate change adaptation is seen as competing with the human and economic development needs of the world's poor. Climate change can be perceived as a problem distant in time, uncertain in its effects, and of less consequence than present-day poverty. Adaptation and mitigation may, therefore, seem less urgent and less compelling than increasing development efforts for the world's poor. But climate hazards are immediate, they are growing, they threaten the quality of life and life itself, and they directly impact on the goals of development. In this assessment, the direct link between climate stresses and human poverty is reconfirmed through intense exploration of transmission mechanisms and channels of human vulnerability in the face of interacting and reinforcing multiple stresses.

The foregoing sections on sensitivity and impact establish a credible basis for concrete action in response to the effects of climate change. The components of mountain ecosystems that are the focus of this assessment were found to be the sources of key transmission mechanisms through which climate change could negatively affect human wellbeing. Climate change can also act in concert with other stresses to undermine human wellbeing by modulating livelihood strategies and decisions. Agricultural production and food security are contingent on climate-sensitive resources; without these resources people could be faced with malnutrition and starvation. Subsistence farming is inclined to be risk averse and to prefer risk-proofing over profitability to consolidate household food security. Coping with successive adverse climatic impacts locks people into a poverty trap, as not many resources remain with which to accrue income-generating assets and build up economic safety nets. Selling assets to protect consumption depresses market prices creating conditions for increases in inequalities in income, gender, nutrition, education, and health. Receding glaciers and erratic precipitation shape the facets of water stress and water insecurity in the EH. The fragile mountain ecosystems and precarious biophysical and socioeconomic conditions are prone to hydrometeorological disasters, and 20 to 30% of land species could face extinction under 1.5 to 2.5°C of warming, with serious consequences for the ecosystem services that they provide. Higher temperatures in tandem with variable and extreme conditions of humidity and precipitation could expand the reach of diseases like malaria, dengue, and so forth.

Instead of focusing on one-off extreme events, the governments in the region and the donor agencies must realise the threat that climate change poses to development and ensure that adaptation and mitigation measures are formulated and integrated into the wider development agenda. Climate change could jeopardise the priority targets of enhancing sustainable wellbeing enshrined in the Poverty Reduction Strategy Papers and Millennium Development Goals (MDG). Invariably, socio-political approaches encompassing governance, institutional policies, and legal frameworks are the proven way to weather the adverse impacts of global change, including climate change.

Globally, two broad policy responses have been identified to address climate change. The first is ‘mitigation’, which refers to actions aimed at slowing down climate change by reducing net greenhouse gas (GHG) emissions. The second is ‘adaptation’, which refers to actions taken in response to, or in anticipation of, projected or actual changes in climate.

Adaptation

There is general agreement that humans have already had an overwhelming impact on natural ecosystems and that this interferes with the functioning of ecosystems in ways that are detrimental to our wellbeing. Ecosystem services are essential to human civilisation, but human activities are already impairing the flow of ecosystem services on a large scale. If current trends continue, humanity will dramatically alter virtually all of the Earth’s remaining natural ecosystems within a few decades. The primary threats are: land use changes that cause loss of biodiversity; disruption of carbon, nitrogen, and other biogeochemical cycles; human-caused non-native species invasions; releases of toxic substances; possible rapid climate change; and depletion of stratospheric ozone. Fortunately, the functioning of many ecosystems could be restored if appropriate action is taken in time. However, attempts to take timely action to minimise climate-related risks are often hampered by the following:

1. The perception by some decision makers that the impacts of climate change are distant and speculative and, therefore, do not warrant immediate action
2. The difficulty in making site-specific predictions about future climate at a scale relevant to ecological processes
3. The global nature of climate change requiring large-scale efforts to integrate local, regional, and national activities

Expectations in terms of adaptation within the region have enriched available options and established a context for evaluating the relevance of such options with a specific focus on the EH. Three rounds of stakeholder consultations provided a proper forum for close interaction to identify issues, impacts, and trends, and to make recommendations on adaptation strategies and governance issues for the conservation and management of vulnerable mountain ecosystems under changing climatic scenarios. The outputs from the discussions and recommendations synthesised much of what we already know, and have applied to the real world situation with varying degrees of success. These dialogues contributed to the process of identifying the promising alternatives that could strengthen current practices and help in replicating emerging approaches in addressing climate change issues. The highlights of these workshops in relation to adaptive capacity in the EH include the following:

1. The initial symptoms of climate change are sufficiently apparent to necessitate proactive and anticipatory adaptation measures.
2. High priority areas for adaptation are ecosystem resources conservation and management, poverty alleviation, human health, hazard mitigation, and climate risk reduction.
3. Early action towards adaptation to climate change is imperative in tackling the vulnerabilities associated with climate change. In particular, action should be taken to strengthen the instruments for protected area management; mainstream climate adaptation policies into national poverty reduction programmes and plans; empower communities in natural resources management; and create an enabling environment for equal partnerships and inclusive participation. A promising entry point with a quick payoff is to integrate traditional knowledge of land use with sustainable production systems. With the predominantly poor socioeconomic context and near absolute reliance on climate-sensitive resources, the coping capacities of people are somewhat limited, making them highly vulnerable to the loss of particular ecosystem services.
4. Adaption strategies cannot be developed in isolation from wider policies for socioeconomic development in the region. Across the EH, climate change is merely one among many important stresses including environmental pollution, land use change, and the development pathway embraced within each nation's vision of progress and prosperity. Resources available for adaptation to climate are limited and adaptive responses are closely linked to human capacity and development activities, which should be considered in evaluating adaptation options.
5. Large numbers of adaptation and mitigation measures are being proposed to address climate change issues across and along sectors, systems, and themes, and over various time horizons considered important for mountain ecosystems and the people dependent on their services. Some of these are local, micro-scale response actions to cope with short-term extremes, some merely anecdotal, but most are long-term strategies to strengthen resilience and reduce the vulnerability of ecosystems and humans. These options include policy harmonisation and adjustment; support for traditional ingenuity with science and technology; community empowerment and capacity building; applying existing and generating new information; development of physical infrastructure like check dams, water-harvesting, afforestation, and river embankments; putting forecasting and early warning systems in place; awareness building; and expanding the insurance industry. The only shortcoming, and a defining one, is the disconnect between forward looking adaptation measures and those adopted autonomously by individuals.
6. Prerequisites for developing effective adaptation strategies include an understanding of current perceptions and coping strategies at local levels to deal with emerging climate change challenges, and of ecological knowledge systems and ecosystems conditions; recognition of the existence of multiple stresses on the sustainable management of resources; and collaboration between locals and scientists.
7. Climate change vulnerability varies across space and among groups depending on policies, services, and governance; levels of human wellbeing and livelihoods; and the gravity of environmental disruptions. Accountable and responsive government and the empowerment of people to improve their lives are also necessary conditions for successful adaptation.
8. The potential for successful adaptation to climate change in the EH lies in sustainable natural resources management, poverty reduction, ecosystems and biodiversity conservation, integrated watershed management, human development, and disaster risk reduction.
9. Adaptation strategies need to be treated as an integral part of national programmes, not as isolated projects outside the planning system. Adaptation will also benefit from taking a more systems-oriented approach, emphasising multiple interactive stresses, horizontally coordinated and vertically integrated.

Table 23 presents a list of the adaptation efforts related to climate change and mountain ecosystems identified through the stakeholders' workshops. The list is not intended to be comprehensive, but rather to present an overview of actions that have been identified in the EH. The list has been compiled based on regional consultations and supplemented by an overview keyword search of the primary literature. It must be emphasised that this list is limited to actions either being currently implemented or recommended for implementation that are specific to coupled human-environment system management in response to climate change. Many other adjustment and management activities are undoubtedly underway that are supportive of climate change adaptation, but not yet explicitly linked to it.

Table 23: **Climate adaptation management actions currently being implemented or recommended for implementation in the Eastern Himalayas**

Adaptation action	Capacity building				Biodiversity target						
					System		Level			Range	
Description	Research/monitoring/assessment	Education/extension	Plans/policies	Implementation	Terrestrial	Freshwater	Ecosystem	Species	Genetic	Local	Widespread
Livelihood and human wellbeing											
Capacity development (human, institutional, financial, political, social)	●	●		●	■	□	■	■	□	■	□
Enhance information and access, education and training, and awareness	○	○	○	○	■	□	■	□	□	■	□
Agroecological approach based on agricultural productivity potential	○	○	●	○	□		■		□	■	□
Community empowerment and participation		●	○	●	■	□	□	□		□	■
Population control and regulation of pressure			●	●	□					□	
Enabling policy instruments			○	○	■	□	■	□		■	
Increase or diversify livelihood options	●	●	●	●	■	□	■	□		■	
Insurance for social risk management and poverty reduction			○	○	□		□			□	■
Water, wetlands and hazards											
Water control and conservation infrastructure	●	●	●	●		■	□			□	■
Monitoring, forecasting and early warning systems	○	○		○	■		■			□	■
Scientific management of water/wetland bodies to enhance aquatic resource productivity (fisheries, medicinal plants, reeds, etc.)	○		○	○		■		□		■	□
GLOF mitigation	●	○	○	●	□	□	□	□		■	
Disaster risk reduction	○	○	○	○	□	□	□	□		■	□
Integrated watershed management integrating traditional techniques	○	○		○	■	□				■	□
Ecosystems and biodiversity											
Landscape ecosystem approach to biodiversity conservation	○		●		■	□	■	□	□		
Forest fire management	●	●	●	●	■		□	□			□
Sustainable management and use of forest resources	●	●	●	●	■		□	□			□
Shift to green, environmentally friendly technologies	○		○		□		□	□			□
Enhance sinks and reduce sources of GHG emissions	○		○		□	□	□				□
Conserve natural habitats in climatic transition zones	○		○		□		■	□		■	
Restoration of degraded ecosystems	○		○	○	■	□	■	□			□
Formalise traditional knowledge systems			○	○			□	□		■	
Promote community-based ecotourism			●		■		■	□		■	
Shift in social habits in the consumption and use of ecosystem services		○		○	■	■	■	□		□	□
Improve shifting cultivation practices	●	●			■		■			□	
Human health											
Measures to reduce air and water pollution			○	○	□	■	□	□			□
Adapt solutions to prevent vector-borne diseases/epidemics	●	●	○	●	□	□	□	□			□
Improve health care system, including surveillance, monitoring, and information dissemination	●	●	●	●							■
Improve public education and literacy rate in various communities	○	●	●	●							■
Increase infrastructure for waste disposal			●	○	□	□	□				■
Improve sanitation facilities in RMCs		●		●							■

Note: blank cell = not applicable

● Being practiced
○ Recommended for future

■ Primary target
□ Secondary benefits

Highlights of some of the highest priority options for adaptation to climate change in the EH are summarised in Table 24. The information compiled was sourced from various national reports, which were then reconciled with the practices and prospects shared during the three rounds of stakeholder consultations.

Ecosystems and biodiversity

Mountain ecosystems warrant protection, not only to maintain ecosystem integrity and adaptability, but also to secure their protective role against slope erosion and as a component of mountain hydrology and water quality. There is general agreement that humans have already had an overwhelming impact on natural ecosystems and that this interferes with the functioning of ecosystems in ways that are detrimental to our wellbeing. On the other hand, adaptation of natural ecosystems to climate change cannot be achieved without some kind of human intervention.

Effective conservation and the sustainable use of natural resources are the overarching precepts of sound biodiversity management. Humans are integral parts of the ecosystems that are now being increasingly exposed to climate change stress. Without addressing the socioeconomic wellbeing of people, there is very little incentive for them not to overexploit or to protect biodiversity resources. Adaptation strategies must be people-oriented within the framework of protecting landscapes, ecosystems, habitats, and species so that anthropogenic interferences are kept to a minimum for natural resilience to take over and sustain the ecosystem

Table 24: **A sector-wise summary of potential adaptation options generally identified for the region**

Sector	Adaptation options
Agriculture	• Promote water use efficiency in agriculture through effective water storage (soil conservation, water harvesting) and optimising water use (drip, microjet, and sprinkler irrigation) • Adjust agricultural production systems to production environment (short, early-maturing crops, short-duration, resistant and tolerant varieties, appropriate sowing and planting dates, proactive management) • Improve land cultivation management • Adopt agroecosystems approach to planning and production methods • Weather and seasonal forecasting for climatic conditions, crop monitoring, and early warning systems • Adjust cropping calendar and crop rotation to deal with climatic variability and extremes
Water Resources	• Ensure the economic and optimised use of water through rainwater harvesting and modern water conservation systems (groundwater supply, water impoundments), and strengthen the unified management and protection of water resources (efficient water resource systems) • Flood regulation, protection, and mitigation; tapping water sources to increase water-supply capacity • Adopt integrated watershed management and protect ecosystems (restore vegetation cover, prevent and control soil erosion and loss) • Construct irrigation systems and reservoirs, and adjust the operation of water supply infrastructure • Monitor water resources to readjust national and sectoral plans (reduce future developments in floodplains) • Improve preparedness for water-related natural disasters
Ecosystems and biodiversity	• Prevent deforestation and conserve natural habitats in climatic transition zones inhabited by genetic biodiversity with potential for ecosystem restoration, and reintroduce endangered species • Adopt integrated ecosystem planning, monitoring, and management of vulnerable ecosystems • Reduce habitat fragmentation and promote development of migration corridors and buffer zones • Enhance forest management policy for the protection of natural forests (control and stop deforestation and ecological damage), prevent desertification processes, and mixed-use strategies • Plan to develop forestry planting and growth technology for fast growth species to increase share of forest (afforestation and reforestation), to conserve and rehabilitate soil and prevent slope failure and mass wasting, and for forest protection • Undertake preventive measures for forest hazards • Preserve gene material in seed banks
Human health	• Strengthen preventative medicinal activities and reinforce disease prevention measures • Implement epidemic prediction programmes to cope with possible vector-borne diseases, both for humans and domestic animals • Adopt technological/engineering solutions to prevent vector-borne diseases/epidemics; increase infrastructure for waste disposal; improve sanitation facilities; reduce air and water pollution; and track water quality, water treatment efficiency, and soil quality • Improve healthcare systems, including surveillance, monitoring, and information dissemination • Improve public education and literacy rates in various communities
Natural disasters	• Strengthen the early warning system within the national meteorological and hydrological service • Undertake full assessment of wildfire-risk zones and increase public awareness

Source: Stakeholder consultations; documents pertaining to the NAPA, NCSA and NCs of EH countries to UNFCCC structure and functions. Recently, there has been a strong drive to transition from contemporary conservation approaches to a new paradigm of landscape-level interconnectivity between protected area systems that are defined around the protectionist focus on species and habitats. The concept emphasises the shift from the mundane species-habitat dichotomy to a more inclusive perspective on expanding biogeographic range so that natural adjustments to climate change can proceed without restriction. However, the benefits of this approach have yet to be realised. Whatever the conservation approach, communities in a protected area system must be regarded as a medium of adaptation, rather than being perceived as the reason for environmental degradation and biodiversity loss. Local participation in conservation efforts should include decision-making prerogatives and a cooperative environment of shared ownership in the process.

On the other hand, biodiversity in natural ecosystems has also been adapting naturally or autonomously without much adjustment from the people and communities that benefit from their services. As the magnitude of climate change, and other global change stressors for that matter, increases with time, the need for planned adaptation will become more acute. Traditionally, communities that depend on biodiversity resources have informal institutions and customary regulations in place to ensure that external perturbations do not exceed natural resilience beyond a certain threshold. Judging by the rate of the changes taking place in the demographic, economic, and socio-political landscapes of human society, and their positive feedback to the climate system, these traditional approaches may need to be supplemented by formal adaptation measures to address the new threats to biodiversity.

Maintaining resilience in ecosystems is the primary objective of adaptation strategies for protecting wildlife and habitats (IPCC 2007 b,c). Activities that conserve biological diversity, reduce fragmentation and degradation of habitat, and increase functional connectivity among habitat fragments will increase the ability of ecosystems to resist anthropogenic environmental stresses, including climate change. An effective strategy for achieving this is to reduce or remove existing pressures. However, adaptation options for ecosystems are limited, and their effectiveness is uncertain. Measures directed at specific effects of climate change are unlikely to be applied widely enough to protect the range of ecosystem services upon which societies depend. Fortunately, reducing the impacts of non-climate stresses on ecosystems would also buffer ecosystems from the negative effects of climate change. The range of potential strategies given in Table 25 is broad enough to address most of the problems associated with mountain ecosystems in the EH.

Table 25: **Strategies to increase resilience of ecosystems to climate change and other stressors**

Stressor	Strategy/human response	Examples
Physical habitat alteration	Conservation	• Establish protected areas, parks and refugia • Protected landscapes
	Restoration	• Afforestation • Reforestation • Soil conservation
Pollution	Regulation of emissions	• Control SO_2, CO_2, NOx, and volatile organic carbon emissions • Regulate emissions of CFCs (Montreal Protocol) • Reduce point source water pollution
	Regulation of land use and non-point sources	• Protect riparian buffers • Change urban and agricultural practices
Non-native invasive species	Prevention of introduction and establishment	• Monitor areas around ports of entry and eliminate new populations
	Management of established populations	• Release biological controls • Eradicate invasive species
Global climate change	Reduction of greenhouse gas emissions	• Reduce fossil fuel combustion • Conserve energy
	Reduction of climate impacts via reduction of other stressors	• Increase ecosystem resilience to climate impacts via habitat protection, reduced pollution, control of invasive species, sustainable resource use
	Direct reduction of climate change impacts	• Schedule dam releases to protect stream temperatures • Transplant species • Establish migration corridors

A common approach to ecosystem conservation in mountains and uplands is the setting up of climate refugia, parks and protected areas, and migration corridors to allow ecosystems to adapt or migrate. National parks with restricted access and biosphere reserves are one form of refugium. A major problem in many parts of populated mountain regions is that ecosystems have been so fragmented and the population density is so high that many options may be impossible to implement. In addition, various assessment studies have shown that the designation of interconnected and comprehensive reserve networks and the development of ecologically benign production systems would result in increasing conflict between economic development and environmental concerns (Chapter 13 of Agenda 21).

Challenges remain to the adoption of an effective strategy to address climate and non-climate related risks to ecosystems. A significant challenge is to incorporate biodiversity thinking into adaptive responses to ensure that future development activities do not further jeopardise the world's biological resources. Setting priorities among strategies is difficult, partly because so little is known about the effectiveness of alternative actions intended to reduce ecosystem vulnerability. Caution is needed in developing adaptive measures, because lack of information and/or conflicting ecosystem goals can lead to mal-adaptation. For example, diverting hazardous pollutants from water to air or land may benefit aquatic ecosystems, but cause problems in terrestrial ecosystems. Likewise, corridors connecting habitat fragments may help some species disperse, but might also allow aggressive invasive species to enter fragile habitats.

Good practices in planned adaptation are premised on the availability of adequate information on the status of biodiversity, trends in environmental change, including climate change, and their potential impacts on biodiversity, human resources, expertise, institutional capacity, political commitment, and financial resources. Without being inclusive, some adaptation options in the EH are as follows:

1. Develop institutional arrangements that are responsive to addressing climate change issues and sensitive to the societal and economic priorities at the national and local levels.
2. Conduct research and development in agroforestry and community forestry to enhance carbon sequestration, reduce soil erosion, and improve water quality and livelihood options.
3. Operationalise a transboundary landscape approach in biodiversity conservation and protected area management.
4. Establish climate-monitoring stations to facilitate the generation of accurate, long-term climatological time-series data and associated infrastructure for operational networking and data sharing.
5. Identify and monitor climate sensitive organisms as indicators for early detection of climate change signals and facilitate proactive adaptation mediation.
6. Ensure the sustainable management of rangelands and formalise climate-conscious pastoralism, not only to enhance productivity, but also to protect the ecosystem, reduce CO_2 emissions, and increase storage above and below ground.

Water and wetlands

Climate change will increase variability and uncertainty in the availability of water resources, while at the same time exposing people to altered frequency and intensity of water-related hazards (floods, droughts, water-borne diseases). Adaptation must focus on addressing these problems by enhancing the capability of people to deal with such situations. Water harvesting and water storage structures are some common measures used to manage the variability and uncertainty associated with water use systems and to prepare for droughts. Flood mitigation work and the construction of protective embankments along flood-prone rivers, as well as operationalising early warning systems, can diminish the risks posed by flooding, and protect people's lives, property, and productive assets. The demand and competition for water resources in the EH is likely to intensify as the resource base is eroded due to climate change and human interference. Appropriate institutional mechanisms of governance, policy changes, and a regulatory framework are necessary to ensure equitable resource access and distribution, as well as to safeguard the resilience of wetlands and curb overexploitation.

A key strategy for ensuring the future of wetlands and their services is to maintain the quantity and quality of the natural water regimes on which they depend, including the frequency and timing of flows. This means that an ecosystem-based integrated water resources management policy has to be developed and implemented. Integrated water resources management can rationalise supply and demand situations by maintaining adequate supply and improving water use efficiency. Tradeoffs may be required between competing water uses, but decisions on water management must consider the need to protect wetlands. Adaptation strategies must consider other major drivers of change alongside climate change, as climate change cannot be managed in isolation. The triangulation of the three environmentally relevant 'Rs' – reduce, recycle, and reuse – in relation to wastewater is emphasised as another adaptation method. Finally, the importance of education and awareness, as well as capacity building at all levels, cannot be underestimated.

Hazards

In addition to short-term approaches such as response and recovery, there is a need to think about the long-term goal of awareness, preparedness, and risk reduction. From the natural hazards perspective, responding to climate change involves an iterative risk management process that includes both adaptation and mitigation, as neither on its own can address all potential climate change impacts. At the policy level, adaptation needs to be mainstreamed into the planning process and integrated into sectoral development programmes and activities. At the institutional level, capacity building is an obvious priority to enhance the knowledge and information base, strengthen networks across agencies and governments, and promote regional cooperation. Adaptation options include, among others, improvement of observation and forecasting, development of early warning systems, mapping of hazards and vulnerabilities, community awareness and participation, and forest and water conservation. Engineering works are alternative options for adaptation through risk mitigation.

Human wellbeing

Human wellbeing in the EH is inextricably linked to natural resources, such as agriculture and hydropower, which are highly sensitive to climate change. People live under constant threat from natural hazards such as water stress and scarcity, food insecurity, food, water, and vector-borne diseases, GLOFs, landslides, floods, and droughts. The adaptation of populations to the spread of malaria and other vector-borne diseases is determined by the economic level of a given population, the quality and coverage of medical services, and the integrity of the environment. Good health is a good indicator of a population's adaptive capacity to climate change. Adaptation measures for livelihoods and human wellbeing include the following, among others:

1. Establish and strengthen infectious disease surveillance systems.
2. Build the capacity of the health sector through training, exposure, and networking of professionals to enhance their understanding of the threats posed by climate change to human health.
3. Conduct research to fill the knowledge gaps and reduce uncertainties in adaptation measures.
4. Facilitate community involvement and awareness in using water resources more sustainably.
5. Improve land use planning to promote afforestation in degraded water catchment areas.
6. Develop varieties of crops and livestock with greater resilience to climate change, variability, and extreme events.
7. Undertake community-based forest management and afforestation projects for conservation and development purposes; increase wood production to reduce the extractive pressure on natural forests and enhance carbon sequestration.

Adaptations are mostly aimed at eliminating projected climate change impacts. However, in some cases adaptations can be aimed at exploiting a climate change opportunity. Regardless of whether or not countries around the world succeed in achieving major reductions in GHG emissions, climate change models predict that excess greenhouse gases already in the atmosphere will drive climate change and its impacts for centuries to come. As a result, the need to implement activities aimed at adapting to the potential changes is imperative.

Mitigation

Global reductions in GHG concentrations are expected to slow the rate and magnitude of climate change over the long term. To do this, both sources of and sinks for greenhouse gases must be managed. Examples are using fossil fuels more efficiently and expanding forests to sequester greater amounts of carbon dioxide from the atmosphere. Because the potential responses of natural systems to human-induced climate change are inherently limited, the best overall strategy is to minimise the amount of change.

Broadly speaking, any effort to reduce the rate or magnitude of climate change by reducing atmospheric GHG concentrations can be viewed as a long-term activity toward mitigating impacts on biodiversity at all levels. Therefore, developing strategies that reduce GHG emissions and maximise the carbon sequestration potential of living systems should be viewed as critical elements in stabilising climate and minimising the long-term impacts on biodiversity. Deforestation, peatland degradation, and forest fires account for about one-fifth of the global carbon footprint. Conservation of forests and soil offers triple benefits: climate mitigation, people, and biodiversity.

Mitigation actions that have complementary adaptation benefits, and vice versa, should be preferred. The restoration of degraded landscapes with vegetation and the implementation of agroforestry systems are two examples where carbon sequestration benefits can be achieved simultaneously with reduced soil erosion and improved water quality, both of which can provide biodiversity conservation benefits (Watson 2005). Freshwater biological systems can be assisted to help mitigate the impacts of climate change, particularly through the increase and protection of riparian vegetation, and by restoring river and stream channels to their natural morphologies.

GHG management is a global issue, and mitigation efforts in the EH can rightfully be placed in this context. According to National Communications (NC) of the regional countries to the UNFCCC, the region is assessed to be a net sink and GHG emissions are minimal compared to other regions of the world. The EH has low per capita GHG emissions, but could face considerable challenges in achieving further improvement in energy efficiency due to limited capability.

6 Gaps and Needs

Capacity Building and Training Needs

Capacity-building actions aim to increase the capacity of institutions, governments, businesses, and the public to prepare for climate change. Capacity-building actions include research and assessment, monitoring, extension and training, and policy change. Many capacity-building initiatives are underway in the EH related to climate change adaptation. A number of these initiatives are highlighted below.

1. Addressing climate change and extreme weather in government planning and operations.
2. Implementing effective monitoring and reporting procedures for climate change and its impacts.
3. Developing climate models and other tools for addressing climate change risks and adaptation options.
4. Supporting applied climate change research that meets the needs of decision-makers.
5. Developing capacity throughout the EH to respond to extreme weather and climate change.

The National Adaptation Programmes of Action (NAPAs) in the regional countries are currently at various levels of development. Within the EH, Bhutan is at an advanced stage of implementing its NAPA proposals, while Nepal is still in the conceptual and formulation stages. Besides what is envisaged under NAPA, there are several potential areas of intervention that could contribute to building adaptation capacity in the region. The following are some of the priority recommendations:

1. Improve knowledge through analysis and research (impacts of climate change on surface and groundwater in the EH, hydrological modelling tools that work with climate change scenarios).
2. Review operational policies and practices (flood risk management, conservation area management).
3. Build awareness and capacity (forecasting capacity, information for education, policies and decision-making, climate observation and monitoring systems, high-resolution maps of climate variables and other biophysical parameters).
4. Implement action on the ground (drought and flood management initiatives, region-wide consultations and survey to assess views on climate change impacts and adaptation).

The countries in the EH lack the capacity to invest in meteorological data collection and analysis to provide their citizens and climate-sensitive sectors with a steady flow of good quality information. The IPCC acknowledges that current climate models for the HKH region provide insufficient information to downscale data on rainfall, temperature, and water. One reason for this is that the region has a low density of meteorological stations, a situation exacerbated by data/information access issues. Long, historical time-series of important climatological variables are needed to conduct meaningful climate change studies. Therefore, a strategically placed network of automated weather stations traversing the length of the EH and positioned along ecologically defined north-south transects would strengthen the data collection platform. Research on climatological proxies such as tree-ring studies and glacial ice-cores need to be intensified to extend the time-series back into the discernible past.

Opportunities in education and training are critical for the development of meteorological infrastructure and to ensure that relevant research is conducted. The human capital and institutions for these activities are comparatively lacking in the region, as evidenced by the distribution of published international research. The capacity for monitoring and forecasting climate can have an important bearing on livelihood security. For agricultural producers, advance warning of abrupt changes in rainfall patterns or temperature can mean the difference between a successful harvest and crop failure. Seasonal forecasting systems and the effective dissemination of the information they generate can enable farmers to monitor potential hazards and respond by adjusting planting decisions or changing the mix of crops.

The education and training of stakeholders, including policy-level decision makers, is important in the successful assessment of vulnerabilities and planning adaptation activities, as well as the implementation of adaptation plans. Training is also needed for models to be effectively applied and used for assessments at the national and regional levels. Therefore, it is imperative to build the capacity of key government officials in the EH on vulnerability to climate change and potential adaptation activities. This can be achieved through the creation of a regional pool of experts/trainers to facilitate country-based programmes to address climate change impacts through the development of a common regional training module by collating and synthesising available scientific information. Some of the rationales for training needs are as follow:

- Experts on climate change are still not competent and need exposure and capacity building.
- Information and databases in the region are weak and need to be developed.
- Remote sensing and modelling technologies, which are currently embryonic or nonexistent, need to be developed.
- There is a need for hands-on experience on climate models with capacity to capture complex terrain features.
- There is a need to improve understanding of the regional and local dimensions of vulnerability, keeping in mind integrated approaches.
- There is a need to raise public awareness, focus government attention, and build capacity at all levels of society.
- The capacity to carry out specific research in taxonomy, conservation biology, and impact assessment needs to be improved.

Knowledge Gaps and Potential Research Areas

We still do not have sufficient understanding of the natural dynamics of mountain ecosystems to come up with solutions to the problems confronting the environment and people in the region. Current knowledge on climate change and impacts in the EH is poor with few hard data, despite the fact that mountain issues like retreating glaciers have received global attention. The knowledge gap is so vast that we could think of limitless interventions to contribute to enhancing our wisdom in dealing with mountain-specific issues. By far the greater proportion of past efforts has been expended on considering the potential impacts of climate change on forest ecosystems, notwithstanding all the current attention on glaciers, permafrost, and wetlands. There has also been more consideration of potential climate change impacts at the ecosystem level, although some specific plans for species at risk that identify climate change as a potential threat are underway and policies for the management of target wildlife do already exist. There is also a relative lack of focus on understanding the impacts at the genetic level. On the climate front, there has been a relatively high focus on impacts associated with changes in mean annual or seasonal temperature, compared to other climate drivers. Climate extremes play a dominant role in many impact processes (Parmesan 2005), and more attention should be given to the potential for changes in the magnitude and frequency of extreme weather events in the EH.

Knowledge gaps

Three broad areas stand out as knowledge and data gaps in need of further development and refinement. First, there is still a great deal to be learned about the potential magnitude and rate of climate change at the regional and local levels, and subsequent impacts on the full range of biodiversity endpoints. However, given the reality of scarce resources, efforts should be made to develop a focused research agenda in order to maximise the practical benefits of research investments. Considerations in developing that agenda should include: priority climate change threats to biodiversity in the EH; current gaps in existing knowledge (e.g., research in the freshwater realm is under-represented); and linking information requirements to the specific needs of assessing feasible climate change mitigation and adaptation options for biodiversity management

Second, there is no consolidated handbook of proven biodiversity conservation techniques or climate adaptation techniques that are targeted to the EH. Consideration should be given towards building local biodiversity and climate change case studies through targeted investment. Over time, further consideration should be given to developing a training manual specifically for the EH, perhaps modelled after the one published by WWF (Hansen et al. 2003).

Finally, it is beyond the scope of this report to develop detailed assessments for each of the priority climate change threats to biodiversity. However, we can begin by outlining the steps for a strategic approach to the task. These steps include:

1. defining biodiversity management priorities in terms of the specific endpoint at risk for each system (i.e., ecosystem, species, or genetic diversity);
2. identifying the climate stressors and developing future scenario projections for the climate variables of interest;
3. identifying the impact mechanisms and documenting potential future impacts and uncertainties;
4. developing a set of feasible adaptation actions; and
5. collecting information on the costs and benefits of adaptation options.

Potential areas for research

Some potential research areas include, among many others, an inter-comparison of key physical and biological processes along a series of transects placed over the region; establishing a comprehensive regional mountain database; in depth study of the mountain cloud forests; and strategies for responding to new health hazards in mountains and for addressing human migration in response to adverse climatic and other environmental pressures. More specific areas for action research that could bring about tangible and considered results are categorised in the following sections under the focal components of mountain ecosystems defining the basis for the assessment framework. These research ideas and prospects are reflected in the six technical papers prepared to inform and guide this assessment report.

Ecosystems and biodiversity

Climate change adaptation in biodiversity conservation and sustainable use needs to grow out of a clear understanding of the important habitats and species and the nature of their resiliency to climatic stresses. The various conservation initiatives in the EH must be coordinated and collective partnerships must be developed between stakeholders so that the entire EH is able to cope with the present and future impacts of climate change. Research needs to be conducted to advance our understanding of climate change and its possible impacts on biodiversity, and to inform mitigation and adaptation strategies in the EH.

Research areas identified for biodiversity include the following:

1. Strengthen and review policies to make them more sensitive to the interaction in processes and the linkages between the consequences of biodiversity and climate change.
2. Develop a comprehensive database of species and ecosystems, and properly document indigenous knowledge and practices on adaptation to climate change, including variability and extremes.
3. Carry out an extensive and in depth assessment of the movement of invasive species; critical landscape linkages to flagship species; PAs coverage and effectiveness; the adaptability of biodiversity entities; fire management regimes; and impact on agricultural productivity. More emphasis should be placed on riparian habitats, least explored ecosystems, habitats of threatened species, and floral and faunal hotspots.
4. Conduct a comprehensive survey and inventory of the distribution range of plant and animal biodiversity within PAs, population trends of flagship/endemic or threatened species, and the status of mid-sized mammals and other groups of animals.
5. Carry out thorough research on ecosystem structures, functioning, productivity, and delivery of ecosystem goods and services, including piloting.
6. Conduct a study of the interaction between climate change and land use change to assess their combined impact on biodiversity, atmospheric CO_2 concentration, species composition, and carbon dynamics for different ecosystems.
7. Perform valuation of ecosystem services from biodiversity conservation areas.
8. Conduct a socioeconomic study on land tenure systems, food security, resources use rights, decision-making processes, and governance systems, which influence community resilience to climate change.

Water and wetlands

There is an urgent need to undertake a detailed inventory of wetlands that includes basic information on their hydrological, physical, chemical, and biological characteristics, as well as human interactions (impacts and use) with their functions and services. Wetlands need to be classified according to their functional attributes and their ecosystem services need to be prioritised.

Research areas identified for water and wetlands include the following:

1. Conduct a detailed inventory of wetlands with quantitative data on their ecological characteristics, functions, and services.
2. Study the planktonic and benthic diversity of different types of wetlands and their role in carbon and nutrient transfer along the food chain.
3. Study the responses of both plant and animal species to components of climate change such as elevated CO_2 concentration, temperature, and hydrological parameters.
4. Conduct a study of the environmental flow requirements of various organisms in different stretches of rivers and other kinds of wetlands.
5. Conduct a study of the effects of enhanced CO_2 concentration on primary production, decomposition, N metabolism, and transpiration in major plant communities (species).
6. Conduct detailed limnological studies on the structure and functioning of glacial lakes.
7. Conduct a study of the effects of temperature on primary and secondary production, decomposition,

nutrient dynamics, and the growth of various aquatic species.

8. Conduct a study of the effects of temperature and enhanced CO_2 levels on growth, carbon sequestration, and methane emission in different wetland types.
9. Carry out monitoring of distribution ranges of various plant and animal species.

Hydrometeorological hazards

The major concern of people and communities in the EH region is the fate of the glaciers. There is a need to improve our understanding of the cryospheric processes of snow and ice and the effects on climate, biodiversity, and human wellbeing. Integrated model-based studies of environmental change in the EH, including monsoonal variation, are urgently required to clarify projected changes in weather patterns.

Research areas identified for hydrometeorological hazards include the following:

1. Carry out mapping of glacial hazard areas and proper analysis of potential threats.
2. Undertake snow avalanche forecasting and risk mapping for mountain tourism.
3. Conduct a vulnerability assessment of local people to natural hazards.
4. Develop an authoritative set of climate change scenarios for the region.

Human wellbeing

There is still insufficient understanding of, and high uncertainty about, how climate change will impact on the various dimensions of human wellbeing. The information brought to light by the limited studies that have been conducted has not been translated into policies and adaptation plans. Climate change issues are still pursued in isolation from mainstream development activities and not fully integrated into development plans and policies. Stakeholders argue that very little is known about the livelihoods of local people let alone the impacts of climate change or, for that matter, the linkages between ecosystem changes and livelihoods of local populations. Problems associated with data and information availability, access, standards, and unequal holdings have been a constant source of exasperation over the years. This state of affairs in the EH opens up enormous opportunities for inter-disciplinary and cross-sectoral research on livelihoods, health, and human wellbeing to be conducted in a comprehensive and equitable manner.

Research areas identified for human wellbeing in close consultation with stakeholders from the region include the following:

1. Conduct cross-sector, cross-boundary, and transdisciplinary research on climate change and its impacts on human wellbeing in the EH region, covering human health and its relationship with poverty and migration, and the implications for ecosystems.
2. Develop a comprehensive and readily accessible information system encompassing demographic, socioeconomic, biophysical, cultural, technological, and institutional aspects of the region.
3. Undertake an assessment of people's vulnerability to natural hazards and document adaptation techniques to both beneficial and adverse impacts of climate change, identify how they contribute to human wellbeing, and the associated implications for ecosystems.
4. Isolate climate change effects from other interacting effects of global change, including the potential snowballing influence of climate change on other more conspicuous drivers of change.
5. Conduct a trade-off analysis between conservation and development in protected area systems, and an analysis of the impact on the wellbeing of communities living inside park boundaries focusing on human-biodiversity interactions and the institutions involved.
6. Conduct epidemiological studies of vector-borne and water-borne diseases under changes in climatic conditions.

Stakeholder consultations

The outcomes and recommendations from both rounds of stakeholders' workshops were profuse, providing a wish list of researchable topics based on obvious and perceived knowledge gaps in our understanding of the differentials in climate change from the IPCC report and the far-reaching ramifications for mountain ecosystems. While most of the proposed research areas were legitimate, there were some suggestions that were speculative and that do not qualify as researchable areas, some topics were too broad, and some perceived knowledge gaps were not in fact gaps. Nonetheless, the stakeholder consultative workshops identified a number of research gaps with sector and system specific research priorities (Annex 4). The stakeholders recommended that the research focus be on action-oriented research with the involvement of all relevant stakeholders and that research should focus on sectors and systems that as yet lack careful research.

The positions articulated in the stakeholder consultations and the conclusions made in the technical papers on the research themes present some broad perspectives on the status of knowledge and understanding in the region on issues pertaining to climate change and mountain ecosystems. As expected, there was some common ground on the significance and priority of certain research areas, differing mainly in setting the agenda for research proposals, approaches to developing and improving management options, and some strategic inflections largely conditioned by professional affiliations and schools of thought. In a process of concurrence and conciliation, the outcomes of these two phases of assessment were consolidated into preliminary research concepts for the region. The purpose of assessing the potential impacts of climate change upon mountain ecosystems is to provide information to decision-makers and stakeholders about the consequences of possible actions. Research should be guided to meet these information needs, taking stock of past efforts and establishing a sound basis for future elaboration.

Crucial research gaps and most desirable research concepts that ICIMOD could foray into include:

1. Research on ecosystem valuation: We need to improve our understanding of how society depends upon ecosystems and how people value different aspects of ecosystems. This information should be used in developing research priorities and in choosing among alternatives for increasing ecosystem resilience. A viable research project would be how to enhance ecosystem services through sustainable natural resource management by implementing an integrated watershed approach, adopting PES (payment for ecosystem services) schemes, and securing ecosystem functions under the adverse impacts of economic and demographic factors.

2. Research on ecosystem functioning: We still lack basic information and knowledge on how ecosystems function, limiting our ability to predict and understand how changes in one part of an ecosystem affect other parts, and how non-climatic stresses interact with climate change in determining ecological impacts. A promising research area is to conduct a dynamic or process-based investigation along altitudinal gradients from cryosphere and upstream headwaters to downstream river basins to assess the sensitivity of vegetation, snow, ice, and water resources to a range of forces at ecological and climatological boundaries. The data requirement can be supported by a data-mining and clearinghouse project in ICIMOD, and through the proposed Himalayan Transect initiative.

3. Research on monitoring of ecosystems: Indicators of the status of ecosystems and the magnitude and distribution of stresses upon ecosystems should be included in long-term ecological monitoring plans. Early warning signs of potential loss of valued ecosystem functions should be identified and included as indicators. The concept for a research project could include long-term monitoring and analysis of indicators of climate change in mountain regions, with a particular focus on cryospheric indicators, watershed hydrology, terrestrial and aquatic ecosystems, and human wellbeing. Ecological monitoring is essential to explore the relationships between these systems.

4. Research on management options: Understanding the effectiveness of various management strategies is crucial to targeting limited resources for ecological protection. The Kangchenjunga Landscape Conservation approach illustrates the value of such research, as this novel, in situ paradigm has emerged out of a large body of research and management experiences with conventional protected area systems. The landscape model may be used to design an integrated research strategy for the other major types of EH ecosystems likely to be sensitive to climate change. The agro-ecosystem approach to production agriculture is another area of research that harmonises ecosystem conservation and livelihood strategies, enabling mutual coexistence between man and nature. As it is based on resource use within the limits of ecological potentials, landscape conservation and biosphere reserves could adopt this approach to make conservation people-friendly and economically sustainable. Another project concept could be a decision support system engineered around a core of integrated model-based dynamic simulations of vegetation dynamics, biodiversity, and ecosystem services in different mountain regions with particular emphasis on coupled ecological, hydrological, and land use models, allowing the study of feedbacks between land surfaces and the atmosphere, and integrated (physical, biological and economic) analyses of climate change for policy purposes.

Policy and Governance

Political systems will have to agree to pay the early costs to reap the long-term benefits. Leadership will be required to look beyond electoral cycles. Climate change demands urgent action now to address a threat to two constituencies with little or no political voice: the world's poor and future generations. This raises profoundly important questions about social justice, equity, and human rights across countries and generations.

Building the resilience and coping capacity of the poorest and more vulnerable sections of society will require a fundamental reappraisal of poverty reduction strategies, backed by a commitment to enhanced equity in tackling social disparities. Adaptation policies are likely to be more successful and responsive to the needs of the poor when the voices of the poor identify priorities and shape the design of policies. Accountable and responsive government and the empowerment of people to improve their own lives are necessary conditions for successful adaptation. But the response to adaptation challenges must operate within a programme-based framework, and not through project-based institutional structures operating outside wider national planning systems for budgets and poverty reduction strategies. Because climate change impacts on everything we do, all legislation also needs to be assessed and scrutinised to evaluate its impact on climate change.

The impact of climate change on the lives of the poor is not the result of natural forces. It is the consequence of human action: the product of energy use patterns and decisions taken by people and governments of the 'rich' world. The case for enhanced financing of adaptation in developing countries is rooted partly in the simple ethical principle that the countries that are responsible for causing the harm are also responsible for helping those affected to deal with the consequences. International cooperation on adaptation should be viewed not as an act of charity, but as an expression of social justice, equity, and human solidarity.

As agriculture is the dominant land use system in the EH, ensuring its sustainability can promote rural development, and increase food security and ecosystem vitality. Immediate responses should be conservation, reforestation, redefining protected areas, and adopting integrated watershed management approaches. Good governance is the foundation of any land conservation strategy. Besides providing appropriate legal and policy mechanisms for administering land ownership, it can foster the active participation of civil society in land reform efforts and ensure the equitable distribution of the benefits from agrarian development. The situation is relevant considering the need to recognise and protect the rights of women farmers whose contributions tend to go unnoticed, as benefits are not shared equitably.

The integration of adaptation planning into wider poverty reduction strategies is a priority. Successful adaptation policies cannot be grafted onto systems that are failing to address the underlying causes of poverty, vulnerability, and wide disparities based on wealth, gender, and location; they have to be brought into the mainstream of poverty reduction strategies and budget planning. Dialogue over Poverty Reduction Strategy Papers (PRSPs) provides a possible framework for integrating adaptation into poverty reduction planning. The revision of PRSPs through nationally-owned processes to identify financing requirements and policy options for adaptation could provide a focal point for international cooperation. Climate change adaptation planning should not be seen as a new branch of public policy, but as an integral part of wider strategies for poverty reduction and human development.

Livelihood enhancement, food security, poverty reduction, and environmental protection are high priorities on the development agenda of the nations of the EH. Mechanisms and instruments exist on a broad, regional scale for cooperation in addressing these issues, but imperatives are on a local scale to meet the basic needs for human wellbeing. The focus is on water, agriculture, biodiversity, and natural disasters that are climate-sensitive, and on climate disservices, in building capacities and enhancing the resilience of communities and institutions.

The impacts of climate change can severely hamper development efforts in key sectors, while development policies and programmes will, in turn, influence ability to adapt to climate change. Development approaches have become sensitive to indigenous knowledge and technologies, and traditional methods are being integrated into conventional strategies to ensure success in implementation. An example of such an approach is the UNFCCC's National Adaptation Programmes of Action (NAPAs) for use by least developed countries to prioritise their urgent adaptation needs. The rationale for NAPAs rests on the limited ability of least developed countries to assess their vulnerability and adapt to climate change. NAPAs help to incorporate the human and economic dimensions of local communities, particularly livelihood aspects and inter-sectoral relationships. NAPAs are useful in developing specific strategies and policy implementation building upon existing coping strategies, rather than focusing on scenario-based modelling, but they exhibit a weaker attribution to future climate change.

The Millennium Development Goals (MDGs) set the benchmark for development priorities, and climate change could hamper their achievement unless climate-resilient strategies are adopted to sustain ecosystem resources for human wellbeing. Entry points for managing climate change effects in the development process must be identified for necessary adjustment. Table 26 highlights potential areas for integrating climate change adaptation into development strategies to realise the MDGs.

Consultations with stakeholders and interactions with professionals and key partners as part of this assessment uncovered several issues and options for mitigation and adaptation to climate change in the region. The following actions are some of the initiatives that the governments of the relevant RMCs are undertaking, or will undertake, to address climate change. The actions are grouped into six main categories:

1. Sustainable energy production and efficient use: Enhancing energy conservation and efficiency in industry, and small business
2. Efficient infrastructure: Transportation, buildings, and communities – looking at increasing efficiency and promoting opportunities for innovation
3. Sustainable forests and carbon sink management: Managing forests and agricultural land to increase carbon sequestration and decrease impacts
4. Government leadership and outreach: Reducing emissions from government operations, increasing capacity to adapt, increasing public outreach on mitigation and adaptation
5. Water management: Supporting research geared towards developing water resource management tools, and supporting integrated watershed management to address issues such as drought and floods
6. Ecological tax reform: Addressing key consumption areas – such as energy use, water use, and solid waste disposal – that directly or indirectly harm ecosystems

Noticeably absent from national policy objectives (except for Bhutan and some cursory treatment by other countries) is an explicit objective related to climate change adaptation. Bhutan is set to become the first nation in the world in which the citizens will have a constitutional obligation to preserve the environment and implement environmental standards and instruments based on the precautionary polluter pays principle, and maintenance of intergenerational equity (UNEP 2007). The Government of Bhutan has made environmental protection a centre-piece of its development agenda and has become the first state to ensure sustainable use and reaffirm its sovereign right over its own natural and biological resources. Given the scope of potential impacts in the EH, stated objective for climate change should be included as part of any update to biodiversity conservation action plans of the regional countries. The starting point is to build climate change risk assessment into all aspects of policy planning. In turn, risk management requires that strategies for building resilience are embedded in adaptation policies and mainstreamed across ministries.

There is an urgent need for expanded dialogue so that societal priorities for ecosystem protection can be articulated. Public education, supported by ongoing research, is essential to inform such dialogue. Decisions need to be made with the understanding that the basis for decisions can change as information increases. The diverse research and education initiatives, beyond their intrinsic value, also have the objective of feeding into the policy sphere. The policy response should lead to coordinated action by ICIMOD and the regional countries in favour of environmental protection in mountains and uplands, and to help local populations adapt to changing ecological, economic, and health-related impacts.

Policy should also aim to convince key global actors such as the World Trade Organization to take mountain issues into consideration in the planning of future trade accords and commercial practices. Furthermore, a strengthening of ties between the 'Mountain Chapter' of Agenda 21 and the UN Conventions on Climate Change, Biodiversity, and Desertification may lead to a more efficient, holistic approach to the problems currently facing the Eastern Himalayan region.

Table 26: **Impacts of climate change on human wellbeing and the Millennium Development Goals** (impacts and wellbeing information types taken from Berry 2007)

Climate change impacts	Component of human wellbeing affected	Millennium Development Goal
• Damage to livelihood assets, including homes, water supply, health, and infrastructure • Reduction in crop yields • Changes in natural systems and resources, infrastructure and labour productivity • Social tension over resource use	• Reduced ability to earn a living • Food security endangered • Reduced income opportunities; affects economic growth • Increased human conflicts • Lives and livelihoods destabilised • Communities forced to migrate	Goal 1 Eradicate extreme poverty and hunger
• Loss of livelihood assets and natural disasters • Malnourishment and illness and the decreased ability of children to learn when they are in class • Displacement and migration	• Reduced opportunities for fulltime education; more children (especially girls) are likely to be taken out of school to help fetch water, earn an income, or care for ill family members • Reduced school attendance • Reduced access to education	Goal 2 Achieve universal primary education
• Women become more dependent on the natural environment for their livelihood, including agricultural production • Fewer resources and greater workload • Climate related disasters	• Exacerbation of gender inequality • Poor health • Less time to engage in decision making and earning additional income • Women and girls are typically the ones to care for the home and fetch water, fodder, firewood, and often food • Female-headed households with few assets are particularly affected	Goal 3 Promote gender equality and empower women
• Heat-waves, floods, droughts, and extreme weather • Increase and spread of vector-borne diseases (e.g., malaria and dengue fever) and water-borne diseases (e.g., cholera and dysentery) • Anaemia resulting from malaria • Reduction in the quality and quantity of drinking water • Natural disasters, increased malnutrition and famine	• Increase in death and illness • Negative effects on health of children and pregnant women • Increase in maternal and child mortality • Increase in malnutrition especially among children • Food security endangered	Goal 4 Reduce child mortality Goal 5 Improve maternal health
• Water stress and warmer conditions • Acceleration of the negative effects of AIDS	• Increased incidence of disease • Increase in malnutrition • Lower livelihood assets	Goal 6 Combat HIV/AIDS, malaria, and other diseases
• Alterations and possible irreversible damage to the quality and productivity of ecosystems and natural resources • Decrease in biodiversity and worsening of existing environmental degradation • Alterations to ecosystem-human interfaces and interactions	• Reduced ecosystem services • Loss of biodiversity • Loss of basic support systems for livelihood	Goal 7 Ensure environmental sustainability
• Climate change is a global issue and a global challenge • International relations may be strained by climate impacts	• Global cooperation, especially to help developing countries adapt to the adverse effects of climate change • International relations	Goal 8 Develop a global partnership for development

7 Conclusion

The Eastern Himalayas is vulnerable to climate change due to its ecological fragility and economic marginality. Recent studies confirm its vulnerability, with analysis and predictions showing increasing magnitude of change with elevation, both in mean shifts in temperature and in greater stretch in precipitation variation. As a biodiversity hotspot, the source of the headwaters of four major Asian river systems, and home to millions of the poorest in the world, the Eastern Himalayas presents a unique case in which poverty is not always correlated with desertification and degradation, nor does it seek paybacks from the downstream majority thriving on the ecosystem services flowing out of it. Climate change is poised to alter this status quo with far-reaching consequences for the condition of biodiversity, quality of ecosystem flow downstream, and the wellbeing of the people in the region.

The impact of climate change on biodiversity must be assessed in conjunction with coexistent impacts on the other components of ecosystems and on the socioeconomic condition of the human population occupying the same geographic space. Similarly, just as climate change is coupled with other environmental changes, vulnerability must be assessed in the context of the dynamic flux of both socioeconomic and biophysical factors. The environmental changes the region is experiencing do not influence biodiversity in isolation. Rather, the diversity in ecosystems and the variability in environmental factors like weather, climate, and water interact in a mutually reinforcing manner to create the diversity of life and the huge variety of ecosystem services that emanate from such interactions. However, this ecological equilibrium in the flow of material and energy and the mechanism of connections and feedbacks are being rapidly eroded by human interference with the climate system.

According to current trends and future climate projections, higher temperatures, greater rainfall variability, increased concentration of atmospheric CO_2, and more frequent extreme events are likely scenarios until the end of the 21st Century. The environmental consequences of this faster than natural evolution of climate are going to impact on all spheres of life and life support systems on Earth.

It is becoming clear that the EH can expect major transformations in biodiversity across all systems (terrestrial, freshwater) and all levels (genetic, species, ecosystem) under a changing climate. It is now more urgent that ever to identify clear management objectives to guide management priorities. Our experiences and lessons suggest that maintaining ecosystem resilience, while focusing on the underlying structure, functions, and processes of ecosystems, should be a priority. Creating protected areas and biodiversity networks, minimising habitat fragmentation, and managing invasive species are the obvious starting points for biodiversity management in response to climate change. The scope for better options for managing biodiversity with climate change than we already know is rather limited. In short, we know in principle what to do; what is not well known is where, when, and how to do it.

Many of the impacts elucidated here are based on imperfect knowledge from limited species and location responses to climate change factors. There are conflicting inferences about the response of ecosystems to CO_2 enrichment under climate change, which remain unresolved. However, a new understanding is emerging that the impact of elevated CO_2 will vary with elevation and is unlikely to be a long-term response. This is corroborated by the limitation in the non-structural carbon pool and observations that CO_2 concentration is lower at higher altitudes. Investigation into some of the alpine species carbon assimilation mechanisms suggested that their growth is not always limited by low temperature/ low CO_2 conditions; stomatal conductance was found to be regulated more by endogenous biorhythms than by atmospheric conditions in some alpine species. Vegetation dynamic models do not always take non-climatic factors into account, making predictions about species distribution and range shifts questionable. Some species have wider altitudinal spreads and do not pose an immediate threat of colonising vegetation belts higher up, while other species represent edaphic (soil-related) rather than climatic climax. These are some of the issues that need further scientific investigation.

In the EH, past changes in climate have been recorded and future projections are available; these can provide a starting point for assessing the types of climate stressors that will impact on various biodiversity management endpoints in terrestrial and freshwater systems. It is high time that we moved beyond the planning and background reporting stage; we need to move from concepts and theories into the sphere of implementation. The priorities must be explicit and achievable, without being vaguely all-encompassing, and management options must be considered on a case-by-case basis. There is a need to guard against management inactivity in the face of the major uncertainties raised by climate change. In all cases we should be looking for 'no-regret' actions. These are actions that perform well irrespective of climate change. Features of no-regret options are their relatively low lifecycle cost, short completion horizon, and limited risk to other management objectives.

References

Adger, WN (2000a) 'Social and ecological resilience: Are they related?' *Progress in Human Geography* 24: 347-364

Agarwal, PK; Bandyopadhyay, SK; Pathak, H; Kalra, N; Chander, S; Kumar, S (2000) 'Analysis of yield trends of the rice-wheat system in north-western India.' *Outlook on Agriculture* 29(4): 259-268

Aggarwal, D; Lal, M (2001) *Vulnerability of Indian coastline to sea level rise*. New Delhi: Centre for Atmospheric Sciences, Indian Institute of Technology

AIACC (2007) *A stitch in time: Lessons for climate change adaptation from the AIACC project*. Assessments of Impacts and Adaptations to Climate Change (AIACC) Working Paper No. 48, May 2007. Washington DC: AIACC

Allan, JD; Palmer, M; Poff, NL; (2005) 'Climate change and freshwater ecosystems.' In Lovejoy, TE; Hannah, L (eds) *Climate Change and Biodiversity*. New Haven: Yale University Press

Anand, S; Sen, A (1994) *Human Development Index: Methodology and Measurement,* Occasional Paper 12. New York: United Nations Development Programme, Human Development Report Office

Ando, M (1998) 'Risk assessment of global warming on human health.' *Global Environmental Research* 2: 69–78

Andronova, NG; Schlesinger, ME (2001) 'Objective estimation of the probability density function for climate sensitivity.' *J. Geophys. Res.* 106: 22, 605–22, 612

Anonymous (1993) *Summary of procedures to produce a landslide susceptibility map*. In Geo-haz Consultants, Phase 1 Report to the US Department of Commerce, Economics of Global Change Programme

Anyamba, A; Eastman, JR; Fulk, M (1995) 'NDVI time image series as an indicator of climate variability.' In *ACSM/ASPRS Annual Convention and Exposition Technical Papers 3*: 714–723

APN (2003) *Global change impact assessment for Himalayan mountain regions: Resource management and sustainable development,* Final Report. Kathmandu: APM. www.apn.gr.jp/en/products/project_report/2003/finalreport/2003-03.pdf

APN (2005) *Enhancement of national capacities in the application of simulation models for the assessment of climate change and its impacts on water resources and food and agricultural production,* CAPaBLE Project: 2005-CRP1CMY. Islamabad: APN

ATEAM (2004) *Final Report 2004*. Potsdam: Advanced Terrestrial Ecosystem Analysis and Modeling, PIK

Bajracharya, SR; Mool, PK; Shrestha, BR (2007) *Impact of climate change on Himalayan glaciers and glacial lakes: Case studies on GLOF and associated hazards in Nepal and Bhutan*. Kathmandu: ICIMOD

Ball, GH; Hall, DJ (1965) *A novel method of data analysis and pattern classification*. Menlo Park (California): Stanford Research Institute

Beniston, M (2003) Climate change in mountain regions: A review of possible impacts. *Climate Change* 59: 5–31

Berry, P (2007) *Adaptation options on natural ecosystems*, report to the UNFCCC Financial and Technical Support Division, Bonn, Germany. http://unfccc.int/cooperation_and_support/financial_mechanism/financial_mechanism_gef/items/4054.php (accessed 23 September 2009)

Bhattacharya, PM; Majumdar, RK; Kayal, JR (2002) 'Fractal dimension and b-value mapping in Northeast India.' *Curr. Sci.* 82: 1486–1491

Bohle, HC; Downing, TE; Watts, MJ (1994) 'Climate change and social vulnerability.' *Global Environmental Change* 4(1): 37–48

Bouchama, A; Parhar, RS; El-Yazigi, A; Sheth, K; Al-Sedairy, S (1991) 'Endotoxemia and release of tumor necrosis factor and interleukin 1 alpha in acute heatstroke.' *Journal of Applied Physiology* 70(6): 2640–2644

Brenkert, AL; Malone, EL (2005) 'Modeling vulnerability and resilience to climate change: A case study of India and Indian states.' *Climatic Change* 72: 57–102

Brooks, N (2003) *Vulnerability, risk and adaptation: A conceptual framework*, Working Paper 38. Norwich: Tyndall Centre for Climate Change Research

Bruinsma, J (ed) (2003) *World agriculture: Towards 2015/2030 – An FAO perspective*. Rome: Food and Agriculture Organization, and London: Earthscan

Caldwell, CR; Britz, SJ; Mirecki, RM (2005) 'Effect of temperature, elevated carbon dioxide, and drought during seed development on the isoflavone content of dwarf soybean [*Glycine max* (L.) Merrill] grown in controlled environments.' *J. Agr. Food Chem.* 53(4): 1125–1129

Carpenter, S; Walker, B; Anderies, JM; Abel, N (2001) 'From metaphor to measurement: Resilience of what to what?' *Ecosystems* 4: 765–781

CEPF (2005) *Ecosystem profile: Indo-Burman Hotspot, Eastern Himalayan Region*. Arlington: WWF, US-Asian Program/CEPF

CEPF (2007) *Ecosystem profile: Indo-Burman Hotspot, Indo-China Region*. Arlington: WWF, US-Asian Program/CEPF

Chakravorty, AK (1951) 'Origin of cultivated banana of Southeast Asia.' *Indian J. Genet.* 11: 34–46

Chambers, R (1989) 'Vulnerability, coping and policy.' *Institute of Developmental Studies Bulletin* 20: 1–7

Chen, Hao; El Garouani, A; Lewis, LA (2008) 'Modelling soil erosion and deposition within a Mediterranean mountainous environment utilizing remote sensing and GIS – Wadi Tlata, Morocco.' *Geographica Helvetica* 63: 36–47

Chen, Shenbin; Liu, Yunfeng; Thomas, A (2006) 'Climatic change on the Tibetan plateau: Potential evapotranspiration trends from 1961–2000.' *Climatic Change* (2006) 76: 291–319

Chettri, N; Sharma, E; Shakya, B; Thapa, R; Bajracharya, B; Uddin, K; Oli, KP; Choudhury, D (2010) *Biodiversity in the Eastern Himalayas: Status, trends and vulnerability to climate change*; Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 2. Kathmandu: ICIMOD

CIESIN (2004) *Global spatial data and information: Development, dissemination and use*. New York: Centre for International Earth Science Information Network

CIESIN (2005) *Gridded gross domestic product (GDP)*. New York: Center for International Earth Science Network. http://islscp2.sesda.com/ISLSCP2_1/html_pages/groups/soc

CIESIN/CIAT (2003) *Gridded population of the world version3 (GPW3) – population density grids*. Palisades (NY): Socioeconomic Data and Applications Centre (SEDAC), Columbia University. http://sedac.ciesin.columbia.edu/gpw

Clark, WC; Jaeger, J; Corell, R; et al. (2000) *Assessing vulnerability to global environmental risks,* Report of the Workshop on Vulnerability to Global Environmental Change: Challenges for Research, Assessment and Decision Making, Warrenton, VA. Research and Assessment Systems for Sustainability Program Discussion Paper 2000-12. Cambridge MA: Harvard University, Kennedy School of Government, Environment and Natural Resources Program, Belfer Center for Science and International Affairs (BCSIA)

Clark, WC; Dickson, NM (2003) 'Sustainability science: The emerging research program.' *Proceedings of the National Academy of Sciences* 100(14):8059–8061

Conway, D; Bhattarai, K; Shrestha, NR (2000) 'Population-environment relations at the forested frontier of Nepal.' *Applied Geography* 20: 221–242

Cowling, RM; Pressey, RL (2003) 'Introduction to systematic conservation planning in the Cape Floristic Region.' *Biological Conservation* 112: 1–13

Cowling, RM; Pressey, RL; Rouget, M; Lombard, AT (2003a) 'A conservation plan for a global biodiversity hotspot – the Cape Floristic Region, South Africa.' *Biological Conservation* 112: 191–216

Cutter, SL (1996) 'Vulnerability to environmental hazards.' *Progress in Human Geography* 20(4): 529–539

Cutter, SL (2003) 'The vulnerability of science and the science of vulnerability.' *Annals of the Association of American Geographers* 93 (1): 1–12

Daily, GC (1997) 'Introduction: What are Ecosystem Services?' In Daily, GC *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington DC: Island Press

Dash, SK; Jenamani, RK; Kalsi, SR; Panda, SK (2007) 'Some evidence of climate change in the twentieth-century India.' *Climate Change* 85: 299–321

De Groot (1992) *Functions of nature: Evaluation of nature in environmental planning, management and decision making*. Groningen: Wolters-Noordhoff

De Groot, RS; Wilson, AW; Boumans, RMJ (2002) 'A typology for the classification, description and valuation of ecosystem functions, goods and services.' *Ecological Economics* 41: 393–408

Dhar, U (2002) 'Conservation implications of plant endemism in high-altitude Himalaya.' *Current Science* 82: 141–148

DHM (1996) *Glacier lake outburst flood study of the Tama Koshi Basin*. Draft Report prepared by BPC Hydroconsult, November 1996 for the Department of Hydrology and Meteorology, Kathmandu, Nepal

DHM (2004) *Initial national communication of Nepal under the United Nations Framework Convention on Climate Change*. Kathmandu: Department of Hydrology and Meteorology

Dinerstein, E; Wikramanayake, ED (1993) 'Beyond 'hotspots': How to prioritise investments to conserve biodiversity in the Indo-Pacific region.' *Conservation Biology 7*: 53–65

Dinerstein, E; Powell, G; Olson, D; Wikramanayake, E; Abell, R; Loucks, C; Underwood, E; Allnutt, T; Wttengel, W; Ricketts, T; Strand, H; O'Connor, S; Burgess, N (2000) *A workbook for conducting biological assessments and developing biodiversity. Visions for ecoregion-based conservation. Part 1: Terrestrial ecoregions*. Washington DC: Conservation Science Program, WWF-USA

Downing, TE (1992) *Climate change and vulnerable places: Global food security and country studies in Zimbabwe, Kenya, Senegal and Chile*, Research Report 1. Oxford: University of Oxford, Environmental Change Unit

Downing, TE; Butterfield, R; Cohen, S; Huq, S; Moss, R; Rahman, A; Sokona, Y; Stephen, L (2001) *Climate change vulnerability: linking impacts and adaptation*. Oxford: University of Oxford

Downing, TE; Patwardhan, A (2003) *Vulnerability assessment for climate adaptation. Adaptation policy framework, Technical Paper 3: A Guide for Policies to Facilitate Adaptation to Climate Change*. New York: United Nations Development Programme

Dye, DG; Tucker, CJ (2003) 'Seasonality and trends of snow-cover, vegetation index, and temperature in northern Eurasia.' *Geophysical Research Letters* 30(7): 1405

Dyurgerov, MB; Meier, MF (1997) 'Mass balance of mountain and sub-polar glaciers: A new global assessment for 1961–1990.' *Arctic and Alpine Research* 29(4): 379–391

Epstein, PR; Diaz, HF; Elias, S (1998) 'Biological and physical signs of climate change. Focus on mosquito-borne diseases.' *Bull. Amer. Meteorol. Soc.* 78: 410–417

Epstein, Y; Sohar, E; Shapiro, Y (1995) 'Exceptional heatstroke: a preventable condition.' *Israel Journal of Medical Science* 31: 454–462

Erikson, SH; Kelly, PM (2007) 'Developing credible vulnerability indicators for climate adaptation policy assessment.' *Mitigation and Adaptation Strategies for Global Change* 12: 495–524

Esty, DC; Levy, M; Srebotnjak, T; de Sherbinin, A (2005) *Environmental Sustainability Index: Benchmarking national environmental stewardship*. New Haven: Yale Center for Environmental Law and Policy

Esty, DC; Levy, MA; Kim, CH; de Sherbinin, A; Srebotnjak, T; Mara, V (2008) *2008 Environmental Performance Index*. New Haven: Yale Center for Environmental Law and Policy

Fang Jing; Leduc, B (2010) *Potential threats from climate change to human wellbeing in the Eastern Himalayan Region;* Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 6. Kathmandu: ICIMOD

FAO (2003) *World agriculture: Towards 2015/2030 – An FAO perspective*. Bruinsma //initials?// (ed). Rome and London: Food and Agriculture Organization and Earthscan

Feenstra, JF; Burton, I; Smith, JB; Tol, RSJ (eds) (1998) *Handbook on methods for climate change impact assessment and adaptation strategies*. Nairobi: UNEP, and Amsterdam: Institute for Environmental Studies/Vrije Universiteit

Fetke, BM; Vörösmarty, CJ; Grabs, W (2000) *Global composite runoff fields based on observed river discharge and simulated water balances*. Durham: Complex Systems Research Center, University of New Hampshire

Fischer, G; Frohberg, K; Parry, ML; Rosenzweig, C (1994) 'Climate change and world food supply, demand and trade: Who benefits, who loses?' *Global Environmental Change* 4: 7–23

Fischer, G; van Velthuizen, H; Shah, M; Nachtergaele, FO (2002a) *Global agro-ecological assessment for agriculture in the 21st Century: Methodology and results*, IIASA RR-02-02. Laxenburg (Austria): IIASA

Fischer, G; Shah, M; van Velthuizen, H (2002b) *Climate change and agricultural vulnerability, special report to the UN World Summit on Sustainable Development, Johannesburg 2002*. Laxenburg (Austria): IIASA

Fussel, HM (2005) *Vulnerability to climate change: A comprehensive conceptual framework*, University of California International and Area Studies Breslauer Symposium Paper 6. Berkeley CA: University of California

Fussel, HM; van Minnen, JG (2001) 'Climate impact response functions for terrestrial ecosystems.' *Integr. Assess.* 2: 183–197

Fussel, HM; Klein, RJT; Ebi, KL (2006) 'Adaptation assessment for public health.' In Menne, B; Ebi, KL (eds) *Climate Change and Adaptation Strategies for Human Health*, pp 41–62. Darmstadt: Steinkopff Verlag

Gabet, EJ; Burbank, DW; Putkonen, JK; Pratt-Sitaula, BA; Ojha, T (2004) 'Rainfall thresholds for landsliding in the Himalayas of Nepal.' *Geomorphology* 63: 131–143

Garg, A; Rana, A; Shukla, PR; Kapshe, M; Azad, M (2007) *Handbook of Current and Next Generation Vulnerability and Adaptation Assessment Tools*. Bombay: Indian Institute of Technology

Giorgi, F; Mearns, LO (1991) 'Approaches to the simulation of regional climate change: A review.' *Rev. Geophys* 29: 191–216

Godde, P; Price, MF; Zimmermann, FM (eds) (2000) *Tourism and development in mountain regions*. Wallingford: CABI Publishing

Gopal, B; Shilpakar, R; Sharma, E (2010) *Functions and Services of Wetlands in the Eastern Himalayas: Impacts of Climate Change;* Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 3. Kathmandu: ICIMOD

Gopal, B; Chatterjee, A; Gautam, P (2008) *Sacred waters of the Indian Himalaya*. New Delhi: WWF-India

Gosain, AK; Shrestha, AB; Rao, S (2010) *Modelling climate change impact on the hydrology of the Eastern Himalayas*; Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 4. Kathmandu: ICIMOD

Grabherr, G; Gottfriend, M; Pauli, H (1994) 'Climate effects on mountain plants.' *Nature* 369: 448

Guisan, A; Holten, J; Spichiger, R; Tessier, L (eds) (1995) *Potential impacts of climate change on ecosystems in the Alps and Fennoscandian Mountains*. Annex Report to the IPCC Working Group II Second Assessment Report, Publication Series of the Geneva Conservatory and Botanical Gardens. Geneva: University of Geneva

Haeberli, W; Beniston, M (1998) 'Climate change and its impacts on glaciers and permafrost in the Alps.' *Ambio* 27: 258–265

H-Acevedo, D; Currie, DJ (2003) 'Does climate determine broad-scale patterns of species richness? A test of the causal link by natural experiment.' *Global Ecology and Biogeography* 12 6: 461–473

Halpin, PN (1994) 'Latitudinal variation in the potential response of mountain ecosystems to climate change.' In Beniston, M (ed) *Mountain Environments in Changing Climates*, pp 180–203. London: Routledge

Hansen, LJ; Biringer, JL; Hoffman, JR (eds) (2003) *Buying time: A users' manual for building resistance and resilience in natural systems*. Berlin: WWF

Hansen-Bristow, KJ;, Ives, JD; Wilson, JP (1988) 'Climatic variability and tree response within the forest-alpine tundra ecotone.' *Annals of the Association of American Geographers* 78: 505–519

Hijmans, RJ; Cameron, SE; Parra, JL; Jones, PG; Jarvis, A (2005) 'Very high resolution interpolated climate surfaces for global land areas.' *International Journal of Climatology* 25: 1965–1978

Hill, JL; Curran, PJ (2003) 'Area, shape and isolation of tropical forest fragments: Effects on tree species diversity and implications for conservation.' *Journal of Biogeography* 30(9): 1391–1403

Hirzel, AH; Helfer, V; Métral, F (2001) 'Assessing habitat-suitability models with a virtual species.' *Ecological Modeling* 145: 111–121

Hore, DK (2005) 'Rice diversity collection, conservation and management in Northeastern India.' *Genetic Resources and Crop Evolution* 52: 1129–1140

Imhoff, JL; Bounoua, L; Ricketts, T; Loucks, C; Harriss, R; Lawrence, WT (2004) 'Global patterns in human consumption of net primary production.' *Nature*, 429:870-873

IPCC (1997) *The regional impacts of climate change: An assessment of vulnerability*, Special Report of IPCC Working Group II [Watson, RT; Zinyowera, MC; Moss, RH (eds)] Cambridge: Cambridge University Press

IPCC (1998) *The regional impacts of climate change*. Cambridge: Cambridge University Press

IPCC-TGCIA (1999) *Guidelines on the use of scenario data for climate impact and adaptation assessment*, Version 1. Prepared by Carter, TR, Hulme, M; Lal, M, Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment. Geneva: IPCC

IPCC (2000) *Presentation of Robert Watson*. Chair, Intergovernmental Panel on Climate Change, at the Sixth Conference of the Parties to the United Nations Framework Convention on Climate Change, the Hague, 13th and 20th November, 2000

IPCC (2001a) *IPCC third assessment report*, Climate Change 2001: Synthesis Report. (Working Group I: The Scientific Basis; Working Group II: Impacts, Adaptation and Vulnerability; Working Group III: Mitigation) Cambridge: Cambridge University Press

IPCC (2001b) *Climate change 2001 – Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change: McCarthy, JJ; Canziani, OF; Leary, NA; Dokken DJ; White, KS (eds). Cambridge: Cambridge University Press

IPCC (2002) *Climate change and biodiversity*: Gitay, H; Suarez, A; Watson, R; Dokken, D (eds), administered by the IPCC Working Group II Technical Support Unit. Geneva: IPCC

IPCC (2007a) *Fourth assessment report. Geneva: Intergovernmental Panel on Climate Change Secretariat*

IPCC (2007b) *Climate change 2007: Summary for policymakers,* Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press

IPCC (2007c) *Climate change 2007: Climate change impacts, adaptation and vulnerability*, Contribution of Working Group II contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC. www.ipcc.ch/SPM13apr07.pdf (accessed June 2007)

IPCC (2007d) *Climate change 2007: The physical science basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press

Ives, JD; Messerli, B; Spiess, E (2004) 'Mountains of the world: A global priority.' In Messerli, B; Ives, JD (eds) *Mountains of the World: A Global Priority*, pp 1–15. New York and London: Parthenon

Ives, JD; Shrestha, RB; Mool, PK (2010) Formation of glacial lakes int he Hindu Kush-Himalayas and GLOF risk asessment. Kathmandu: ICIMOD

Jin, ZQ; Shi, CL; Ge, DK; Gao, W (2001) 'Characteristic of climate change during wheat growing season and the orientation to develop wheat in the lower valley of the Yangtze River.' *Jiangsu Journal of Agricultural Science* 17(4): 193–199

Johnson, DW (1992) 'Effects of forest management on soil carbon storage.' *Water, Air and Soil Pollution* 64: 83–120

Kaly, U; Briguglio, L; McLeod, H; Schmall, S; Pratt, C; Pal, R (1999) *Environmental Vulnerability Index (EVI) to summarise national environmental vulnerability profiles*, SOPAC Technical Report 275. Fiji: SOPAC

Kaly, UL; Pratt, CR; Mitchell, J; Howorth, R (2003) *The Demonstration Environmental Vulnerability Index (EVI)*, SOPAC Technical Report 356. Fiji: SOPAC

Karim, Z; Hussain, SG; Ahmed, M (1996) 'Assessing impacts of climatic variations on foodgrain production in Bangladesh.' *Water, Air, and Soil Pollution* 92: 53–62

Kasperson, JX; Kasperson, RE (2001) *International Workshop on Vulnerability and Global Environmental Change, 17–19 May 2001, Stockholm Environment Institute (SEI), Stockholm, Sweden*, A Workshop Summary prepared on behalf of workshop participants, SEI Risk and Vulnerability Programme Report 2001–01. Stockholm: Stockholm Environment Institute

Kasperson, RE; Mabogunje, A; Matson, PA; Mooney, HA; Moore III, B; O'Riordan, T; Svedin, U (2001) 'Sustainability science.' *Science* 292: 641–642

Kasperson, JX; Kasperson, RE; Turner II, BL; Schiller, A; Hsieh, WH (2003). 'Vulnerability to global environmental change.' In Diekmann, A; Dietz, T; Jaeger, C; Rosa, ES (eds) *The Human Dimensions of Global Environmental Change*. Cambridge: MIT

Kates, RW (2000) 'Cautionary tales: Adaptation and the global poor.' *Climatic Change* 45: 5–17

Kates, RW; Clark, WC; Corell, R; Hall, JM; Jaeger, CC; Lowe, I; McCarthy, JJ; Schellnhuber, HJ; Bolin, B; Dickson, NM; Faucheux, S; Gallopin, GC; Gruebler, A; Huntley, B; Jaeger, J; Jodha, NS; Kasperson, RE; Matson, P; Mooney, H; Moore III, B; O'Riordan, T; Svedin, U (2001) 'Sustainability science.' *Science* 292: 641–642

Kelly, PM; Adger, WN (2000) 'Theory and practice in assessing vulnerability to climate change and facilitating adaptation.' *Climatic Change* 47: 325–352

Klein, RTJ (2001) *Adaptation to climate change in German development assistance – An inventory of activities and opportunities, with a special focus on Africa*. Eschborn: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)

Klein, RJT (2002) 'Adaptation to climate variability and change: What is optimal and appropriate?' In Giupponi, C; Shechter, M (eds) *Climate Change and the Mediterranean: Socio-Economics of Impacts, Vulnerability and Adaptation*. Cheltenham: Edward Elgar

Kuh, N; Honglei, Z (2008) 'GIS-based modeling of runoff source areas and pathways.' *Geographica Helvetica* 63: 48–57

Lal, M (2005) 'Implications of climate change on agricultural productivity and food security in South Asia.' In *Key vulnerable regions and climate change – Identifying thresholds for impacts and adaptation in relation to Article 2 of the UNFCCC*. European Climate Forum, and Dordrecht: Springer

Leary, N; Kulkarni, J (2007) *Climate change vulnerability and adaptation in developing country regions*. Draft Final Report of the AIACC Project, April 2007, The International START Secretariat, Washington DC

Lehner, B; Doll, P (2004) 'Development and validation of a global database of lakes, reservoirs and wetlands.' *Journal of Hydrology* 296: 1–22

Leichenko, R; O'Brien, K; Aandahl, G; Tompkins, H; Javed, A (2004) *Mapping vulnerability to multiple stressors: A technical memorandum*. Oslo: CICERO

Levy, PE; Cannell, MGR; Friend, AD (2004) 'Modelling the impact of future changes in climate, CO_2 concentration and landuse on natural ecosystems and the terrestrial carbon sink.' *Global Environmental Change* 14 (1): 21–30

Ligon, E; Schechter, L (2002) *Measuring vulnerability*. Washington, DC, USA, September 23–24, 2002. www.ifpri.org/events/conferences/2002/092302.htm (accessed June 2007)

Liu, X; Chen, B (2000) 'Climatic warming in the Tibetan Plateau during recent decades.' *Int. J. Climatol* 20: 1729–1742

Luers, AL; Lobell, DB; Sklar, LS; Addams, CL; Matson, PA (2003) 'A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico.' *Glob Environ Change* 13: 255–267

Malcolm, JR; Markham, A (1997) *Climate change threats to the national parks and protected areas of the United States and Canada*. Washington, DC: WWF

Malone, EL; La Rovere, EL (2004) 'Assessing current and changing socio-economic conditions.' In Lim, B; Spanger-Siegfried, E; Burton, I; Malone, EL; Huq S (eds) *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, pp 147–163. Cambridge: Cambridge University Press

Malone, EL; Smith, JB; Brenkert, AL; Hurd, BH; Moss, RH; Bouille, D (2004) *Developing socioeconomic scenarios: For use in vulnerability and adaptation assessments.* New York: United Nations Development Programme

Mansuri, G; Healy, A (2002) 'Vulnerability prediction in rural Pakistan.' Washington DC: International Food Policy Research Institute. www.ifpri.org/events/conferences/2002/092302/mansuri.pdf (accessed June 2010)

Martens, P; Kovats, RS; Nijhof, S; de Vries, P; Livermore, MTJ; Bradley, DJ; Cox, J; McMichael, AJ (1999) 'Climate change and future populations at risk of malaria.' *Global Environmental Change* 9: S89–S107

McArthur, RH (1972) *Geographical Ecology*. New York: Harper and Row

McKee, JK; Sciulli, PW; Fooce, CD; Waite, TA (2004) 'Forecasting global biodiversity threats associated with human population growth.' *Biological Conservation* 115: 161–164

McMichael, A; Githeko, A; Akhtar, R; Carcavallo, R; Gubler, D, Haines, A; Kovats, RS; Martens, P; Patz, J; Sasaki, A (2001) 'Human health.' In McCarthy, JJ; Canziani, OF; Leary, NA; Dokken, DJ; White, KS (eds) *Climate change 2001: Impacts, adaptation, and vulnerability*, pp 451–485. Cambridge: Cambridge University Press

McNeely, JA; (1990) 'Climate change and biological diversity: Policy implications, landscape-ecological impact of climatic change.' In Boer, MM; de Groot, RS (eds) *Landscqpe ecological impact of climate change*. Amsterdam: IOS Press

MEA (2003) *Ecosystems and human well-being: A framework for assessment.* Washington DC: Island Press

MEA (2005) *Ecosystems and human well-being: Synthesis*, p 155. Washington, DC: Island Press, published for World Resources Institute

Menon, S; Pontius, RG; Rose, J; Khan, MI; Bawa, KS (2001) 'Identifying conservation-priority areas in the tropics: A land-use change modeling approach.' *Conservation Biology* 15: 502–512

Metzger, MJ; Bunce, RGH; Jongman, RHG; Mucher, CA; Watkins, JW (2005a) 'A climatic stratification of the environment of Europe.' *Glob Ecol Biogeogr* 14: 549–563

Metzger, MJ; Bunce, RGH; Leemans, R; Viner, D (2008) 'Projected environmental shifts under climate change: European trends and regional impacts.' *Environ Conserv* 35:64-75

Metzger, MJ; Leemans, R; Schröter, D; Cramer, W; the ATEAM Consortium (2004) *The ATEAM vulnerability mapping tool. Quantitative approaches in systems analysis* No. 27. Wageningen: Office CT de Wit Graduate School for Production Ecology and Resource Conservation (PEandRC) (CD-ROM)

Metzger, MJ; Leemans, R; Schröter, D (2005b) 'A multidisciplinary multi-scale framework for assessing vulnerability to global change.' *International Journal Appl Geo-inf Earth Observ* 7:253–267

Metzger, MJ; Rounsevell, MDA; Acosta-Michlik, L; Leemans, R; Schröter, D (2006) 'The vulnerability of ecosystem services to land use change.' *Agric Ecosyst Environ* 114: 69–85

Metzger, MJ; Schröter, D (2006) 'Towards a spatially explicit and quantitative vulnerability assessment of environmental change in Europe.' *Reg Environ Change* 6: 201–216

Metzger, MJ; Schröter, D; Leemans, R; Cramer, W (2007) 'A spatially explicit and quantitative vulnerability assessment of ecosystem service change in Europe.' *Reg Environ Change* 8:91-107

Mitchell, TD; Carter, TR; Jones, PD; Hulme, M; New, M (2004) *A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: The observed record (1901–2000) and 16 scenarios (2001–2100),* Working paper No. 55. Norwich: Tyndall Centre for Climate Change Research, University of East Anglia

Mitchell, TD; Jones, PD (2005) 'An improved method of constructing a database of monthly climate observations and associated high-resolution grids.' *International Journal of Climatology* 25: 693–712

Mitsch, WJ; Gosselink, JG (2007) *Wetlands* (4th edn). New York: John Wiley

Mool, PK; Bajarchayra, SR; Joshi, SP (2001a) *Inventory of glaciers, glacial lakes and glacial lake outburst floods, monitoring and early warning system in the Hindu Kush-Himalayan Region, Bhutan*. Kathmandu: ICIMOD

Mool, PK; Wangda, D; Bajrachary, SR; Kunzang, K; Gurung, DR; Joshi, SP (2001b) *Inventory of glaciers, glacier lakes and glacial lake outburst floods, monitoring and early warning system in the Hindu Kush-Himalayan Region, Nepal*. Kathmandu: ICIMOD

Moss, R; Brenkert, A; Malone, EL (2000) *Measuring vulnerability: A trial indicator set*. Richland, WA: Pacific Northwest Laboratories. www.pnl.gov/globalchange/projects/vul/indicators.pdf

Moss, RH; Brenkert, AL; Malone, EL (2001) *Vulnerability to climate change: A Quantitative approach*. Richland, WA: Pacific Northwest Laboratories, US Department of Energy

Mountain Agenda (1998) *Mountains of the world: Water towers for the 21st Century*. Berne: Mountain Agenda group, Centre for Development and Environment (CDE), University of Berne

Myers, N (1988) 'Threatened biotas: "Hot spots" in tropical forests.' *Environmentalist* 8: 187–208

Myers, N; Mittermeier, RA; Mittermeier, CG; da Fonseca, GAB; Kent, J (2000) 'Biodiversity hotspots for conservation priorities.' *Nature* 403: 853–858

Nakicenovic, N; Alcamo, J; Davis, G; et al. (2000) *IPCC special report on emissions scenarios (SRES)*. Cambridge: Cambridge University Press

Nakicenovic, N; Swart, R (eds) (2000) *Emissions scenarios.* Cambridge: Cambridge University Press

NAST (National Assessment Synthesis Team) (2001) *Climate change impacts on the United States.* Cambridge: Cambridge University Press

Nilsson, C; Grelsson, G (1995) 'The fragility of ecosystems: A review.' *Journal of Applied Ecology*, 32(4):677-692

Noble, I; Gitay, H (1998) 'Climate change in desert regions.' In Watson, RT; Zinyowera, M; Moss, R (eds) *The Regional Impacts of Climate Change*, pp 191–217. Cambridge: Cambridge University Press

North, DC (1990) *Institutions, institutional change, and economic performance*. New York: Cambridge University Press

O'Brien, K; Leichenko, RM (2000) 'Double exposure: Assessing the impacts of climate change within the context of economic globalization.' *Global Environ. Change* 10: 221–232

O'Brien, K; Eriksen, S; Schjolen, A; Nygaard, L (2004a) *What's in a word? Conflicting Interpretations of vulnerability in climate change research*, CICERO Working Paper 2004:04. Oslo: CICERO, Oslo University

O'Brien, K; Leichenko, R; Kelkar, U; Venema, H; Aandahl, G; Tompkins, H; Javed, A; Bhadwal, S; Barg, S; Nygaard, L; West, J (2004b) 'Mapping vulnerability to multiple stressors: Climate change and globalization in India.' *Global Environ. Change* 14: 303–313

O'Brien, K; Sygna, L; Haugen, JE (2004c) 'Vulnerable or resilient? A multi-scale assessment of climate impacts and vulnerability in Norway.' *Clim Change* 64: 193–225

Olson, DM; Dinerstein, E; Wikramanayake, ED; et al. (2001) 'Terrestrial Ecoregions of the World: A New Map of Life on Earth.' *BioScience* 51: 933–938

Parmesan, C (2005) 'Biotic response: Range and abundance changes.' In Lovejoy, TE; Hannah, L (eds) *Climate Change and Biodiversity*. New Haven: Yale University Press

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

Parry, M; Carter; T (1998) *Climate impact and adaptation assessment*. London: Earthscan

Parry, ML; Rosenzweig, C; Iglesias, A; Livermore, M; Fischer, G (2004) 'Effects of climate change on global food production under SRES emissions and socio-economic scenarios.' *Global Environmental Change* 14 (1): 53–67

Pathak, D; Gajurel, AP; Mool, PK (2010) *Climate change impacts on hazards in the Eastern Himalayas*; Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 5. Kathmandu: ICIMOD

Patwardhan, A; Narayanan, K; Parthasarathy, D; Sharma, U (2003) 'Assessment of vulnerability and adaptive capacity in coastal zones.' In Shukla et al. (eds) *Climate Change and India Vulnerability Assessment and Adaptation*. Hyderabad: Universities Press

Patz, JA; Martens, WJM (1996) 'Climate impacts on vector-borne disease transmission: Global and site-specific.' *Journal of Epidemiology* 6: S145–S148

Patz, JA; Cambell-Lendrum, D; Holloway, T; Foley, JA (2005) 'Impact of regional climate on human health.' *Nature* 438: 310–317

Pauli, H; Gottfried, M; Grabherr, G (1998) 'Effects of climate change on mountain ecosystems. upward shifting of alpine plants.' *World Resources Review* 8: 382–390

PC-GOI (2006) *Report of the task force on the mountain ecosystems (environment and forest sector) for eleventh five year plan*. Delhi: Planning Commission, Government of India

Pebley, AR (1998) 'Demography and the environment.' *Demography* 35: 377–389

Pei, S (1995) *Banking on biodiversity. Report on the regional consultations on biodiversity assessment in the Hindu Kush-Himalaya*. Kathmandu: ICIMOD

Peng, S; Huang, J; Sheehy, JE; Laza, RE; Visperas, RM; Zhong, X; Centeno, GS; Khush, GS; Cassman, KG (2004) 'Rice yields decline with higher night temperature from global warming.' *Proc. Nat'l Acad. Sci*. 101(27): 9971–9975

Pereira, H; Daily, GC; Roughgarden, J (2004) 'A framework for assessing the relative vulnerability of species to land-use change.' *Ecological Applications* 14: 730–742

Peters, RL; Darling, JDS (1985) 'The greenhouse effect and nature reserves: Global warming would diminish biological diversity by causing extinctions among reserve species.' *Bioscience* 35: 707–717

Peters, RL; Lovejoy, TE (1992) *Global warming and biological diversity*. London: Yale University Press

Piver, WT; Ando, M; Ye, F; Portier, CT (1999) 'Temperature and air pollution as risk factors for heat stroke in Tokyo, July–August, 1980–1995.' *Environmental Health Perspective* 107(11): 911–916

Polsky, C; Schröter, D; Patt, A; Gaffin, S; Long Martello, M; Neff, R; Pulsipher, A; Selin, H (2003) *Assessing vulnerabilities to the effects of global change: An eight-step approach*, Research and Assessment Systems for Sustainability Program Discussion Paper 2003–05. Cambridge MA: Environment and Natural Resources Program, Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University

PRECIS (2001) *The Hadley Centre Regional Climate Modelling System. Providing Regional Climates for Impact Studies*. Bracknell: The Hadley Centre. www.metoffice.com (accessed June 2007)

Price, M; Kohler, T; Wachs, T (eds) (2000) *Mountains of the world: Mountain forests and sustainable development*. Berne: CDE, University of Berne

Qin Dahe (1999) *Map of glacier resources in the Himalayas*. Beijing: Science Press

Quincey, DJ; Richardson, SD; Luckman, A; Lucas, RM; Reynolds, JM; Hambrey, MJ; Glasser, NF (2007) 'Early recognition of glacial lake hazards in the Himalaya using remote sensing datasets.' *Global and Planetary Change* 56: 137–152

Ramesh, R; Yadava, MG (2005) 'Climate and water resources of India.' *Current Science* 89(5): 818-824

Reid, WV; Mooney, HA, Cropper, A; et al. (2005) *Millennium Ecosystem Assessment synthesis report*. Washington: Island Press

Reiter, P (1998) 'Global warming and vector-borne disease in temperate regions and at high altitude.' *Lancet* 351: 839–840

RGoB (2006) *National Adaptation Program of Action, submitted to the United Nations Framework Convention on Climate Change*. Thimpu: Royal Government of Bhutan

Ribot, JC (1996) 'Climate variability, climate change and vulnerability: Moving forward by looking back.' In Ribot, JC; Magalhães, AR; Panagides, SS (eds) *Climate variability, climate change and social vulnerability in the semi-arid tropics*. Cambridge: Cambridge University Press

Rinne, J; Riutta, T; Pihlatie, M; Aurela, M; Haapanala, S; Tuovinen, JP; Tuittila, ES (2007) 'Annual cycle of methane emission from a boreal fen measured by the eddy covariance technique.' *Tellus* 59B: 449–457

Robertson, MP; Peter, CI; Villet, MH; Ripley, BS (2003) 'Comparing models for predicting species' potential distributions: A case study using correlative and mechanistic predictive modelling techniques.' *Ecological Modelling* 16: 153–167

Root, TL; Hughes, L (2005) 'Present and future phenological changes in wild plants and animals.' In Lovejoy, TE; Hannah, L (eds) *Climate change and biodiversity*. New Haven: Yale University Press

Rupa Kumar, K; Sahai, AK; Krishna Kumar, K; Patwardhan, SK; Mishra, PK; Revadkar, JV; Kamala, K; Pant, GB (2006) 'High resolution climate change scenario for India for the 21st Century.' *Current Science* 90(3): 334-345

Samper, C; Scholes, R; Watson, RT; Zakri, AH; Shidong, Z; Ash, NJ; Bennett, E; Kumar, P; Lee, MJ; Raudsepp-Hearne, C; Simons, H; Thonell, J; Zurek, NB (2005) *Millennium Ecosystem Assessment synthesis report*. Washington: Island Press

Schellnhuber, HJ; Black, A; Cassel-Gintz, M; Kropp, J; Lammel, G; Lass, W; Lienenkamp, R; Loose, C; Luedeke, MKB; Moldenhauer, O (1997) *GAIA* 6: 19–34

Schröter, D; Acosta-Michlik, L; Reidsma, P; Metzger, MJ; Klein, RJT (2003) *Modeling the vulnerability of eco-social systems to global change: human adaptive capacity to changes in ecosystem service provision*. Paper presented at the fifth open meeting of the human dimensions of global environmental change research community, Montreal. http://sedac.ciesin.columbia.edu/openmtg/ (accessed June 2007)

Schröter, D; Cramer, W; Leemans, R; et al. (2005a) 'Ecosystem service supply and human vulnerability to global change in Europe.' *Science* 310: 1333–1337

Schröter, D; Polsky, C; Patt, AG (2005b) 'Assessing vulnerabilities to the effects of global change: An eight step approach.' *Mitigation Adapt Strat Glob Change* 10: 573–595

Schutze, ED; Mooney, HA (1994) *Biodiversity and ecosystem function*. Berlin: Springer Verlag

Sen, A (1981) *Poverty and famines: An essay on entitlement and deprivation*. Oxford: Oxford University Press

Sen, A (1987) *Commodities and capabilities*. New Delhi: Oxford University Press

Shabanov, NV; Zhou, L; Knyazikhin, Y; Myneni, RB; Tucker, CJ (2002) 'Analysis of interannual changes in northern vegetation activity observed in AVHRR data from 1981 to 1994, IEEE Trans.' *Geos Rem Sens* 40: 115–130

Sharma, KP (1993) 'Role of rainwater in major river systems of Nepal.' In Young, GJ (ed) *International Symposium Snow and Glacier Hydrology* p.113–122. Kathmandu: International Association Scientific Hydrology

Sharma, E; Chettri, N; Tse-ring, K; Shrestha, AB; FAng Jing, Mool, P; Eriksson, M (2009) *Climate change impacts and vulnerability in the Eastern Himalayas*. Kathmandu: ICIMOD

Sharma, KP (1997) *Impact of land-use and climatic changes on hydrology of the Himalayan basin: A case study of the Kosi Basin*, Dissertation. Durham: University of New Hampshire

Shrestha, AB; Wake, CP; Mayewski, PA; Dibb, JE (1999) 'Maximum temperature trends in the Himalaya and its vicinity: Analysis based on temperature records from Nepal for the period 1971–94.' *Journal of Climate* 12: 2775–2787

Shrestha, KL; Shrestha, ML; Shakya, NM; Ghimire, ML; Sapkota, BK (2003) 'Climate change and water resources of Nepal.' In Muhammed, A (ed.) *Climate Change and Water Resources in South Asia*. Kathmandu: Asianics Agro Dev International

Shrestha, AB; Devkota, LP (2010) *Climate change in the Eastern Himalayas: Observed trends and model projections;* Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 1. Kathmandu: ICIMOD

Shukla, PR; Sharma, SK; Ramana, PV (eds) (2002) *Climate change in India issues, concerns and opportunities*. New Delhi: Tata McGraw Hill

Sitch, S; Smith, B; Prentice, IC; Arneth, A; Bondeau, A; Cramer, W; Kaplan, JO; Levis, S; Lucht, W; Sykes, MT; Thonicke, K; Venevsky, S (2003) 'Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic vegetation model.' *Glob Change Biol* 9(2): 161–185

Smit, B; Pilifosova, O (2001) 'Adaptation to climate change in the context of sustainable development and equity.' In McCarthy, JJ; Canziani, OF; Leary, NA; Dokken, DJ; White, KS (eds) *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Cambridge: Cambridge University Press

Smith, K (2001) *Environmental hazards: Assessing risk and reducing disaster* (3rd edn). London: Routledge

Smith, JB; Bhatti, N; Menzhulin, G; Benioff, R; Campos, M; Jallow, B; Rijsberman, F; Budyko, MI; Dixon RK (eds) (1996) *Adapting to climate change: Assessment and issues*. New York: Springer-Verlag

Smith, P; Andrén, O; Brussaard, L; Dangerfield, M; Ekschmitt, K; Lavelle, P; Tate, K (1998) 'Soil biota and global change at the ecosystem level: Describing soil biota in mathematical models.' *Global Change Biology* 4: 773–784

Smith, JB; Schellnhuber, H-J; Qader Mirza, M; Fankhauser, S; Leemans, R; Erda, L; Ogallo, LA; Pittock, BA; Richels, R; Rosenzweig, C; Safriel, U; Tol, RSJ; Weyant, J; Yohe, G (2001) 'Vulnerability to climate change and reasons for concern: A synthesis.' In McCarthy, JJ; Canziani, OF; Leary, NA; Dokken, DJ; White, KS (eds) *Climate change 2001. Impacts, adaptation and vulnerability* pp 913–967. Cambridge: Cambridge University Press

Stalmans, M; Balkwill, K; Witkowski, ETF; Rogers, KH (2001) 'A landscape ecological approach to address scaling problems in conservation management and monitoring.' *Environmental Management* 28(3): 389–401

Stephen, L; Downing, TE (2001) 'Getting the scale right: a comparison of analytical methods for vulnerability assessment and household-level targeting.' *Disasters* 25: 113–135

Stern, N (2006) *The Stern review on the economics of climate change*. Cambridge: HM Treasury and Cambridge University Press

Stern, NH; Taylor, C (2007) 'Climate change: Risk, ethics, and the Stern Review.' *Science* 317(5835): 203–204

Street, RB; Semenov, SM (1990) 'Natural terrestrial ecosystems.' In Tegart, WJKcG; Sheldon, GW; Griffiths, DC (eds) *Climate change: The first impacts assessment report.* Canberra: Australian Government Publishing Service

Tao, F; Yokozawa, M; Zhang, Z; Hayashi, Y; Grassl, H; Fu, C (2004) 'Variability in climatology and agricultural production in China in association with the East Asia summer monsoon and El Niño South Oscillation.' *Climate Research* 28: 23–30

TERI (1996) *The economic impact of a one metre sea level rise on the Indian coastline*, Method and case studies report submitted to the Ford Foundation by the Tata Energy Research Institute. www.ccasia.teri.res.in/country/india/impacts/impacts.htm (accessed June 2007)

Thomas, CD (2005) 'Recent evolutionary effects of climate change.' In Lovejoy, TE; Hannah L (eds) *Climate Change and Biodiversity*. New Haven: Yale University Press

Thuiller, W (2003) 'BIOMOD: Optimizing predictions of species distributions and projecting potential future shifts under global change.' *Glob Change Biol* 9: 1353–1362

Tong, SL; Ying, LV (2000) 'Global climate change and epidemic disease.' *Journal of Disease Control* 4(1): 17–19

Tse-ring, K (2003) 'Constructing future climate scenarios of Bhutan.' In *Project report on climate change vulnerability and adaptation study for rice production in Bhutan*; for Project: Climate change studies in Bhutan, Activity No. www094505-But.2. Thimphu: Ministry of Agriculture

Turner, BL II; Kasperson, RE; Matson, PA; McCarthy, JJ; Corell, RW; Christensen, L; Eckley, N; Kasperson, JX; Luers, A; Martello, ML; Polsky, C; Pulsipher, A; Schiller, A (2003a) 'A framework for vulnerability analysis in sustainability science.' *Proceedings of the National Academy of Sciences* 100(14): 8074–8079

Turner, BL II; Matson, PA; McCarthy, JJ; Corell, RW; Christensen, L; Eckley, N; Hovelsrud-Broda, G; Kasperson, JX; Kasperson, RE; Luers, A; Martello, ML; Mathiesen, S; Naylor, R; Polsky, C; Pulsipher, A; Schiller, A; Selin, H; Tyler, N (2003b) 'Illustrating the coupled human-environment system for vulnerability analysis: Three case studies.' *Proceedings of the National Academy of Sciences* 100 (14): 8080–8085

UNDP (2003) *User's guidebook for the adaptation policy framework. Final draft*. New York: United Nations Development Programme

UNDP (2004) *Adaptation policy frameworks for climate change. Developing strategies, policies and measures*, Lim, B; Spanger-Siegfried, E (eds). Cambridge: Cambridge University Press.

UNDP (2007) *Human development report 2007/2008. Fighting climate change: Human solidarity in a divided world*. New York: UNDP

UNEP (1992) *Earth Summit: Agenda 21 (Chapter 13: Managing Fragile Ecosystems: Sustainable Mountain Development)*. United Nations Conference on Environment and Development (UNCED), 3–14 June 1992, Rio de Janeiro, Brazil

UNEP (2002a) *GEO-3: Global environmental outlook report 3*. London: Earthscan

UNEP (2002b) *Assessing human vulnerability due to environmental change: Concepts, issues, methods and case studies*, UNEP/DEWA/RS.03-5. Nairobi: United Nations Environmental Programme

UNEP (2007) *Global environmental outlook 4: Environment for development*. Nairobi: United Nations Environment Programme

Vavilov, NI (1926) 'Studies on the origin of cultivated plants.' *Bulletin of Applied Botany* 16 (2): 405–35

Veech, JA (2003) 'Incorporating socioeconomic factors into the analysis of biodiversity hotspots.' *Applied Geography* 23: 73–88

Villa, F; McLeod, H (2002) 'Environmental vulnerability indicators for environmental planning and decision-making: Guidelines and applications.' *Environmental Management* 29: 335–348

Vincent, K (2004) *Creating an index of social vulnerability to climate change for Africa*, Working Paper 56. Norwich: Tyndall Centre for Climate Change Research

Vohra, CP (1981) 'Himalayan glaciers.' In Lal, JS; Moddie, AD (eds) *The Himalaya: Aspect of change*, pp 138–151. Delhi: Oxford University Press

Watson, R (2005) 'Emissions reductions and alternative futures.' In Lovejoy, TE; Hannah, L (eds) *Climate Change and Biodiversity*. New Haven: Yale University Press

Watson, RT; Noble, IR; Bolin, B; Ravindranath, NH; Verardo, DJ; Dokken, DJ (eds) (2000) *Land use, land-use change and forestry, A special report of the intergovernmental panel on climate change (IPCC)*. Cambridge: Cambridge University Press

Watson, RT; Zinyoera, MC; Moss, RH (1998) *The regional impacts of climate change: An assessment of vulnerability*, A Special Report of IPCC Working Group II. Cambridge: Cambridge University Press

WCS and CIESIN (2005) *Last of the wild project*, 2005 (LWP-2): Global human footprint dataset (Geographic). Edition: version 2. Palisades: Socioeconomic Data and Applications Center (SEDAC), Columbia University

WDPA Consortium (2006) *2006 world database on protected areas, (CD)*. IUCN and UNEP. www.unep-wcmc.org/wdpa (accessed June 2007)

Webster, PJ; Magaña, VO; Palmer, TN; Shukla, J; Tomas, RA; Yanai, M; Yasunari, T (1998) 'Monsoons: Processes, predictability, and the prospects for prediction.' *J. Geophys. Res* 103: 14451–14510

WEF (2003) *Annual report 2002/2003. Building trust, peace and reconciliation*. Geneva: World Economic Forum

WGMS (2000) 'Glacier mass balance.' In Haeberli, W; Hoelzle, M (eds) *World Glacier Monitoring Service*. Zurich: ETH

White, D; Minotti, PG; Barczak, MJ; Sifneos, JC; Freemark, KE; Santelmann, MV; Steinitz, CF; Kiester, AR; Preston, EM (1997) 'Assessing risks to biodiversity from future landscape change.' *Conservation Biology* 11: 349–360

Whiteman, D (2000) *Mountain meteorology*. Oxford: Oxford University Press

Wickham, JD; Neill, RVO; Jones, KB (2000) 'A geography of ecosystem vulnerability.' *Landscape Ecology* 15: 495–504

Wikramanayake, ED; Dinerstein, E; Robinson, JG; Karanth, U; Rabinowitz, A; Olson, D; Mathew, T; Hedao, P; Conner, M; Hemley, G; Bolze, D (1998) 'An ecology-based method for defining priorities for large mammal conservation: The tiger as case study.' *Conservation Biology* 12: 865–878

Wilson, RJ; Gutierrez, D; Gutierrez, J; Monserrat, VJ (2007) 'An elevational shift in butterfly species richness and composition accompanying recent climate change.' *Global Change Biology* 13: 1873–1887

Wikramanayake, ED; Carpenter, C; Strand, H; McKnight, M (eds) (2001a) *Ecoregion-based conservation in the Eastern Himalaya: Identifying important areas for biodiversity conservation*. Kathmandu: WWF Nepal

WWF (2004) *Terrestrial ecoregions of the world, Version 2.0. Vector digital data*. Washington DC: WWF-US

WWF (2005) *An overview of glaciers, glacier retreat, and subsequent impacts in Nepal, India and China*. Kathmandu: WWF-Nepal Program

WWF (2006a) WildFinder: Online database of species distributions, ver. Jan-06. www.worldwildlife.org/WildFinder

WWF (2006b) *Terrestrial ecoregions GIS database*. Washington DC: World Wildlife Fund. www.worldwildlife.org/science/data/terreco.ctm (accessed 12 June 2007)

WWF and ICIMOD (2001b) 'Overarching human pressures on biodiversity in the Eastern Himalaya.' In Wikramanayake, ED; Carpenter, C; Strand, H; McKnight M (eds) *Ecoregion-based conservation in the Eastern Himalaya. Identifying important areas for biodiversity conservation*, pp 101–126. Kathmandu: WWF Nepal

Xiao, XM; Melillo, JM; Kicklighter, DW; Pan, Y; McGuire, AD; Helirich, J (1998) 'Net primary production of terrestrial ecosystems in China and its equilibrium responses to changes in climate and atmospheric CO_2 concentration.' *Acta Phytoecologica Sinica* 22(2): 97–118

Xiao, G; Liu, W; Xu, Q; Sun, Z; Wang, J (2005) 'Effects of temperature increase and elevated CO_2 concentration, with supplemental irrigation, on the yield of rain-fed spring wheat in a semiarid region of China.' *Agricultural Water Management* 74(3): 243–255

Xu, J; Shrestha, A; Vaidya, R; Eriksson, M; Hewitt, K (2007) *The melting Himalayas: Regional challenges and local impacts of climate change on mountain ecosystems and livelihoods*, ICIMOD Technical Paper. Kathmandu: ICIMOD

Yin, YY (2006). *Vulnerability and adaptation to climate variability and change in western China*, AS25 Project Final Report to AIACC. Washington DC: International START Secretariat

Yohe, G; Tol, RSJ (2002) 'Indicators for social and economic coping capacity: Moving toward a working definition of adaptive capacity.' *Glob Environ Change* 12: 25–40

Yohe, G; Malone, E; Brenkert, A; Schlesinger, M; Meij, H; Xing Xiaoshi; Lee, D (2006) *A synthetic assessment of the global distribution of vulnerability to climate change from the IPCC perspective that reflects exposure and adaptive capacity*. New York: CIESIN, Columbia University

Yunling He; Zhang Yiping (2005) 'Climate change from 1960 to 2000 in the Lancang river valley, China.' *Mountain Research and Development* 25 (4): 341–348

Zorita, E; von Storch, H (1999) 'The analog method – A simple statistical downscaling technique: Comparison with more complicated methods.' *J Climate* 12: 2474–2489

Annexes

Annex 1: **Protected areas with indicators of vulnerability in order of vulnerability rank**

Rank	Area Name	Country	Designation	IUCN Category	EST_DATE	AREA_HA	ALT_MIN	ALT_MAX	vul_index	ac_index	cc_exposure	sens_ind
1	**Hootenannies**	Myanmar	Wildlife Sanctuary	III	1/1/1974	215074	0	0	0.630	0.000	0.512	0.379
2	**Orang**	India	Sanctuary	IV	1/1/1985	7260	500	500	0.580	0.281	0.461	0.560
3	**Pabha**	India	Sanctuary	IV		4900	0	0	0.575	0.302	0.494	0.532
4	**D' Ering Memorial**	India	Sanctuary	IV	1/1/1978	19000	150	0	0.570	0.314	0.534	0.491
5	**Laokhowa**	India	Sanctuary	IV	1/1/1972	7011	500	500	0.568	0.297	0.453	0.549
6	**Kaziranga**	India	National Park	II	1/1/1974	84979	40	80	0.568	0.318	0.474	0.548
7	**Sonai-Rupai**	India	Sanctuary	IV	1/1/1998	22000	100	100	0.565	0.305	0.471	0.529
8	**Manas**	India	Sanctuary	IV	1/1/1928	39100	40	150	0.560	0.333	0.486	0.526
9	**Jaldapara**	India	Sanctuary	IV	1/1/1990	21651	0	0	0.560	0.289	0.486	0.482
10	**Koshi Tappu**	Nepal	Wildlife Reserve	IV	1/1/1976	17500	80	95	0.559	0.426	0.505	0.599
11	**Mahananda**	India	Sanctuary	IV	1/1/1976	12722	50	800	0.556	0.294	0.495	0.466
12	**Pabitora**	India	Sanctuary	IV	1/1/1987	3883	0	0	0.554	0.322	0.454	0.530
13	**Garumara**	India	Sanctuary	IV	1/1/1984	852	0	0	0.548	0.318	0.492	0.471
14	**Barnadi**	India	Sanctuary	IV	1/1/1980	2622	150	720	0.547	0.365	0.475	0.531
15	**Sepahijala**	India	Sanctuary	IV	1/1/1987	1853	0	0	0.541	0.300	0.445	0.478
16	**Manas**	India	National Park	II	1/1/1990	50000	0	0	0.541	0.372	0.488	0.507
17	**Trishna**	India	Sanctuary	IV	1/1/1988	19470	500	500	0.539	0.309	0.442	0.483
18	**Keibul-Lamjao**	India	National Park	II	1/1/1975	4000	767	813	0.533	0.322	0.471	0.451
19	**Garampani**	India	Sanctuary	IV	1/1/1952	605	500	500	0.533	0.334	0.467	0.467
20	**Nokrek**	India	National Park	II	1/1/1985	4748	600	1412	0.520	0.380	0.454	0.485
21	**Nameri**	India	Sanctuary	IV	1/1/1985	7560	0	0	0.519	0.387	0.475	0.469
22	**Yaluzangbudaxiagu**	China	Nature Reserve	V		961800	0	0	0.519	0.359	0.539	0.375
23	**Nongkhyllem**	India	Sanctuary	IV	1/1/1981	2900	1000	1000	0.517	0.368	0.485	0.433
24	**Dibang**	India	Sanctuary	IV	1/1/1991	414900	0	0	0.516	0.359	0.537	0.369
25	**Parsa**	Nepal	Wildlife Reserve	IV	1/1/1984	49900	100	950	0.514	0.461	0.527	0.475
26	**Kane**	India	Sanctuary	IV	1/1/1991	5500	0	0	0.513	0.334	0.502	0.371
27	**Neora Valley**	India	National Park	II	1/1/1992	8800	30	3200	0.512	0.346	0.486	0.396
28	**Mehao**	India	Sanctuary	IV	1/1/1980	28150	404	3560	0.510	0.397	0.530	0.398
29	**Puliebadze**	India	Sanctuary	IV	1/1/1980	923	1000	1500	0.509	0.381	0.473	0.437
30	**Gumti**	India	Sanctuary	IV	1/1/1988	38954	0	0	0.506	0.337	0.418	0.436

Annex 1: **cont.**

31	**Baghmara Pitcher Plant**	India	Sanctuary	IV	1/1/1984	2	500	500	0.505	0.377	0.452	0.439
32	**Intanki**	India	Sanctuary	IV	1/1/1975	20202	1000	1000	0.502	0.383	0.459	0.429
33	**Royal Chitwan**	Nepal	National Park-Buffer Zone	VI	1/1/1996	75000	0	0	0.500	0.494	0.509	0.486
34	**Buxa**	India	Sanctuary	IV	1/1/1986	36899	1000	3000	0.499	0.424	0.488	0.433
35	**Yangoupokpi-Lokchao**	India	Sanctuary	IV	1/1/1989	18480	0	0	0.499	0.407	0.463	0.440
36	**Royal Chitwan**	Nepal	National Park	II	1/1/1973	93200	150	815	0.492	0.503	0.504	0.476
37	**Balphakram**	India	National Park	II	1/1/1986	22000	50	1026	0.491	0.408	0.464	0.416
38	**Siju**	India	Sanctuary	IV	1/1/1979	518	40	260	0.490	0.412	0.466	0.416
39	**Shivapuri**	Nepal	National Park	II	1/1/2002	14400	1366	2732	0.490	0.469	0.520	0.419
40	**Sagarmatha**	Nepal	National Park	II	1/1/1976	114800	2845	8848	0.487	0.417	0.539	0.340
41	**Itanagar**	India	Sanctuary	IV	1/1/1978	14030	210	1164	0.485	0.395	0.485	0.364
42	**Mouling**	India	National Park	II	1/1/1986	48300	750	3064	0.482	0.420	0.502	0.365
43	**Makalu-Barun**	Nepal	National Park	II	1/1/1991	15000	456	8463	0.470	0.464	0.510	0.364
44	**Kangchenjunga**	Nepal	Conservation Area	VI	3/1/1998	203500	1200	8586	0.467	0.414	0.511	0.303
45	**Pakhui**	India	Sanctuary	IV	1/1/1977	86195	200	1000	0.463	0.424	0.475	0.337
46	**Langtang**	Nepal	National Park	II	1/1/1976	171000	792	7245	0.463	0.447	0.506	0.329
47	**Eagle Nest**	India	Sanctuary	IV	1/1/1989	21700	0	0	0.461	0.426	0.471	0.337
48	**Sessa Orchid**	India	Sanctuary	IV	1/1/1989	10000	0	0	0.459	0.428	0.471	0.333
49	**Singalila**	India	National Park	II	1/1/1992	7860	2256	3874	0.458	0.437	0.452	0.360
50	**Khangchendzonga**	India	National Park	II	1/1/1977	178400	1829	8586	0.458	0.421	0.501	0.294
51	**Manaslu**	Nepal	Conservation Area	VI	12/1/1998	166300	0	0	0.457	0.452	0.478	0.344
52	**Barsey Rhododendron**	India	Sanctuary	IV	1/1/1998	10400	0	0	0.451	0.443	0.466	0.331
53	**Zhangmukouan**	China	Nature Reserve	V	1/1/1985	6852	1800	5900	0.451	0.474	0.511	0.316
54	**Habaxueshan**	China	Nature Reserve	V	1/1/1984	21908	1700	5396	0.444	0.526	0.469	0.390
55	**Bitahai**	China	Nature Reserve	V	1/1/1984	26869	3180	4159	0.442	0.564	0.493	0.398
56	**Mangkang**	China	Nature Reserve	V	1/1/1990	185300	3000	3500	0.442	0.514	0.544	0.295
57	**Maenam**	India	Sanctuary	IV	1/1/1987	3534	0	0	0.438	0.481	0.479	0.315
58	**Phibsoo**	Bhutan	Wildlife Sanctuary	IV	1/1/1993	27800	0	0	0.437	0.542	0.486	0.366
59	**Annapurna**	Nepal	Conservation Area	VI	1/1/1992	762900	1151	8091	0.436	0.502	0.472	0.337
60	**Dhorpatan**	Nepal	Hunting Reserve	VI	1/1/1987	132500	2850	5500	0.434	0.487	0.460	0.331
61	**Kyongnosla Alpine**	India	Sanctuary	IV	1/1/1977	3100	0	0	0.433	0.434	0.443	0.290

Annex 1: **cont.**

62	**Fambong Lho**	India	Sanctuary	IV	1/1/1984	5176	1280	2652	0.433	0.480	0.480	0.299
63	**Khakaborazi**	Myanmar	National Park	II	1/1/1996	381248	0	0	0.427	0.530	0.493	0.319
64	**Bumhpabum**	Myanmar	Wildlife Sanctuary	III	1/1/2002	186221	0	0	0.425	0.569	0.513	0.331
65	**Hponkanrazi**	Myanmar	Wildlife Sanctuary	III	1/1/2001	270396	0	0	0.423	0.562	0.506	0.325
66	**Dampa**	India	Sanctuary	IV	1/1/1985	50000	200	900	0.423	0.601	0.424	0.446
67	**Hukaung Valley**	Myanmar	Wildlife Sanctuary	III	1/1/2001	645946	0	0	0.422	0.577	0.530	0.314
68	**Gaoligongshan (Yunnan)**	China	Nature Reserve	V	1/1/1986	405200	1090	3917	0.422	0.525	0.471	0.321
69	**Royal Manas**	Bhutan	National Park	II	1/1/1993	102300	200	2310	0.419	0.566	0.485	0.337
70	**Baimaxueshan**	China	Nature Reserve	V	1/1/1988	281640	1950	5430	0.418	0.526	0.491	0.288
71	**Phawngpui (Blue Mountain)**	India	National Park	II	1/1/1992	5000	0	0	0.415	0.609	0.416	0.439
72	**Murlen**	India	National Park	II	1/1/1991	20000	0	0	0.414	0.609	0.420	0.431
73	**Ngengpui**	India	Sanctuary	IV	1/1/1992	11000	0	0	0.412	0.611	0.413	0.436
74	**Kulong Chu**	Bhutan	Wildlife Sanctuary	IV	1/1/1993	130000	0	0	0.410	0.553	0.497	0.286
75	**Khawnglung**	India	Sanctuary	IV	1/1/1991	4100	0	0	0.408	0.619	0.415	0.427
76	**Sakteng**	Bhutan	Wildlife Sanctuary	IV	1/1/1993	65000	0	0	0.407	0.557	0.484	0.293
77	**Jigme Dorji**	Bhutan	National Park	II	1/1/1993	435000	3000	7554	0.403	0.645	0.509	0.344
78	**Bomdeling**	Bhutan	Wildlife Sanctuary	IV	1/1/1995	153800	1400	6000	0.396	0.589	0.491	0.286
79	**Thrumsingla**	Bhutan	National Park	II	1/1/1998	88900	1400	4535	0.390	0.612	0.482	0.300
80	**Jigme Singye Wangchuck**	Bhutan	National Park	II	1/1/1995	173000	640	4925	0.384	0.607	0.479	0.279
81	**Quomolangma**	China	Nature Preserve	VI	3/1/1989	3400000	3000	8000	0.379	0.152	0.174	0.115
82	**Valmiki**	India	Sanctuary	IV	1/1/1978	54467	200	800	0.371	0.000	0.000	0.113
83	**Toorsa**	Bhutan	Strict Nature Reserve	Ia	1/1/1993	65000	0	0	0.356	0.699	0.461	0.307
84	**Zhumulangmafeng**	China	Nature Reserve	V	1/1/1989	3391022	5000	8848	0.339	0.000	0.000	0.017
#N/A	**Fakim**	India	Sanctuary	IV	1/1/1980	641	2000	3000				
#N/A	**Rangapahar**	India	Sanctuary	IV	1/1/1986	470	0	0				
#N/A	**Roa**	India	Sanctuary	IV	1/1/1988	85	0	0				
#N/A	**Rema-Kalenga**	Bangladesh	Wildlife Sanctuary	IV	1/1/1996	1975.54	0	0				
#N/A	**Jiangcun**	China	Nature Reserve	V	1/1/1985	34060	1800	7300				
#N/A	**Napahai**	China	Nature Reserve	V	1/1/1984	6201	3260	3260				
#N/A	**Yading**	China	Nature Reserve	V		56000	0	0				

Annex 2: **Ecological region ranked by vulnerability**

Rank	EH_ ECO_ID	ECO_NAME	%_area_ EH %	REALM	BIOME	ani_Tot_ rich count	Tot_str_ end count	Tot_nr_ end count	Carbon balance C/km²/yr	TOT_PA km²	MAN_AREA	Vul_ind	Ac_index	cc_expo-sure	sens_index
1	1	Brahmaputra Valley semi-evergreen forests	100.00	IM	1	511	0	6	3.86	2065.9	0.91941	0.833655	0.000291	0.000317	0.000317
2	5	Lower Gangetic Plains moist deciduous forests	6.76	IM	1	557	1	9	-20.41	5146.6	0.962645	0.80702	0.540415	0.415148	0.461762
3	6	Meghalaya subtropical forests	100.00	IM	1	633	5	23	10.61	215.7	0.569123	0.75612	0.305134	0.450873	0.479434
4	17	Terai-Duar savanna and grasslands	57.97	IM	7	463	1	5	-9.44	3331	0.730362	0.753296	0.480416	0.476188	0.372761
5	19	Northeastern Himalayan sub-alpine conifer forests	12.12	PA	5	368	0	1	37.00	7749.2	0.141084	0.6941	0.5369	0.492239	0.378746
6	11	North East India-Myanmar pine forests	100.00	IM	3	357	0	2	48.37	4	0.676228	0.671723	0.481479	0.496833	0.373122
7	12	Eastern Himalayan broadleaf forests	100.00	IM	4	630	3	18	4.18	6578.4	0.390545	0.637423	0.430764	0.474467	0.424621
8	3	Himalayan subtropical broadleaf forests	63.95	IM	1	444	0	3	4.40	3435.8	0.493146	0.628257	0.573185	0.416945	0.415754
9	16	Western Himalayan sub-alpine conifer forests	2.86	IM	5	376	1	10	115.85	2236.1	0.409511	0.625924	0.486429	0.487844	0.328325
10	10	Himalayan subtropical pine forests	16.62	IM	3	594	0	14	16.36	2622.3	0.426537	0.625781	0.482273	0.505189	0.322474
11	25	Rock and ice			99	0	0	0	0.01	750110.3	0.014526	0.622356	0.42203	0.503855	0.288977
12	21	Eastern Himalayan alpine shrub and meadows	28.38	PA	10	485	2	10	3.74	50002.9	0.090909	0.608713	0.539998	0.469125	0.305281
13	15	Eastern Himalayan sub-alpine conifer forests	100.00	IM	5	294	3	9	10.69	7229.3	0.239261	0.607018	0.498761	0.478039	0.347321
14	14	Western Himalayan broadleaf forests	2.91	IM	4	213	3	8	153.76	3043	0.407653	0.600748	0.35492	0.507688	0.352191
15	4	Irrawaddy moist deciduous forests	1.85	IM	1	521	0	14	129.04	1496.9	0.657292	0.593879	0.485701	0.498987	0.41626
16	23	Western Himalayan alpine shrub and meadows	3.24	PA	10	411	1	11	47.12	7344	0.075262	0.57831	0.543924	0.538444	0.353945

17	18	Hengduan Mountains sub-alpine conifer forests	11.67	PA	5	947	2	10	28.91	2564.5	0.037052	0.571505	0.405291	0.514483	0.559829
18	22	Southeast Tibet shrublands and meadows	0.07	PA	10	570	1	6	684.43	149471.9	0.040027	0.562036	0.468698	0.49401	0.322475
19	2	Chin Hills-Arakan Yoma montane forests	45.93	IM	1	520	0	3	38.25	0	0.66576	0.548678	0.314447	0.479969	0.535052
20	20	Nujiang Langcang Gorge alpine conifer and mixed forests	25.96	PA	5	599	2	4	14.12	11016.6	0.056503	0.545786	0.372015	0.493598	0.349999
21	7	Mizoram-Manipur-Kachin rainforests	51.67	IM	1	803	4	19	8.44	1913.2	0.63975	0.539498	0.365366	0.468412	0.445886
22	8	Northern Indochina subtropical forests	0.24	IM	1	1209	16	44	497.24	21962.1	0.559428	0.522169	0.413333	0.460644	0.418336
23	9	Northern Triangle subtropical forests	83.94	IM	1	569	8	21	15.26	15.2	0.241674	0.433807	0.49748	0.400283	0.371245
24	13	Northern Triangle temperate forests	100.00	IM	4	490	3	15	45.52	0.1	0.215264	0.317662	0.458661	0.491085	0.348967
#N/A	24	Yarlung Tsangpo arid steppe	0.00	PA	10	246	0	0	150033.17	13449	0.043904		0.505081	0.458804	0.321881

Annex 3: **Administrative units ranked by vulnerability**

Rank	Administrative Unit*	ear	tlr	fgp_pc	tdr	ac_index	cc_exposure	sens_index	vul_index
1	**Sarlahi**	0.473	0.068	0.174	0.694	0.371	0.529	0.574	0.577
2	**Mahottari**	0.400	0.036	0.191	0.701	0.364	0.524	0.565	0.575
3	**Dhanusa**	0.372	0.287	0.209	0.711	0.387	0.520	0.589	0.574
4	**Rautahat**	0.528	0.000	0.183	0.694	0.372	0.528	0.558	0.571
5	**Bara**	0.262	0.179	0.283	0.696	0.387	0.527	0.573	0.571
6	**Siraha**	0.392	0.143	0.221	0.713	0.390	0.512	0.580	0.568
7	**Saptari**	0.397	0.303	0.252	0.739	0.409	0.507	0.587	0.562
8	**Assam**	0.102	0.566	0.097	0.244	0.315	0.476	0.520	0.560
9	**Sunsari**	0.348	0.500	0.229	0.774	0.454	0.499	0.602	0.549
10	**Parsa**	0.421	0.177	0.251	0.728	0.436	0.533	0.534	0.544
11	**Kapilbastu**	0.510	0.163	0.267	0.679	0.420	0.550	0.499	0.543
12	**Rupandehi**	0.272	0.600	0.223	0.726	0.443	0.553	0.517	0.542
13	**Morang**	0.475	0.436	0.263	0.813	0.487	0.496	0.595	0.534
14	**Darjeeling**	0.000	0.720	0.113	0.000	0.334	0.486	0.449	0.534
15	**Bhaktapur**	0.434	0.679	0.117	0.907	0.459	0.505	0.532	0.526
16	**Tripura**	0.022	0.734	0.103	0.052	0.338	0.442	0.463	0.522
17	**Jhapa**	0.383	0.617	0.330	0.846	0.501	0.500	0.553	0.518
18	**Meghalaya**	0.134	0.549	0.054	0.311	0.375	0.476	0.433	0.511
19	**Kathmandu**	0.300	0.798	0.048	0.984	0.467	0.509	0.485	0.509
20	**Nawalparasi**	0.597	0.369	0.212	0.708	0.484	0.532	0.478	0.508
21	**Assam Hills**	0.102	0.502	0.097	0.244	0.361	0.463	0.417	0.506
22	**Udaypur**	0.531	0.375	0.138	0.675	0.460	0.493	0.484	0.506
23	**Chitawan**	0.367	0.688	0.239	0.792	0.531	0.527	0.515	0.503
24	**Lalitpur**	0.369	0.685	0.077	0.945	0.472	0.507	0.463	0.500
25	**Nagaland**	0.161	0.617	0.085	0.363	0.410	0.479	0.427	0.499
26	**Sindhuli**	0.585	0.319	0.151	0.646	0.452	0.495	0.439	0.494
27	**Arghakhanchi**	0.510	0.419	0.162	0.591	0.447	0.520	0.396	0.490
28	**Arunachal**	0.188	0.395	0.115	0.415	0.414	0.511	0.367	0.488
29	**Makawanpur**	0.351	0.550	0.131	0.700	0.472	0.512	0.418	0.486
30	**Ap**	0.188	0.395	0.070	0.415	0.394	0.499	0.353	0.486
31	**Manipur**	0.205	0.648	0.098	0.444	0.454	0.472	0.426	0.481

* Bhutan and Nepal = Districts; NE India = States

Annex 3: **cont.**

32	**Kaski**	0.348	0.706	0.158	0.810	0.474	0.490	0.423	0.480
33	**Gulmi**	0.565	0.450	0.144	0.566	0.459	0.515	0.373	0.476
34	**Ramechhap**	0.760	0.120	0.158	0.597	0.445	0.496	0.378	0.476
35	**Kavre**	0.462	0.561	0.186	0.705	0.474	0.498	0.395	0.473
36	**Syangja**	0.489	0.609	0.204	0.626	0.494	0.517	0.388	0.470
37	**Nuwakot**	0.611	0.335	0.225	0.684	0.467	0.510	0.367	0.470
38	**Palpa**	0.445	0.600	0.190	0.628	0.497	0.522	0.382	0.469
39	**Dhading**	0.731	0.197	0.140	0.659	0.458	0.501	0.360	0.468
40	**Tanahun**	0.533	0.525	0.213	0.673	0.504	0.510	0.395	0.467
41	**Solukhumbu**	0.801	0.237	0.163	0.702	0.462	0.514	0.339	0.464
42	**Dolakha**	0.753	0.330	0.086	0.717	0.474	0.510	0.354	0.463
43	**Okhaldhunga**	0.752	0.298	0.195	0.628	0.475	0.490	0.368	0.461
44	**Parbat**	0.646	0.436	0.226	0.645	0.490	0.514	0.359	0.461
45	**Gorkha**	0.633	0.387	0.200	0.660	0.473	0.493	0.362	0.461
46	**Rasuwa**	0.893	0.029	0.117	0.721	0.456	0.507	0.329	0.460
47	**Sindhupalchok**	0.796	0.142	0.196	0.687	0.477	0.510	0.346	0.460
48	**Baglung**	0.470	0.520	0.158	0.641	0.477	0.492	0.363	0.459
49	**Sankhuwasabha**	0.550	0.385	0.222	0.701	0.488	0.483	0.370	0.455
49	**Bhojpur**	0.616	0.396	0.306	0.684	0.494	0.467	0.392	0.455
51	**Sikkim**	0.290	0.663	0.117	0.578	0.441	0.494	0.304	0.452
52	**Khotang**	0.762	0.314	0.235	0.630	0.504	0.478	0.372	0.449
53	**Myagdi**	0.632	0.418	0.173	0.668	0.476	0.476	0.343	0.448
54	**Zhongdian**	0.510	0.606	0.000	0.948	0.540	0.493	0.383	0.445
55	**Taplejung**	0.681	0.357	0.200	0.670	0.454	0.490	0.299	0.445
56	**Terhathum**	0.565	0.477	0.234	0.715	0.481	0.447	0.368	0.445
57	**Lamjung**	0.636	0.434	0.235	0.697	0.494	0.488	0.336	0.443
58	**Dhankuta**	0.576	0.566	0.266	0.763	0.523	0.453	0.379	0.436
59	**Ilam**	0.472	0.606	0.185	0.782	0.525	0.474	0.360	0.436
60	**Manang**	0.631	0.497	0.061	0.957	0.486	0.479	0.302	0.432
61	**Panchthar**	0.561	0.407	0.211	0.664	0.511	0.452	0.337	0.426
62	**Thimphu**	0.521	0.704	0.093	0.993	0.604	0.488	0.389	0.424

Annex 3: **cont.**

63	**Fugong**	0.510	0.606	0.000	0.948	0.538	0.441	0.369	0.424
64	**Gongshan**	0.510	0.606	0.000	0.948	0.526	0.475	0.322	0.424
65	**Chin state**	0.118	0.920	0.100	0.861	0.567	0.418	0.420	0.423
66	**Samtse**	0.582	0.303	0.119	0.881	0.531	0.481	0.311	0.420
67	**Mustang**	0.877	0.348	0.106	0.925	0.532	0.470	0.319	0.419
68	**Mizoram**	0.376	1.000	0.086	0.689	0.603	0.420	0.438	0.419
69	**Samdrup Jongkhar**	0.711	0.396	0.253	0.867	0.567	0.483	0.338	0.418
70	**Deqin**	0.510	0.606	0.000	0.948	0.535	0.500	0.284	0.417
71	**Kachine State**	0.118	0.866	0.167	0.861	0.573	0.498	0.324	0.416
72	**Trashiyangtse**	0.627	0.262	0.297	0.815	0.543	0.494	0.294	0.415
73	**Gasa**	0.919	0.136	1.000	0.896	0.634	0.528	0.347	0.413
74	**Sarpang**	0.721	0.480	0.246	0.904	0.591	0.484	0.331	0.408
75	**Wangduephodrang**	0.680	0.333	0.127	0.852	0.570	0.488	0.297	0.405
76	**Zhemgang**	0.711	0.332	0.062	0.815	0.567	0.484	0.297	0.405
77	**Chhukha**	0.607	0.446	0.096	1.000	0.590	0.476	0.327	0.404
78	**Trashigang**	0.821	0.262	0.080	0.852	0.567	0.481	0.298	0.404
79	**Bumthang**	0.627	0.547	0.298	0.926	0.617	0.499	0.328	0.403
80	**Weixi**	0.510	0.606	0.000	0.948	0.549	0.455	0.299	0.402
81	**Paro**	0.600	0.358	0.138	0.941	0.562	0.472	0.295	0.401
82	**Mongar**	0.957	0.246	0.123	0.844	0.590	0.482	0.313	0.401
83	**Lhuenstse**	0.812	0.317	0.121	0.819	0.580	0.495	0.277	0.397
84	**Pema gatsel**	0.763	0.267	0.552	0.822	0.617	0.484	0.292	0.386
85	**Dagana**	0.938	0.375	0.152	0.800	0.614	0.478	0.283	0.382
86	**Trongsa**	0.682	0.543	0.145	0.822	0.620	0.481	0.277	0.379
87	**Punakha**	0.671	0.362	0.741	0.889	0.668	0.480	0.294	0.369
88	**Tsirang**	1.000	0.382	0.287	0.859	0.648	0.481	0.267	0.367
89	**Haa**	0.777	0.581	0.609	0.915	0.693	0.463	0.303	0.358

Annex 4: **Knowledge gaps and research priorities for different systems in each country**

Nepal	
Knowledge gap	**Research and capacity area**
Biodiversity	
1. Information on mountains 2. Impact of climate change on biodiversity 3. Coping strategies	a. Mountain research on ecosystems, peoples, traditional knowledge, and others b. Impact of human actions on biodiversity c. Research on coping and adaptation d. Identification of vulnerable species (morphology, habits); ecosystems e. Species competition (invasive species) f. Traditional knowledge g. Historical migration patterns of biodiversity h. Coping patterns of humans in the past
Livelihood and wellbeing	
1. Documentation of traditional knowledge for adaptation to a changing environment 2. Hydrological and meteorological data at micro level 3. Scientific verification of encountered changes in the environment due to climate change 4. Analytical instruments to assess impacts of climate change on livelihoods 5. Emergence and transmission pattern of diseases 6. Climate change implications for agricultural production	a. Documentation of changing patterns of climate at micro level b. Identifying impact areas of climate change on livelihoods – health, food security, resource availability, and so on c. Documentation of local people's experiences and adaptation to climate change d. Identification of coping mechanisms e. Knowledge sharing f. Stakeholder involvement at all levels of policy innovations g. Policy implementation h. Capacity building
Water, wetlands and hazards	
1. Acquisition of baseline data for climate change studies with emphasis on high altitudes 2. Cryospheric research on snow and glaciers 3. High altitude hydrology and meteorology 4. Watershed status (biophysical, socioeconomic, paleoclimatic data) 5. Capacity building in regional climate modelling 6. Impact assessment of water, wetlands, and hazards 7. Developing two-way awareness mechanism between scientific and local communities	a. Better data and information sharing mechanisms b. Establishment of metadata centre c. Research on climate change tolerant/resistant crop varieties d. Understanding sedimentation procedures resulting from extreme events e. Documentation of human activities on water utilisation f. Climatic (hydrometeo) hazard mapping g. Understanding monsoon and westerly dynamics under climate change scenarios

North East India and Bhutan	
Knowledge gap	**Research and capacity area**
Biodiversity	
1. Phenology in relation to productivity 2. Comprehensive inventory and database on biodiversity, status and access 3. Documentation of indigenous knowledge and practices in relation to climate change adaptation and mitigation 4. Awareness within vulnerable groups including women and children 5. Reorientation of management plans (protected areas) and other activities to address climate change issues 6. Prioritisation of protected areas, critical ecosystems, and habitats (micro-level) 7. Policy research linking conservation, livelihoods, NRM, and climate change 8. Study on the adaptability of species and the resilience of their habitats 9. Capacity building on taxonomy and conservation biology	a. Small habitats and ecological niches b. Methane emission from wetlands c. How some important species adapt to climate change d. Specific ecosystems net carbon sequestration e. Climate change impact on agricultural productivity as it is the mainstay of livelihoods f. Prioritise critical ecosystems
Livelihood and wellbeing	
1. Baseline and needs assessment, capacity building, and information on sector-wise interests, and others 2. Need to build awareness about the issues and close the gaps in information through educational materials for both teachers and students 3. Need to better understand traditional institutions and panchayats 4. Skills and knowledge for data collection and documentation 5. Lack of awareness and social responsibilities among government departments 6. Advanced soft skills (e.g., leadership, communication skills) and technical information skills 7. Need to enable communities to respond to the threats and changes requiring immediate attention 8. Need for participatory action research across sectors	a. The in- and out-migration pattern and the consequences for the socioeconomy of the region b. Enhance data and information base to strengthen evidence with proper feedback mechanisms for verification and validation c. Establish modalities for payment for environmental services for community-managed forests d. Analyse traditional practices to cope with adverse impacts of climate change e. Improve inventory and database of alpine lakes and monitor these lakes (particularly in Bhutan) f. Validate traditional ecosystem knowledge through participatory action research
Water, wetlands and hazards	
1. Limited institutional capacity in the use of high resolution models for localised climate prediction 2. Inadequate data on: – Biodiversity and indicator species of wetlands – Water quality – Water productivity 3. Ecological responses of wetlands to changes in hydrological regime 4. Categorisation of vulnerable groups 5. Lack of awareness on climate change issues among policy implementers at local and regional levels 6. Insignificant contribution by education and research institutes to research efforts on water, wetlands, and hazards 7. Significance of wetlands as GHG source 8. Insufficient capacity and proactive planning in risk/hazard prevention, preparedness 9. Non-existent or ineffective local institutions to support anticipatory actions and preparedness 10. Practical and applicable hydrological models for watershed and basin-level modelling to match demand with supply 11. Isolated interventions and lack of integrated approaches in water resources management 12. Poor water quality	a. Need meteorological data and data sharing network b. Improve the observation/monitoring stations of required spatial coverage and temporal continuity c. Water policy analysis d. Strengthen traditional knowledge and practices e. Awareness of climate change issues at the local and regional level and among policy makers f. Development of weather-based index for crop and property insurance **Wetlands** g. Inventorying of and research on aquatic and wetland ecosystems by universities and research institutes h. Impact of acid rain on water and wetland ecosystems i. Assessment of methane emission from wetlands **Hazards** j. Hazard and risk vulnerability mapping k. High-altitude wetlands and glaciers and glacial lakes inventory and monitoring l. Establish flood early warning system, floodplain zoning m. Mechanisms to improve preparedness with site-specific adaptation framework for disaster risk reduction **Water** n. Water demand and supply scenario modelling using snow-melt runoff model and mass-balance model (basin-wise) o. Integrated wetlands and water resource management p. Improved monitoring of water quality

Acronyms and Abbreviations

AET	actual evapotranspiration
AIACC	Assessments of Impacts and Adaptations to Climate Change
APN	Asia-Pacific Network for Global Change Research
AR4	Fourth Assessment Report (of IPCC)
CBD	Convention on Biological Diversity
CEPF	Critical Ecosystem Partnership Fund
CO_2	carbon dioxide
CR	critical
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DJF	December-January-February season
EH	Eastern Himalayas
EN	endangered
GCM	General Circulation Model
GHG	greenhouse gas
GIS	geographic information system
GLOF	glacial lake outburst flood
HKH	Hindu Kush-Himalayas/n
ICIMOD	International Centre for Integrated Mountain Development
INMC	Integrated Natural Resource Management
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
JJA	June-July-August season
LWP-2	Last of the Wild Data Version 2
MAM	March-April-May season
MDG	Millennium Development Goal
MEA	Millennium Ecosystem Assessment
NAPA	National Adaptation Programme of Action
NC	National Communication (to UNFCCC)
NCSA	National Capacity Self Assessment
NDVI	normalised difference vegetation index
NPP	net primary production
PA	protected area
PAGE	Pilot Analysis of Global Ecosystems
PES	payment for ecosystem services
PET	potential evapotranspiration
PRECIS	Providing Regional Climates for Impacts Studies
PRSP	Poverty Reduction Strategy Paper
RCM	regional climate model
RMC	regional member country
SON	September-October-November season
SRES	Special Report on Emissions Scenarios
TAR	Third Assessment Report (of IPCC)
Tibet AR	Tibet Autonomous Region (China)
TGCIA	Task Group on Scenarios for Climate Impact Assessment (of IPCC)
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UV	ultraviolet rays
VU	vulnerable
WWF	World Wide Fund for Nature

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The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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