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 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

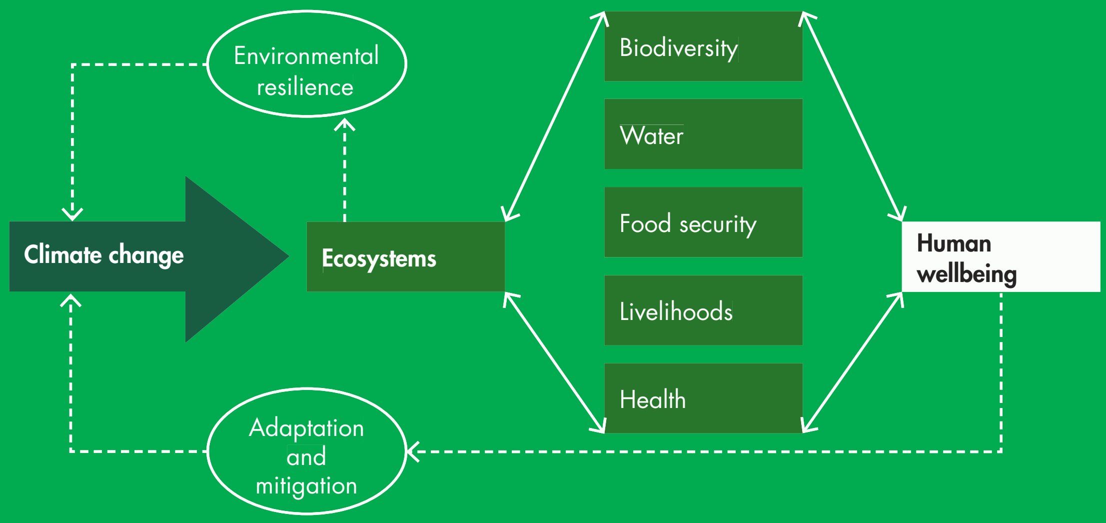
Spiritual and religious values, knowledge system, education and inspiration, recreation and aesthetic values, sense of place

Supporting services

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

ECOSYSTEM FUNCTIONS

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

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

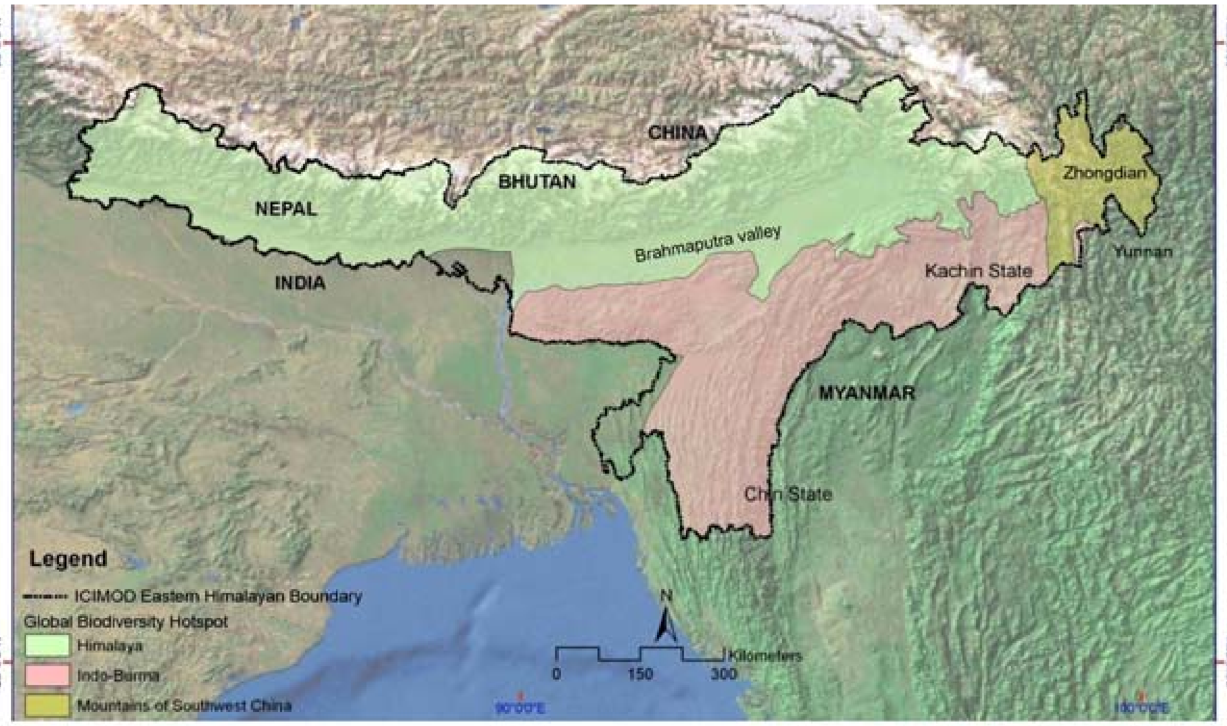
Country	Areas	% of EH area
India	Sikkim, Arunachal Pradesh, Assam, Meghalaya, Nagaland, Mizoram, Manipur, Tripura; and Darjeeling Hills of West Bengal	52.03
Myanmar	Chin and Kachin states	17.90
Nepal	Kaligandaki Valley, Koshi Basin, Mechi Basin	16.08
Bhutan	Whole country	7.60
China	ZhongDian, DeQin,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

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.

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.

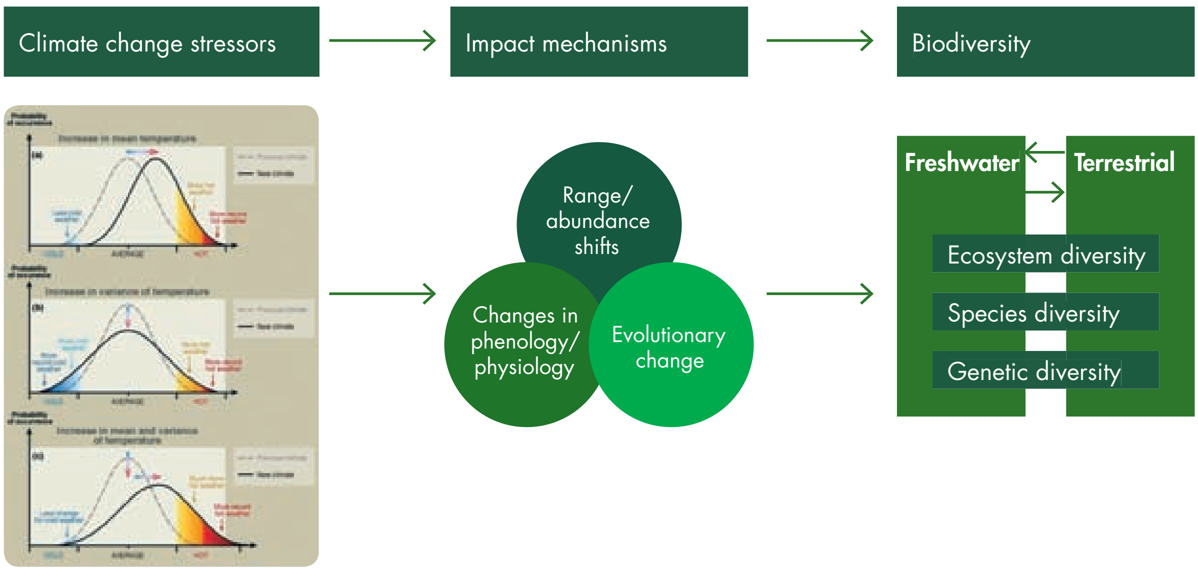
Analytical Framework

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).