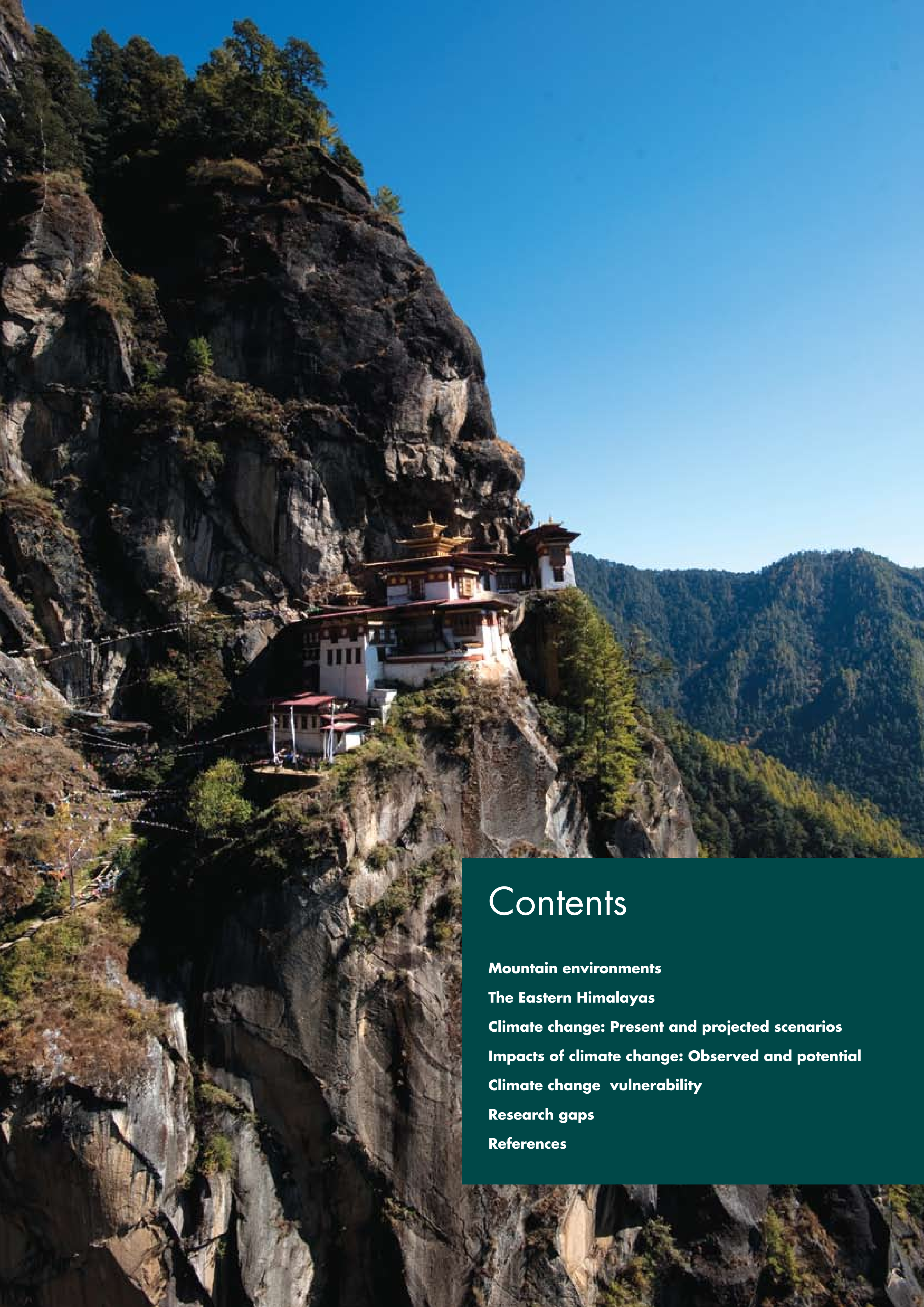
ICIMOD

FOR MOUNTAINS AND PEOPLE

Climate Change Impacts and Vulnerability in the Eastern Himalayas

MacArthur Foundation



Contents

Climate Change Impacts and Vulnerability in the Eastern Himalayas

Eklabya Sharma, Nakul Chettri, Karma Tse-ring, Arun B Shrestha, Fang Jing, Pradeep Mool and Mats Eriksson

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 that will have an impact on general human wellbeing. 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 particularly true for the Hindu Kush-Himalayas, 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 or make projections of the likely impacts of climate change. Supported by the MacArthur Foundation, 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 assess the vulnerability of this region to climate change (for details see ICIMOD 2009). 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 projections for the region based on the observed data. This publication presents a summary of the findings of the assessment. Clearly much more, and more precise, information will be needed to corroborate these preliminary present findings. Nevertheless, the assessment highlighted 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.

Mountain environments

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 (Hamilton 2002; Korner 2004; Viviroli and Weingartner 2004). Mountains are home to some of the world's most threatened and endemic species, as well as to the poorest people, who are highly dependent on their biological resources (Kollmair et al. 2005). Realising the importance of mountains as ecosystems of crucial significance, the Convention on Biological Diversity (CBD) 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 (Nogues-Bravo et al. 2007). Under the influence of climate change, mountains are likely to experience wide ranging effects on the environment, biodiversity, and socioeconomic conditions (Beniston 2003). Changes in the hydrological cycle may significantly change precipitation patterns leading to changes in river runoff and ultimately affecting hydrology and nutrient cycles along the river basins, including agricultural productivity and human wellbeing. However, there has been little detailed research on observed climate change in the mountains, and generalisations have been made from scattered studies carried out at sites widely separated in space and time (IPCC 2007a; Nogues-Bravo et al. 2007). The limited evidence that exists (Shrestha et al. 1999; Liu and Chen 2000; Shrestha et al. 2000; Xu et al. 2009) is ringing alarming bells on the fate of Himalayan biodiversity and the services it provides. Recent scientific understanding, led by the Intergovernmental Panel on Climate Change (IPCC), is that global climate change is happening and will present practical challenges for local ecosystems (IPCC 2007a). These include the prospect of more severe weather, longer droughts, higher temperatures (milder winters), heat waves, changes in local biodiversity, and reduced ground and surface water quantity and quality. These changes will impact on everything from the natural landscape to human health, built infrastructure, and socioeconomic conditions. The global community is currently trying to understand the nexus between climate change and mountain vulnerability, especially in the most remote and highest mountains of the world – the Hindu Kush-Himalayas. In order to do this we must overcome the huge information and research gaps in this field in the greater Himalayan region.

The Hindu Kush-Himalayan ranges are highly heterogeneous in geographical features. Vegetation changes from subtropical semi-desert and thorn steppe formations in the northwest to tropical evergreen rainforests in the southeast (Schickhoff 2005). As a result, these mountains contain a huge biodiversity, often with sharp transitions (ecotones) in vegetation sequences and equally rapid changes from vegetation and soil to snow and ice (Messerli and Ives 2004). The mountains are also important as 'water towers', containing the largest accumulation of snow and ice outside the polar regions, that are the source of ten major Asian rivers – the Amu Darya, Brahmaputra, Ganges, Indus, Irrawaddy, Salween, Tarim, Yangtze and Yellow – which collectively provide water for about 1.3 billion people (Schild 2008; Xu et al. 2009). However, these mountains are facing numerous environmental and anthropogenic stresses. Various studies suggest that warming in the Himalayas has been much greater than the global average of 0.74°C over the last 100 years (Du et al. 2004; IPCC 2007a) and high altitude ecosystems are even more at threat (Shrestha et al. 1999; Liu and Chen 2000; New et al. 2002). However, due to the lack of comparable data on climate change for the region, there are many uncertainties, adding to the challenges involved in maintaining resilience in the region and sustaining the ecosystem services that the region provides (IPCC 2007a).

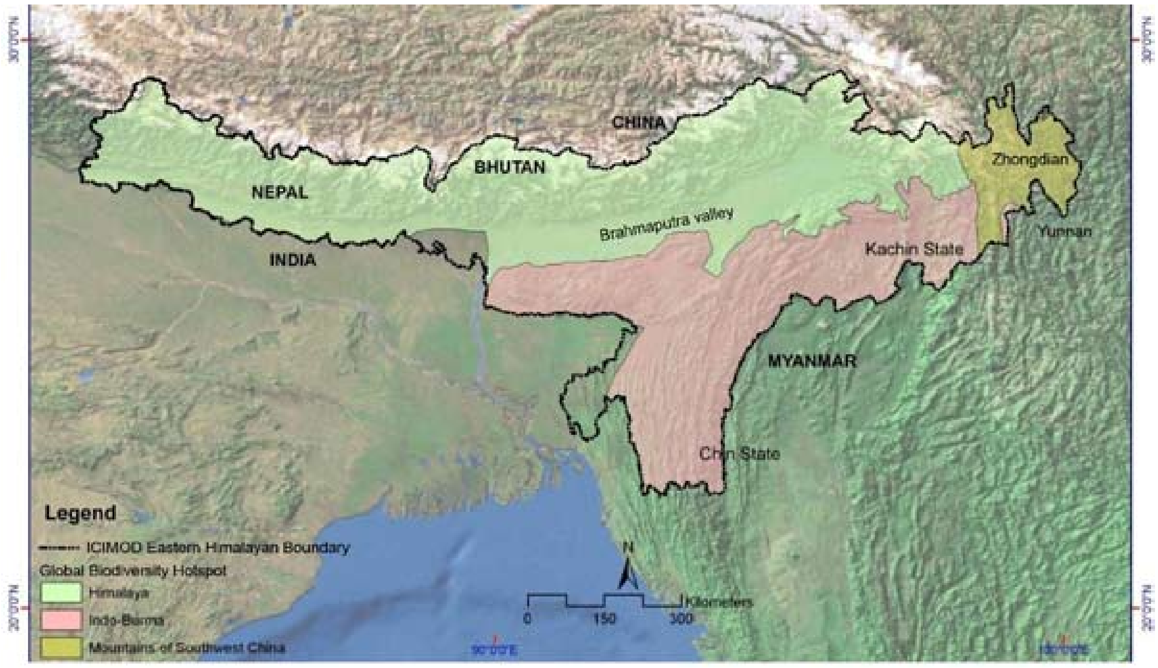
Climate change will make water availability more uncertain, both in time and space. While overall trends are difficult to decipher, there are clear indications that the frequency and magnitude of high intensity rainfall events are increasing (Goswami et al. 2006), with negative implications for infiltration and groundwater recharge, and also for long-term soil moisture and water accessibility for plants. In addition, there are indications that the dry season is becoming drier and seasonal droughts and water stress more severe. The timing and length of the monsoon period also seems to be changing (Ramesh and Goswami 2007). These early signs will have to be followed up and confirmed, but are likely to have profound effects on agricultural and natural ecosystems alike, as well as on the availability of water for household use, industry, and energy, thereby impacting considerably on people's livelihoods and wellbeing.

The Himalayan region stands as a globally unique area for understanding the effects of global climate change. It has a characteristic east-west mountain chain with rapidly changing altitude over a short distance, as well as variations in climatic conditions. It is evident that the climate in the Himalayas has been fluctuating, but the intensity of fluctuations in warm and cold climate regimes in different parts of the Himalayan ecosystem are not synchronised.

The Eastern Himalayas

The Eastern Himalayas extend from the Kaligandaki Valley in central Nepal to northwest Yunnan in China – encompassing Bhutan, the North East Indian states and north Bengal hills in India, southeast Tibet and parts of Yunnan in China, and northern Myanmar – a total area of nearly 525,000 sq.km (Figure 1). The region spans a wide spectrum of ecological zones and contains parts of three global Biodiversity Hotspots. The five countries traversed by the Eastern Himalayas (Bhutan, China, India, Myanmar, and Nepal) have very different geo-political and socioeconomic systems, and contain diverse cultures and ethnic groups. The region is the meeting place of three realms, namely, the Indo-Malayan, Paleoarctic, and Sino-Japanese. The region's complex topography and extreme altitudinal gradients – from less than 300 m (tropical lowlands) to more than 8000 m (high mountains) over a few hundred kilometres – have contributed to the highly varied vegetation patterns. The complex mountain topography has created diverse bioclimatic zones (near tropical, subtropical, lower temperate, upper temperate, subalpine evergreen, alpine evergreen, and alpine shrubs and meadows) and 'island-like' conditions for many species and populations, making them reproductively isolated. This isolation has given rise to genetic differences among populations, thereby contributing to the exceptionally rich array of biodiversity.

Figure 1: **The Eastern Himalayas**



Biodiversity

The Eastern Himalayas are physiographically diverse and ecologically rich in natural and crop-related biodiversity. This area has been in the spotlight as it contains Crisis Ecoregions, Biodiversity Hotspots, Endemic Bird Areas, Mega Diversity Countries, and Global Ecoregions (Brooks et al. 2006). The region contains parts of three of the 34 global Biodiversity Hotspots: 39 per cent of the Himalayan Hotspot, 8 per cent of the Indo-Burma Hotspot, and 13 per cent of the Mountains of Southwest China Hotspot; taking in 25 ecoregions (WWF 2006) – 12 in the Himalayan Hotspot, 8 in the Indo-Burma Hotspot, and 5 in the Mountains of Southwest China (Chettri et al. 2008) – of which 19 have high conservation significance in terms of their global conservation value.

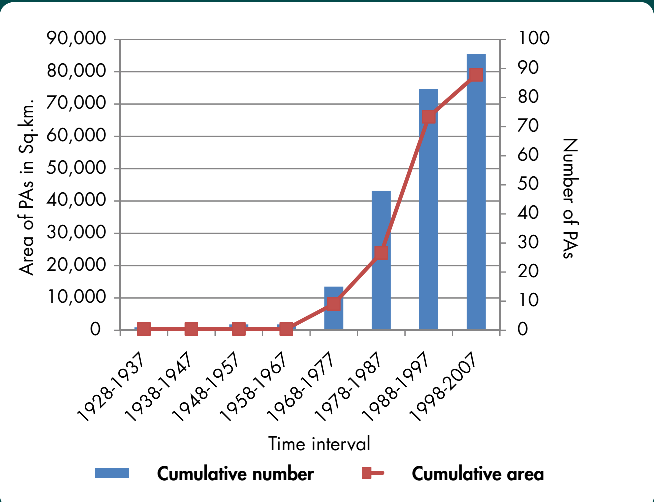
The region contains a globally significant array of unique flora and fauna with a high proportion of endemism (Takhtajan 1969; Myers et al. 2000; Dhar 2002). There are at least 7,500 species of flowering plants, 700 orchids, 58 bamboos, 64 citrus, 28 conifers, 500 mosses, 700 ferns, and 728 lichens (WWF and ICIMOD 2001). The Indo-Burma Hotspot alone is home to 2.3 per cent of global endemic plants and 1.9 per cent of global endemic vertebrates (Myers et al. 2000). The recent review conducted by the Critical Ecosystem Partnership Fund (CEPF) revealed that the Eastern Himalayas are home to a large 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). In addition, the Eastern Himalayas is known as the 'centre of origin of cultivated plants', as over 50 important tropical and sub-tropical fruits, cereals, and types of rice originated in the region (Chakravorty 1951; Dhawan 1964; Hore 2005). Interestingly, about 300 of the estimated 800 plant species consumed as food in India are found in the Eastern Himalayas (Rao and Murti 1990).

The Eastern Himalayan region also provides a diverse range of ecosystem services (provisioning, regulating, cultural, supporting), making it useful for studying the relationship between loss of biodiversity and loss of ecosystem services. The diversity of services is in part the result of the geographic complexity, which exerts considerable influence over the weather patterns in the region, in many instances creating microclimatic conditions that result in the formation of a unique range of ecosystems. For example, the Himalayan range towards the north acts as a barrier to the southwest monsoon from the Bay of Bengal, resulting in less moisture towards the western side and comparatively more precipitation on the eastern side. This precipitation recharges 4 out of 10 of the major rivers of the Hindu Kush-Himalayas with a significant volume of water, namely, the Brahmaputra, Ganges, Irrawaddy, and Salween (Xu et al. 2007). The Indo-China subtropical forests have been created by the effects of summer monsoonal rain from May to September and dry conditions from November to March. In the Eastern Himalayas, declining moisture conditions and increasing elevation create various vegetation types such as tropical seasonal rainforests, tropical montane rainforests, evergreen broadleaf forests, and also the distinctive monsoon forests over limestone, where water is quickly lost, and the monsoon forests on riverbanks, where water is available throughout the year.

Conservation and management interventions

Biodiversity conservation and management interventions in the Eastern Himalayas date back to the 19th Century, along with the exploration of the region by renowned botanists, zoologists, and nature explorers from across the world. Over the last two decades, many new approaches to conservation have evolved in this region. The conservation initiatives undertaken by the World Wide Fund for Nature (WWF) with the support of ICIMOD, the United Nations Development Programme (UNDP), and other organisations have identified many conservation landscapes and corridors across the Eastern Himalayas. This has been further supplemented by the identification of gaps, potential corridors and conservation target sites, and species outcomes across the region (Chettri et al. 2007). There are 17 protected area complexes in the Eastern Himalayas, 41 candidate priority areas of high biodiversity importance, 175 key biodiversity areas, and 5 transboundary (landscape) complexes of high significance (CEPF 2005).

Figure 2: **Cumulative number and coverage of protected areas in the Eastern Himalayas from 1928 to 2007**



Recently, there has been a significant paradigm shift in conservation from 'people exclusive' (i.e., the traditional fines and fences approach) to more participatory approaches at the landscape and ecosystem level (GoN/MoFSC 2006; Chettri et al. 2007; Sharma et al. 2007). The conservation and management interventions in the Eastern Himalayas have also been progressive in terms of the establishment of protected areas (Figure 2), the first protected area being the Pidaung Wildlife Sanctuary in Myanmar, established in 1918. Now there are about 100 protected areas of different sizes and categories covering nearly 84,000 sq.km (20% of the total region) (Figure 2), a significant amount when compared with the global mountain protected area coverage of 11.5 per cent (Kollmair et al. 2005). However, these efforts may not be enough. Climate change will have far-reaching consequences on the condition of biodiversity, the quality of ecosystem functioning and services, and the wellbeing of the people both in the region and downstream. The Eastern Himalayan region warrants protection in order to maintain ecosystem integrity and adaptability.

Climate change: Present and projected scenarios

In the Eastern Himalayas, a substantial proportion of the annual precipitation falls as snow. Climate controls river flow and glacier mass balance and varies considerably from west to east. The monsoon from the Bay of Bengal, which develops over the Indian subcontinent, produces heavy precipitation – predominantly in the southeast – and primarily synchronous summer accumulation and summer melt in the east. With rising temperatures, areas covered by permafrost and glaciers are decreasing in much of the region. In many areas a greater proportion of total precipitation appears to be falling as rain than before. As a result, snowmelt begins earlier and winter is shorter. Whereas snow masses have acted as a natural form of storage, releasing moisture slowly into the ground or rivers, water is increasingly only available at the time of precipitation. This affects river regimes, natural hazards, water supplies, people's livelihoods, and overall human wellbeing (Xu et al. 2007; Erickson et al. 2009).

The Himalayan region, including the Tibetan Plateau, has shown consistent warming trends during the past 100 years (Yao et al. 2006). However, little is known in detail about the climatic characteristics of the Eastern Himalayas both because of the paucity of observations and because insufficient theoretical attention has been given to the complex interaction of spatial scales in weather and climate phenomena in mountain areas.

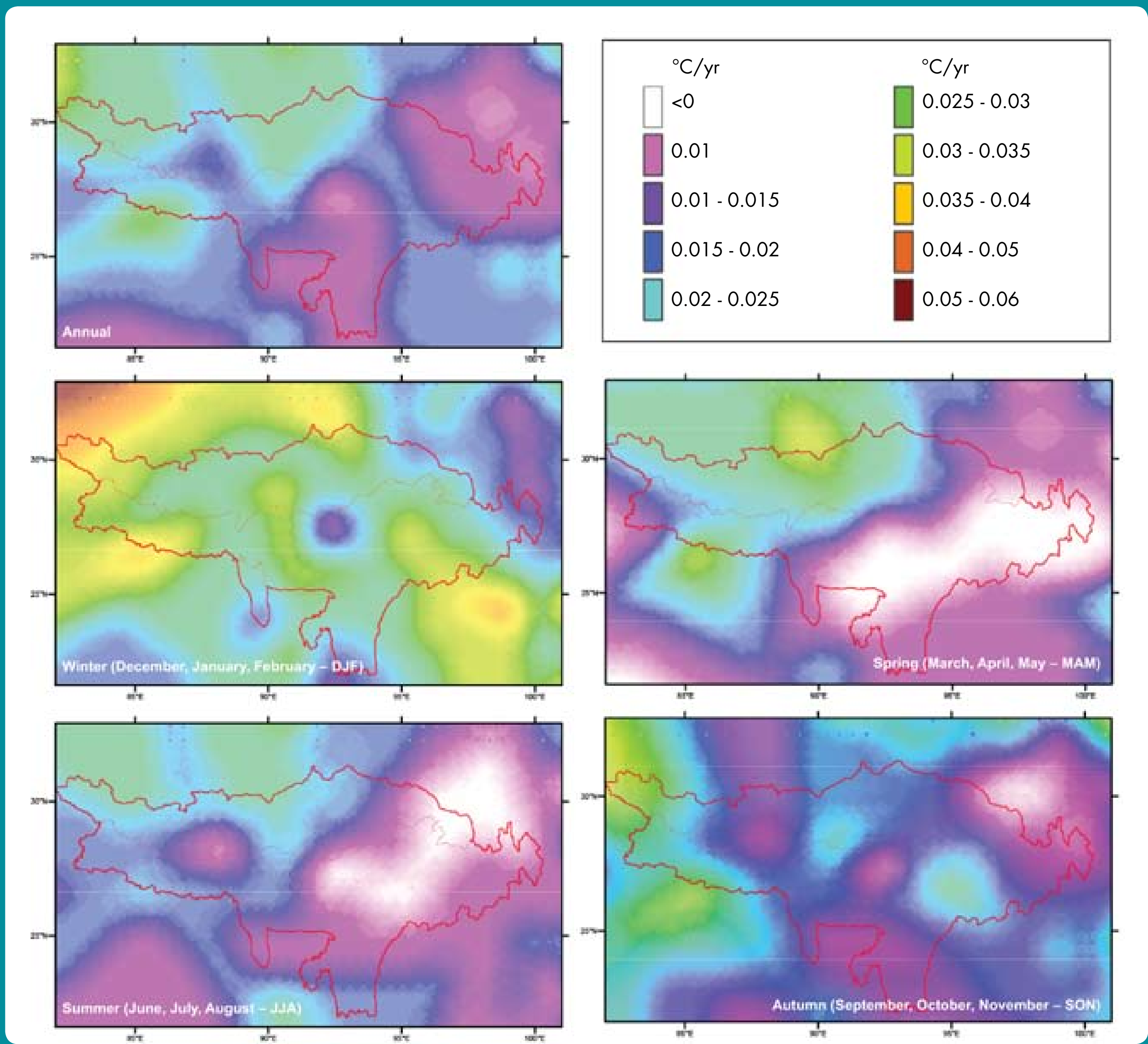
Long-term data sets are needed to determine properly the degree and rate of climate change, but there are none available for most of the region. Despite the limitations, studies of climate in the past and projections based on climate models have increased in recent times, albeit on various spatio-temporal scales, some of which cover the Eastern Himalayas in part or as a whole.

This assessment's analysis of the spatial distribution of annual and seasonal temperature trends is illustrated in Figure 3. The analysis indicates that a large part of the region is undergoing warming. Annual mean temperature is increasing at the rate of 0.01°C per year or higher. However, there is a diagonal zone from the south-west to the north-east of the region that is undergoing relatively less or even no warming. This zone encompasses the Yunnan province of China, part of the Kanchin State of Myanmar, and the far eastern part of India. The zone to the upper left of this area, including eastern Nepal and eastern Tibet, is undergoing relatively higher warming. The warming in the winter (DJF) is at a much higher rate and over a more widespread area. The analysis shows progressively greater warming rates with increasing elevation (Table 1). The zone of low warming is significantly small and limited to Yunnan and Arunachal Pradesh. Overall, the analysis indicates that the Eastern Himalayas are experiencing widespread

Table 1: **Temperature trends by elevation zone for the period 1970–2000 (°C/yr)**

	Annual	DJF	MAM	JJA	SON
Level 1: (<1000 m)	0.01	0.03	0.00	-0.01	0.02
Level 2: (1 –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

Figure 3: **Spatial distribution of temperature trends** (Change in annual and seasonal temperatures. The red line shows the border of the Eastern Himalayan region plus parts of the Brahmaputra and Koshi basins.)

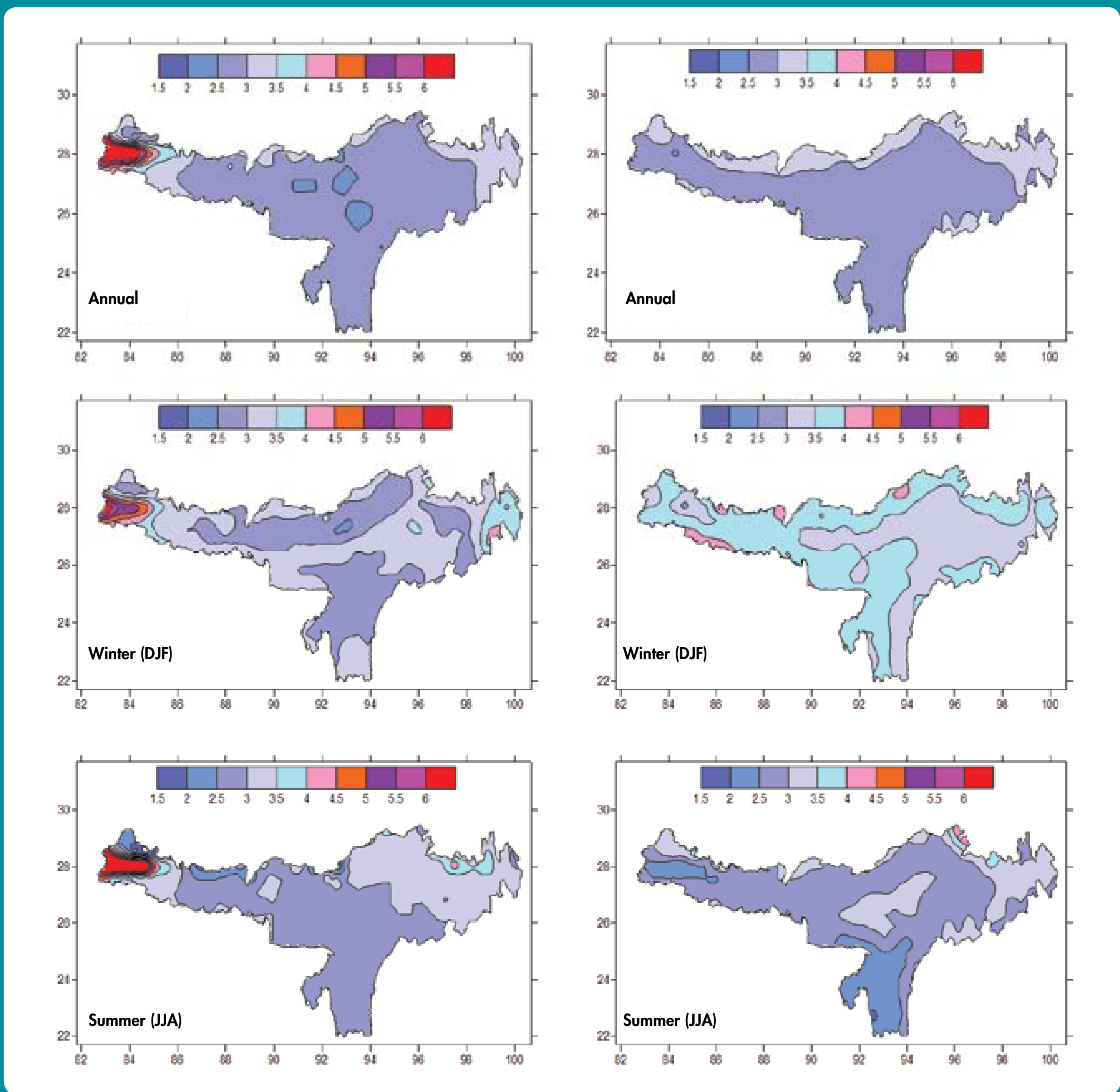


warming of generally 0.01 to 0.04°C per year; the highest rates of warming are in winter with the lowest, or even cooling, in summer; and there is progressively more warming with elevation, with areas above 4000 m experiencing the greatest warming rates (up to 0.06°C).

Past trends and change projections suggest that temperatures will continue to rise and rainfall patterns will become more variable, with both localised increases and decreases. The figures for the Eastern Himalayas do not present a drastic deviation from the IPCC outcomes for South Asia, but they reinforce the scientific basis for the contention that the region is warming.

The results also suggest that the seasonal temperature fluctuations are changing in both timing and extent and the rate of change of temperature with altitude is becoming less (ie, higher altitude areas are warming faster than lower areas so the difference in temperature between them is becoming less). Annual mean temperatures are projected to increase on average by 2.9°C by the middle of the century (the projected rates of increase are much higher than the rate of increase observed up to 2000) with an average range (places/seasons) of 2.9 to 4.3°C by the end of the century (Figure 4).

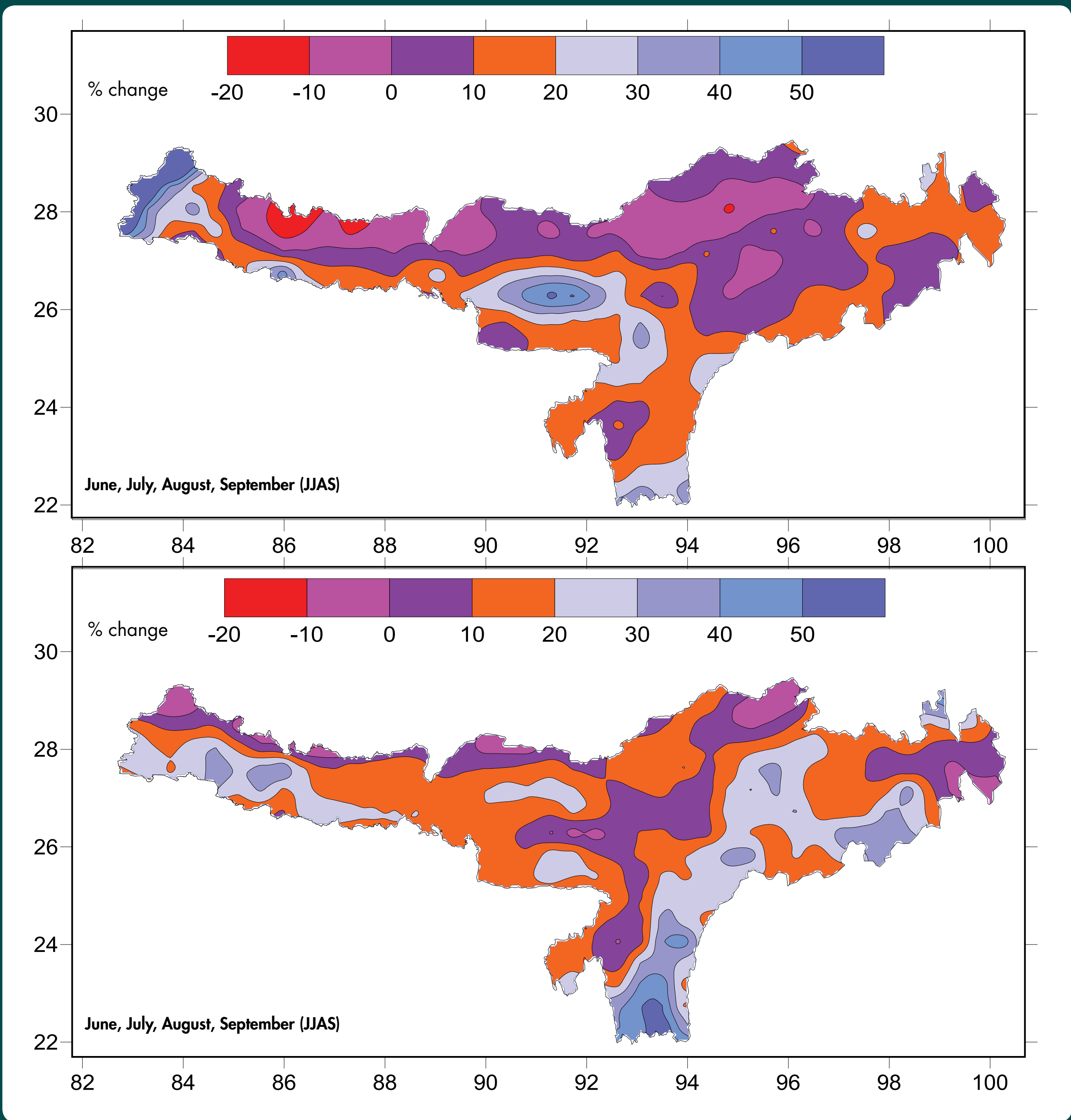
Figure 4: **Spatial distribution of scenarios of simulated future annual, winter, and summer mean temperature change (°C) over the Eastern Himalayan region according to the HadRM2 model (2041-2060, left) and the PRECIS model (2071-2100, right)**



Projections suggest an increase in winter, pre-monsoon, monsoon, post-monsoon, and annual precipitation in the region. Annual precipitation is projected to increase by 18 per cent by the middle of the century, and by 13 to 34 per cent by the end of the century (Figure 5). Higher monsoon precipitation is also projected at higher altitudes (wet bias), and lower at lower altitudes (dry bias). However, uncertainties still exist in the analysis due to lack of data and comprehensiveness, as well as geographical complexities. Some of the key complexities that need to be taken into account in any attempt to understand climate change in the Eastern Himalayas are the modifying effects of the high Himalayan range, the complex physiographic environment, and the natural variations and cycles in the large-scale monsoonal circulation on weather and climate.

Despite the challenges and uncertainties, certain conclusions appear to be justified. Overall the assessment indicates that the magnitude of change increases with elevation in relation to both temperature and precipitation, and further that climate change effects are likely to occur faster and be more pronounced than the global average.

Figure 5: **Spatial distribution of scenarios of simulated future monsoon precipitation (change as % of current simulation) over the Eastern Himalayan region according to the HadRM2 model (2041-2060, top) and the PRECIS model (2071-2100, bottom)**



Impacts of climate change: Observed and potential

Climate change will have a range of direct and indirect impacts on both the environment and the people of the Eastern Himalayan region. These impacts are closely interlinked, ranging from biodiversity impacts and related effects on ecosystem goods and services, through impacts on water balance and availability and hazards, to socioeconomic and health impacts on the population. The impacts are embedded in and affected by a range of other global and local drivers of change. The impact of climate change on biodiversity will occur in concert with well-established stressors such as habitat loss and fragmentation, invasive species, species exploitation, and environmental contamination, to name just a few (Chase et al. 1999). Problems associated with modernisation like greenhouse gas (GHG) emissions, air pollution, land use conversion, deforestation, and land degradation, are slowly creeping into mountain regions (Pandit et al. 2007). The out-migration of the rural workforce has decreased economic activities in rural areas. Thus, landscapes and communities in mountain regions are being simultaneously affected by rapid environmental and socioeconomic threats and perturbations.

Climate change will have a significant effect on all natural ecosystems, but the impacts will be far greater on the already-stressed ecosystems of the Eastern Himalayas. Projections about climate change variability sound alarm bells for the fate of ecosystems and their long term sustainability. The region is particularly vulnerable to climate change due to its ecological fragility and economic marginality. The high level of poverty linked with pervasive livelihood challenges has already brought indicative changes in forest quality. Land use and land cover changes contribute to local and regional climate change (Chase et al. 1999) and global climate warming (Houghton et al. 1999), as well as having a direct impact on biotic diversity (Chapin et al. 2000; Sala et al. 2000), influencing the reduction in species diversity (Franco et al. 2006). These changes also affect the ability of biological systems to support human needs (Vitousek et al. 1997). The impacts of climate change in the Eastern Himalayan region include changes in the hydrological regime, an increase in hazard frequency and intensity, and impacts on human health. There is evidence of noticeable increases in the intensity and frequency of many extreme weather events in the region such as heat waves, tropical cyclones, prolonged dry spells, intense rainfall, snow avalanches, thunderstorms, and severe dust storms (Cruz et al. 2007).

Flora and fauna

Climate change increases the risk of extinction of species that have a narrow geographic and climatic range (Hannah et al. 2007; Sekercioglu et al. 2008). Threatened and endemic species are the most vulnerable, while invasive species from warmer regions will consolidate at the expense of existing local communities. According to the prevailing extinction theory, larger and more specialised species are likely to be lost due to habitat destruction (Sodhi et al. 2004). This is a special risk factor for highland species, which are sensitive to climate change (Pounds et al. 2006) and more likely to be at risk of extinction.

Globally, there is much evidence that species in the northern hemisphere are shifting towards northern latitudes (Grabherr et al. 1994; Hickling et al. 2006) or higher elevations (Peterson 2003; Wilson et al. 2007). Species in transition zones between subalpine and alpine are especially vulnerable to climate change as they have limited scope to move further. However, there are few such analyses for the Eastern Himalayas and they are limited to certain pockets (Carpenter 2005).

Some observations have been made in relation to changes in plant and animal phenology, and also regarding the shifting of the tree line and encroachment of woody vegetation into the alpine meadows. The phenological changes, such as early budding or flowering and the ripening of fruits in plants, could have an adverse impact on pollination patterns and may have an impact on the population of pollinators, leading to changes in ecosystem productivity and the species composition of high altitude habitats (Thuiller et al. 2008). Changes have also been observed in the timing of hibernation, migration, and breeding in animals. Changes in phenology or species composition may have significant relevance in the Eastern Himalayas on habitats and forest quality.

The ecosystems in the three global Biodiversity Hotspots in the Eastern Himalayas are layered in the form of narrow bands along the longitudinal axis of the mountain range, and are thus easily impacted by climatic variations. The region is rich in threatened and endemic species with restricted distribution and/or narrow habitat ranges (Wikramanayake et al. 2002) that are at particular risk (Table 2). Examples include the snow leopard *(Uncia uncia)*, red panda *(Ailurus fulgens)*, wild water buffalo *(Bubalus bubalis)*, tiger *(Panthera tigris)* and other members of the cat family (Felidae), Asian elephant *(Elephas maximus)*, and one-horned rhinoceros *(Rhinoceros unicornis)*,

Table 2: **Strict endemic mammals with their threatened status and respective ecoregions**

Scientific name	Common name	IUCN status*	Ecoregions
Scaptonix fusicauda	-	-	Northern triangle subtropical forests
Talpa grandis	-	-	Northern triangle subtropical forests
Chimarrogale styani	Styan's water shrew	LR	Northern triangle subtropical forests
Hypsugo anthonyi	Anthony's pipistrelle	CR	Northern triangle subtropical forests
Sciurotamias davidianus	Pere David's rock squirrel	LR	Northern triangle subtropical forests
Hypsugo joffrei	Joffre's pipistrelle	CR	Mizoram-Manipur Kachin rainforests
Tadarida teniotis	European free-tailed bat	LR	Lower Gangetic plains moist deciduous forests
Sus salvanius	pygmy hog	CR	Terai-Duars savanna and grassland
Myotis longipes longipes	Kashmir cave bat	VU	Western Himalaya broadleaf forests
Hyperacrius wynnei	Murree vole	LR	Western Himalayan subalpine conifer forests
Apodemus gurkha	Himalayan field mouse	EN	Eastern Himalayan subalpine conifer forests
Nycticebus intermedius	-	-	Northern Indo China subtropical forests
Hyalobates leucogehys	-	-	Northern Indo China subtropical forests
Hemigalus owstoni	-	-	Northern Indo China subtropical forests
Muntiacus rooseveltorum	-	-	Northern Indo China subtropical forests
Eothenomys olitor	Chaotung vole	LR	Northern Indo China subtropical forests
Sorex kozlovi	Kozlov's shrew	CR	Nujiang Langcang Gorge alpine conifer and mixed forests
Biswamoyopterus biswasi	Namdapha flying squirrel	CR	Eastern Himalayan broadleaf forests

Source: Wikramanayake et al. (2002)

* CR = critically endangered; EN = endangered; VU = vulnerable; LR = lower risk

which are all found in small, isolated, widely scattered habitats across the Eastern Himalayas. Similarly, the region is home to narrowly endemic species like the golden langur *(Trachypithecus geei)*, pygmy hog *(Sus salvinus)*, Namdapha flying squirrel *(Biswamoyopterus biswasi)*, takin *(Budorcas taxicolor)* and hoolock gibbon *(Bunopithecus hoolock)*. These species, and many others, by virtue of their specific habits and habitat needs, are more vulnerable to climate change and more likely to face extinction in the face of the expected changes (Brooks et al. 2003). Although habitat loss has primarily threatened lowland species, highland species in intact habitats are now facing the additional threat of warming temperatures, which increasingly pushes these species towards the mountain tops (Williams et al. 2003; Pimm et al. 2006). Now in addition to conserving habitats, it is becoming important to manage likely vulnerable species.

Table 3 shows examples of the impacts of climate change on biodiversity in the Eastern Himalayas based on observations and projections without taking into account any changes or developments in adaptive capacity or mitigation measures. The list has been compiled based on literature, stakeholders' workshops, and a stakeholder survey conducted as part of this assessment. The impacts tabled are not exhaustive of the region, but rather present an overview of the impacts identified in the Eastern Himalayas. `The circle coding' is intended to provide a broad differentiation between impacts that have been observed (or documented scientifically), versus those that are projected (or otherwise hypothesised). The extent to which these impacts have contributing causes other than climatic change has also not been assessed.

Ecosystem goods and services

Ecosystem services regulate and support natural and human systems through processes such as the cleansing, recycling, and renewal of biological resources and water; such services are crucial for the economic, social, cultural, and ecological sustainability of human development (Daily et al. 1997). As the world's population and the global economy are growing, both the demand for these services and the likelihood of negative impacts are likely to increase. The Millennium Ecosystem Assessment (MA 2005) grouped ecosystem services into four broad categories: provisioning (such as food, fibre, fuel, and water); regulating (such as climate regulation, water purification, and erosion control); cultural (such as education, recreation, and aesthetic); and supporting (such as nutrient cycling and soil formation). These varied services from ecosystems, many of them often overlooked, have immense

Table 3: **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 (Mikania, Eupatorium, Lantana, etc.)	●○			●○			●○	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

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, deforestion	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

significance for human wellbeing (Figure 6). The Eastern Himalayan region, being rich in ecosystems and associated biodiversity, is of high importance in terms of such services, all of which will be affected by climate change. The ecosystem services provided by wetlands are of particular significance and discussed in detail in a separate section below.

Water balance and hazards

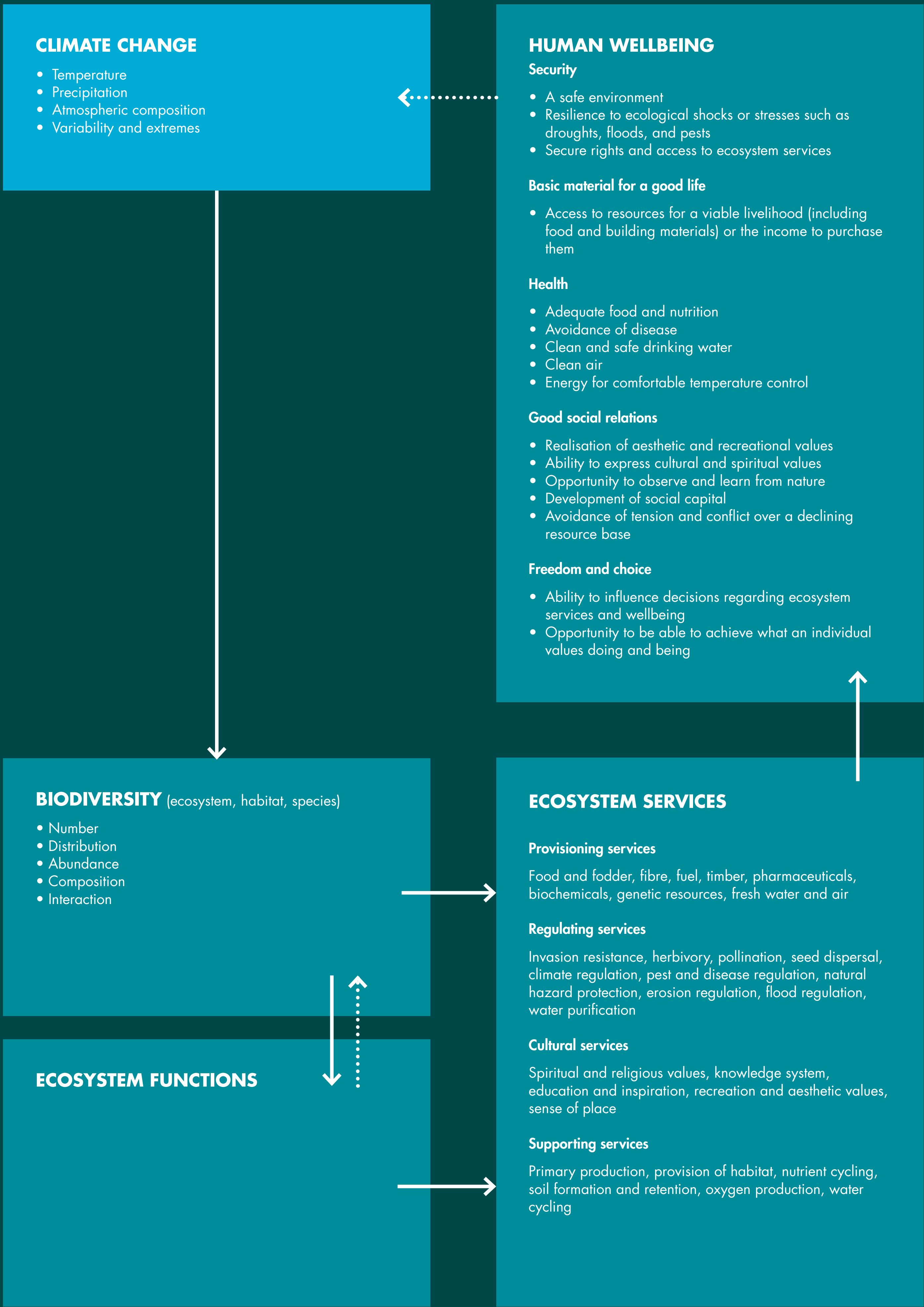
The impacts of climate change are not only important in the context of ecosystem services, but also in connection with the overall water regime and with hazards. Despite the importance of water and the fact that climate change may have a profound impact on it, there have been few quantitative analyses of changes to water regimes in the Eastern Himalayas due to the dearth of the baseline data which is essential for such analyses. Even so, it is clear that the hydrological systems of the Eastern Himalayas are very sensitive to climate change, variability, and extremes, both on a seasonal basis and over longer time periods. The shifts in precipitation and temperature can have a considerable impact on future flow regimes.

Global warming is accelerating the melting of glaciers in the Himalayas, which are melting faster than the global average (ICIMOD and UNEP 2000; Dyurgerov and Meier 2005; Bajracharya et al. 2007); the snow line will rise and potentially some glaciers could disappear or stabilise at a much reduced mass (IPCC 2007a; 2007b). In the short term, this means an increase in meltwater; in the longer term, a reduction.

Spatial analysis of water balance components indicates that stream flows will increase significantly across most of the Eastern Himalayas in response to precipitation and temperature changes, but effects will vary spatially. Overall increases are likely to be more in the wet months, with a potential reduction in the dry months – which could have serious impacts on the populations relying on rivers fed by meltwater from the Himalayas. The projected increase in the frequency and magnitude of high intensity rainfall events could affect infiltration and groundwater recharge with further implications for water availability for people as well as water accessibility for plants. Much concern has also been expressed about the likely impact of the increased variability in flow on hydropower generation in the region (Alam and Regmi 2004).

Natural hazards in the Eastern Himalayas are mainly linked to water, 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 water-related natural hazards (Pathak et al. 2008); over the past three decades, the region has witnessed an increased frequency in events such as floods, landslides, mudflows, and avalanches affecting human settlements (Shrestha 2004; WWF 2005).

Figure 6: **Linkages between climate change, biodiversity, ecosystem services, and human wellbeing (adapted from MA 2003)**



In the Eastern Himalayas, particularly in Bhutan and Nepal, there is considerable concern about the supraglacial and moraine-dammed lakes that have developed in the wake of general glacier retreat since the Little Ice Age ended, because of their potential to breach catastrophically (Quincey et al. 2007). The IPCC Fourth Assessment Report (IPCC 2007a; 2007b) states that there is a high degree of confidence that in the coming decades many glaciers in the region will retreat, while smaller glaciers may disappear altogether. As they retreat, lakes can develop at the glacier snout, the meltwater held back by the unstable end moraine. A number of glacial lakes in the Eastern Himalayas have the potential to burst leading to a glacial lake outburst flood or GLOF with catastrophic consequences for nature and humans alike; GLOFs have occurred at various locations in the Eastern Himalayas including in Bhutan, China, India, and Nepal (ICIMOD 2007). Nepal has 20 lakes considered to be potentially dangerous, Sikkim 14, and Bhutan 24 (Mool et al. 2001; Mool pers. comm. 2009). GLOF events can have a widespread impact on the socioeconomic situation, hydrology, and ecosystems.

This assessment attempted to make a preliminary analysis of the likely impacts of climate change in the Brahmaputra and Koshi basins based on the limited data available, with validation by field observation, and climate projections from the models. The exercise provided insights into possible future changes. The assessment shows, in general, a significant increase of up to 20 to 40 per cent from the baseline in the water yield and surface runoff resulting from increases in both precipitation and snowmelt. The increase is significantly more in the Koshi basin than the Brahmaputra basin, and much higher during the wet months and less or absent in the dry months, suggesting the possibility of an increase in flood frequency and magnitudes. The problem is more prominent in the lower parts of the basins. The increase in water yield will lead to a 25 to 40 per cent increase in sediment yield assuming no change in land use/land cover.

Drought-related disasters could also become more frequent. Throughout Asia, one billion people could face water shortages leading to drought and land degradation by the 2050s (Christensen et al. 2007, Cruz et al. 2007). The predicted increase in sediment load in rivers will lead to dams, reservoirs, canals, and waterways suffering from massive siltation, reducing their economic lifespan, and incurring huge costs in de-silting and restoration work. The effects, however, vary spatially across the Eastern Himalayas and under different assumptions about the future. This assessment is preliminary in view of the data used for analysis, and the results are far from conclusive.

Wetlands and their goods and services

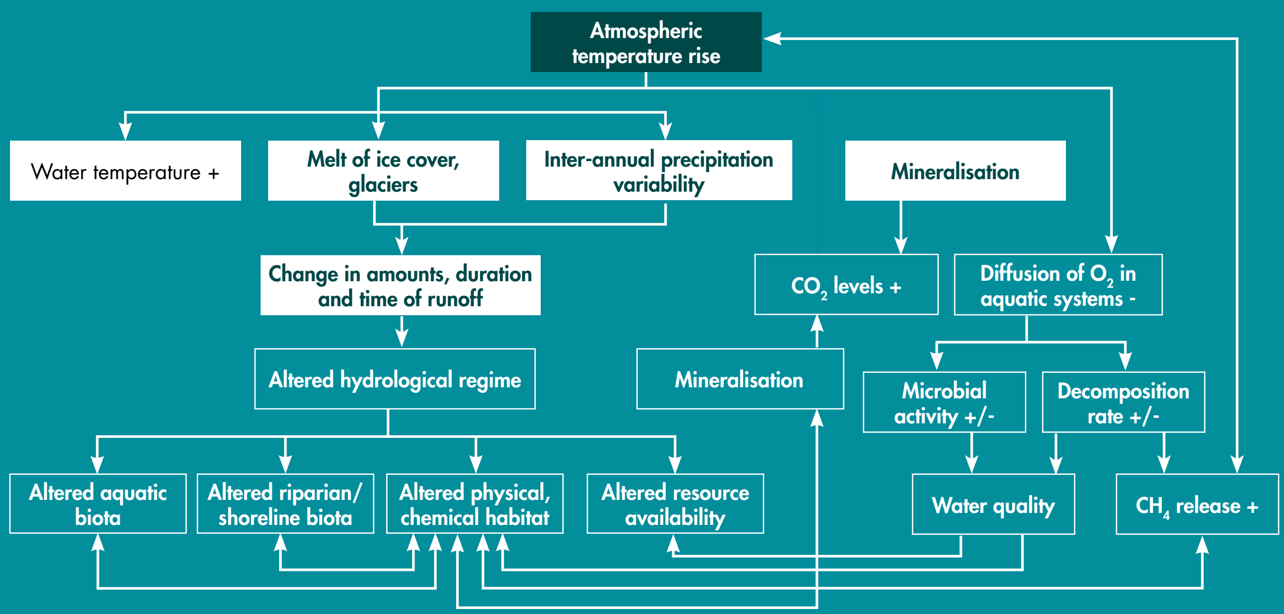
The impacts of climate change on wetlands and freshwater resources have been discussed in many recent publications, including the assessment reports of the IPCC (Gitay et al. 2001; van Dam et al. 2002; Sharma et al. 2002; Sharma 2003). However, there are very few studies or assessments of climate change impacts on freshwater wetlands in developing countries in general, and the Himalayan region in particular. In the following account an attempt is made to assess the likely scenario mainly by extrapolating from other research work.

There are two main levels of climate change impacts on wetlands: direct impacts on wetland processes and functions, and overall impacts on different kinds of ecosystem goods and services. Some pathways of these changes are summarised diagrammatically in Figure 7. In the Eastern Himalayan region it is also important to consider the difference in the impacts along the altitudinal gradient, and the cascading influence at successively lower elevations. Unfortunately, very little is known about altitudinal differences in climate change, except that there is a general trend towards a greater temperature increase with altitude.

The wetland plant communities of the Eastern Himalayas vary from alpine to tropical and are likely to respond differently. This will certainly have major implications for their carbon sequestration potential. The impacts that feed back into climate change – mitigating or accelerating – are of particular interest . The possible role of carbon sequestration through enhanced carbon fixation by wetland plants is not clear, but climate change will certainly trigger increased emissions of GHGs from many wetlands. Methane emission occurs from a variety of wetlands during the summer following thawing of ice in permafrost regions (e.g., Rinne et al. 2007).

Recent reports from northern temperate zones show that lakes also emit significant amounts of methane into the atmosphere (Michmerhuizen and Striegl 1996). Interestingly, lakes with smaller surface areas emit proportionately more methane during the spring melt, apparently because of their larger shorelines, where littoral vegetation adds large amounts of organic matter to the sediment (Michmerhuizen and Striegl 1996). Higher rainfall, as projected in most of the Eastern

Figure 7: **Possible impacts of climate change on inland wetlands and other aquatic ecosystems**



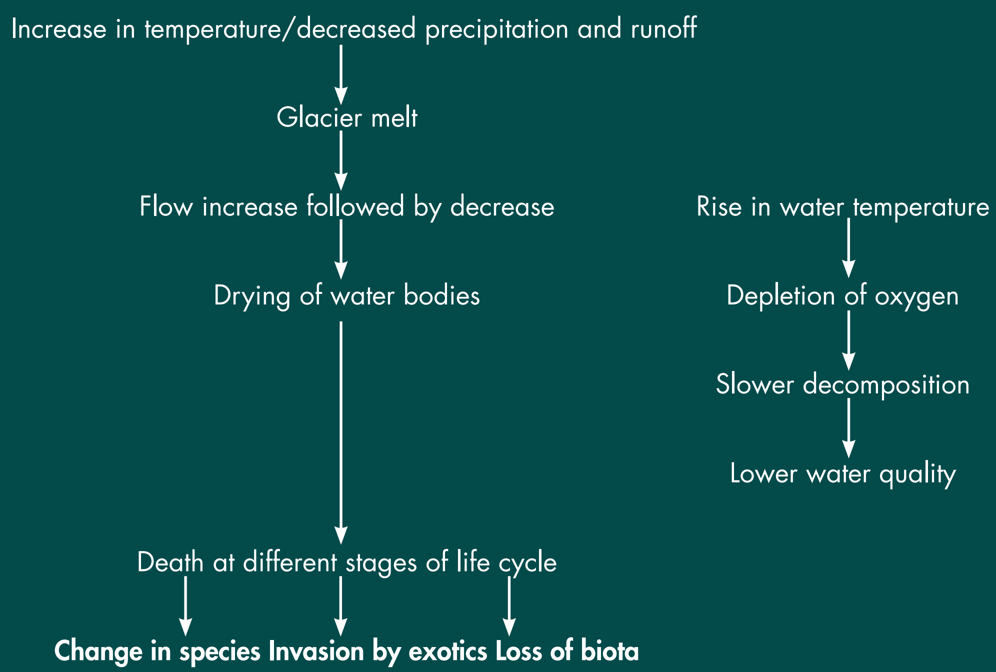
Himalayas, could enhance sediment loads leading to peat formation and the reduction of lake size (Jain et al. 2004). The longer and warmer growing seasons are also projected to result in desiccation of peat and the production of CO_2.

An increase in temperature will result in a rise in the snow line, and species are expected to shift to higher elevations (Anderson et al. 2009). Exotic invasive species such as water hyacinth have already extended their range into the hills, and may spread even higher. In natural wetlands, the elevated CO_2 concentrations promote greater carbon fixation in C_3 plants such as emergent macrophytes, although the response of *Sphagnum* species and other plants occurring in bogs is not clear (Gitay et al. 2001). Another effect of rising temperatures will be an increase in water temperature and, consequently, a lower availability of dissolved oxygen (Figure 8). This may affect a number of animals – both invertebrates and vertebrates. Many invertebrates and their larval stages have narrow temperature ranges for development and a rise of 1°C may affect their life cycles. The rising temperatures will alter the ice-free period, make the growing season longer, bring about changes in the patterns of thermal mixing in lakes, and lead to a greater incidence of anaerobic conditions for benthic organisms including microbes. This will have consequences for food web interactions, community structures, nutrient dynamics, and water quality.

One of the most significant points is the fact that climate change impacts will cascade down from higher elevations to lower elevations. This cascading effect is caused by the hydrological connectivity between upstream (uphill) and downstream (downhill) wetlands. The wetlands in the valleys and other lower elevation areas will bear the brunt of the changes taking place at higher elevations. Changes in the amount, timing, and duration of water availability; changes in extreme events; and changes in the intensity and timing of monsoon precipitation will affect the wetlands most at lower elevations. As noted earlier, wetlands are both a source and sink of greenhouse gases, and this switch in the 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 emitted. While wetlands may help sequester more carbon and, thereby, mitigate climate change impacts, they may also become a source of increased methane emission, and, hence, drive climate change further.

The wetlands of the Eastern Himalayas provide numerous services to people (Table 4), the single most important service being the provision of water throughout the year. Eastern Himalayan wetlands at higher elevations (above ~3000 m) remain frozen for 6 to 11 months of the year; there is little direct anthropogenic influence

Figure 8: **Generalised effects of temperature rise on wetlands**



on these wetlands, their ecosystem service is mainly the provisioning of water in the valleys and at lower elevations. Most of the glacial lakes are direct sources for the various rivers that join downstream to form the major rivers of the region. The temperature increase and differential warming between the seasons will increase the snow-free period, and affect the patterns of thermal mixing in these lakes. A recent study in Nepal predicts that the total water availability in the country will increase from the present 176 km^3/yr to 178 km^3/yr in 2030, and then drop to 128 km^3/yr by 2100 (Chaulagain 2006). This would have significant consequences for wetlands at lower elevations and in the plains that depend largely on runoff from upstream areas.

Wetlands and marshes also play a role in nutrient cycling, provide crucial fish and wildlife habitats, and remove pollutants from 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 to millions of people living in the Eastern Himalayas and the downstream basins. In addition, wetlands in the Eastern Himalayas have great spiritual and cultural value both as sacred lakes and of value 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 cultural and religious sites.

Human wellbeing

The impact on hydropower plants could 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. This problem could be more prominent in the lower parts of the river basins.

Climate change affects human wellbeing directly through extreme weather events and indirectly through its effects on ecosystems – the foundation of human wellbeing. Specific knowledge and data on human wellbeing in the Eastern Himalayas is limited, but it is clear that the effects of climate change will be felt by people in their livelihoods, health, and security, among other things. Although the Eastern Himalayas is one of the richest areas in the world for biological diversity, it is also one of poorest regions in terms of economic development. The majority of people living in the Eastern Himalayas are dependent on the goods and services provided by the biologically rich ecosystems and landscapes. As natural resources and ecosystem services decline with increasing human interference through industrial and infrastructural development and over exploitation, the human conflict and competition for scarce resources could reach alarming proportions, which, in turn, will set the context for further desolation. The consequences of biodiversity

Table 4: **Ecosystem services provided by wetlands**

Services	Examples
Provisioning	
Food	Production of fish, wild game, fruit, and grains
Freshwater	Storage and retention of water for domestic, industrial, and agricultural use
Fibre and fuel	Production of logs, fuelwood, peat, and fodder
Biochemical	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 aspects of wetlands	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: MA (2005)

loss from climate change are likely to be the greatest for the poor and marginalised people who depend almost exclusively on natural resources. Poverty, poor infrastructure (roads, electricity, water supply, education and health care services, communication, and irrigation), reliance on subsistence farming and forest products for livelihoods, substandard health indicators (mean mortality rate [MMR] and infant mortality rate [IMR] and life expectancy), and other indicators of underdevelopment make the Eastern Himalayas more vulnerable to climate change as the capacity to adapt is inadequate.

A major area of serious impact is agricultural production – the direct or indirect source of livelihood for over 70 per cent of the population in the region, and a substantial contributor to national incomes. Agriculture is highly sensitive to climate change and is expected to be affected differently throughout the region, with some 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. 2002). The management of climate hazards and climate change impacts in the agricultural sector will be critical for the viability of local communities. The positive effects of climate change – such as longer growing seasons 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, and not least water availability. Indirect effects will include potentially detrimental changes in diseases, pests, and weeds, the effects of which have not yet been quantified. The livelihoods of subsistence farmers and pastoral people, who make up a large portion of the rural population, could be negatively affected by a decline in forage quality, heat stress, and diseases like foot and mouth in livestock. Grassland productivity is expected to decline by as much as 40 to 90 per cent with an increase in temperature of 2 to 3°C combined with reduced precipitation (Smith et al. 1996).

Climatic changes are predicted to undermine regional food security. Several studies in the past showed that the production of rice, corn, and wheat has declined due to increasing water stress arising partly from increasing temperatures and a reduction in the number of rainy days (Fischer et al. 2002; Tao et al. 2004). The net cereal production in the region is projected to decline by at least 4 to 10 per cent by the end of this century, under the most conservative climate change scenario (Lal 2005). In Bhutan, only around 16 per cent of the land is cultivable, which severely constrains agricultural production and also exposes the nation to the risk of food insecurity (Alam and Tshering 2004). Although China has made significant progress in poverty reduction and eradicating hunger, it is projected that by 2050 China's grain output could fall by as much as 10 per cent unless crop varieties adapt to new temperature and water regimes, while by the latter half of the century production of wheat and rice could drop by as much as 37 per cent (Kishan 2007). This poses new threats to food security in China. Similarly, food security is a chronic problem in Nepal, particular among hill and mountain populations and indigenous groups. However, it is believed that long-term male migration and the lengthy political conflict have also contributed to reduced food production and disrupted the food distribution in Nepal (Gill 2003).

Climate change will have a wide range of health impacts across the Eastern Himalayas through, for example, increases in malnutrition due to the failure of food security; disease and injury due to extreme weather events (Epstein et al. 1995); increased burden of diarrheal diseases from deteriorating water quality; increased infectious diseases; and increased frequency of cardio-respiratory diseases from the build-up of high concentrations of air pollutants such as nitrogen dioxide (NO_2), lower tropospheric and ground-level ozone, and air-borne particles in large urban areas. A reduction in wintertime deaths is anticipated; however, human health is likely to suffer chronically from heat stress (Bouchama et al. 1991; Ando 1998). In particular, the 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).

Mortality due to diseases primarily associated with floods and droughts is expected to rise. In the lowlands, hygrothermal stresses (warmer and wetter conditions) will also influence increased transmission of epidemic diseases and higher incidence of heat-related infectious diseases (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 the existing endemic areas because of climate change. Vectors require specific ecosystems for survival and reproduction; and epidemics of these diseases can occur when their natural ecology is disturbed by environmental changes, including changes in climate (Martens et al. 1999; 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 previously uninfected high altitude locations. Expanding the geographic range of vectors and pathogens into new areas, increasing suitable habitats and numbers of disease vectors in already endemic areas, and extending transmission seasons could potentially 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 kalaazar. Climate change-attributable water-borne diseases including cholera, diarrhoea, salmonellosis, and giardiasis, as well as malnutrition conditions are prevalent in Bhutan, India, Myanmar, and Nepal. The risk of contracting such diseases or suffering from malnutrition in 2030 is expected to increase as a result of elevated temperatures and increased flooding (Patz et al. 2005).

Human perceptions of trends and impacts of climate change

The overall perceptions of climate change were investigated through interviews and questionnaires. Among the people of the Eastern Himalayas, climate change is perceived as a threat and a challenge. Climate change is perceived by the people of the region to be a consequence of excessive human activity and its impact on natural resources, as well as, to a certain extent, a natural phenomenon of cyclical climatic variation. The people of the region also associate climate change with floods, landslides, increases in temperature, land degradation, the drying of water sources, pest outbreaks, and food shortages, with the melting of snow and shrinking and retreating of glaciers as the most disastrous impact.

The people of the region perceive that climatic patterns have changed, based on observation and personal experiences; farmers are perceived as most affected by such changes, of which they have little knowledge. However, there seems to be very little effort to minimise or combat the impacts of climate change at regional, national, local, or village levels. The people of the Eastern Himalayas are of the view that there has been little action apart from environmental organisations and the media, and that the governments of Bhutan, India, and Nepal have taken little initiative to counteract the effects of climate change on biodiversity.

The threat posed by declining biodiversity and its impact on the economy in the future was also discussed. However, economic insecurity and political insecurity (in the case of Nepal) are perceived as posing a greater threat to people's livelihoods and wellbeing in the region than climate change. Governments are perceived as prioritising overall economic development over climate change issues.

Climate change vulnerability

Climate change affects all aspects of life, making rainfall less predictable, changing the character of the seasons, and increasing the likelihood and severity of extreme events such as floods. Assessing the impacts of and vulnerability to climate change, and subsequently working out adaptation needs, requires good quality information from multiple sectors (climate, hydrology, agriculture, socioeconomics) (Fischer et al. 2002; Schroter et al. 2005). As the Eastern Himalayas is home to some of the most fragile ecosystems in the world, the poor and marginalised people living in this region face a pressing challenge of adapting to changing climate. Limited data and restricted access to existing data are major constraints to developing the necessary knowledge base. The situation is no less challenging in relation to the assessment of vulnerability at the coupled human-ecosystem level, and especially when trying to separate the potential impact of climate change from the myriad of real and interacting stresses. An emerging consensus holds that the vulnerability of biodiversity in mountain ecosystems reflects the vulnerability of coupled human-environment systems in the region to perturbations, stresses, and stressors (Ives et al. 2004). In this section, we identify which entities are most vulnerable to climate change in the Eastern Himalayas and analyse the vulnerability of these entities based on various factors.

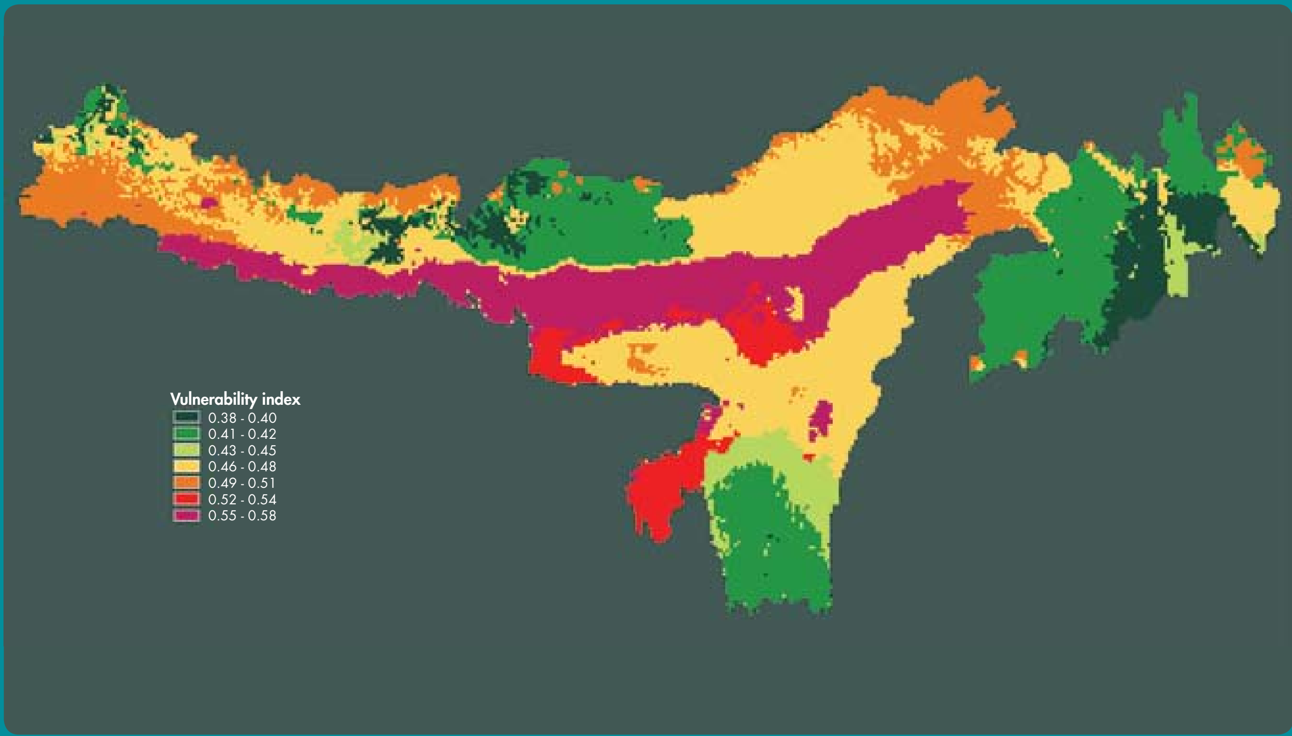
Vulnerability has emerged as a crosscutting theme in research on the human dimensions of global environmental change (Lal et al. 1998; Polsky et al. 2003). Yet vulnerability to climate change has traditionally been studied in isolation from other stressors, including structural changes associated with economic globalisation (O'Brien and Leichenko 2000). It has been acknowledged that exposure to multiple stressors is a real concern, particularly in developing countries where food security is influenced by political, economic, and social conditions, in addition to climatic factors (Leichenko et al. 2004). Nevertheless, no systematic methodology has been developed for operationalising vulnerability in the context of multiple stressors. In this assessment, an attempt was made to assess vulnerability based on human-induced disturbances in ecosystems including the proportion of species listed as vulnerable (VU), endangered (EN), and critically rare (CR) (according to the IUCN categories); renewable water flows and carbon storage (with an inverse relationship to vulnerability); and the percentage tree cover as a metric of an ecosystem's natural adaptive capacity (assuming that less fragmented forests have higher resilience to external stresses). In addition, the 100 protected areas and 25 ecoregions that are found in the Eastern Himalayas were overlaid to identify the most vulnerable ecoregions (see ICIMOD 2009 for more details on methodology). A total of 17 sensitivity indicators grouped under four categories of potential vulnerability (biodiversity, human well-being, water systems, and ecosystems) were evaluated, and the vulnerability under the separate categories and overall calculated and mapped across the region (Figure 9a,b)

The overall depiction of vulnerability averaged across ecosystem elements uncovered large areas in the Eastern Himalayas that would likely be impacted by adverse exposure to the results of climate change stresses. Although the direct climate changes are most marked at high elevation, they have the most impact at lower elevations for two reasons. First is the 'cascading down' of effects from high to low areas, for example increased runoff at high altitude leading to floods, increased sand deposition on agricultural land, and so on at lower altitudes. The second reason is that small changes in climate variables can have a high impact in lower elevation areas where the agricultural and other biodiversity is unable to adjust to the changes.

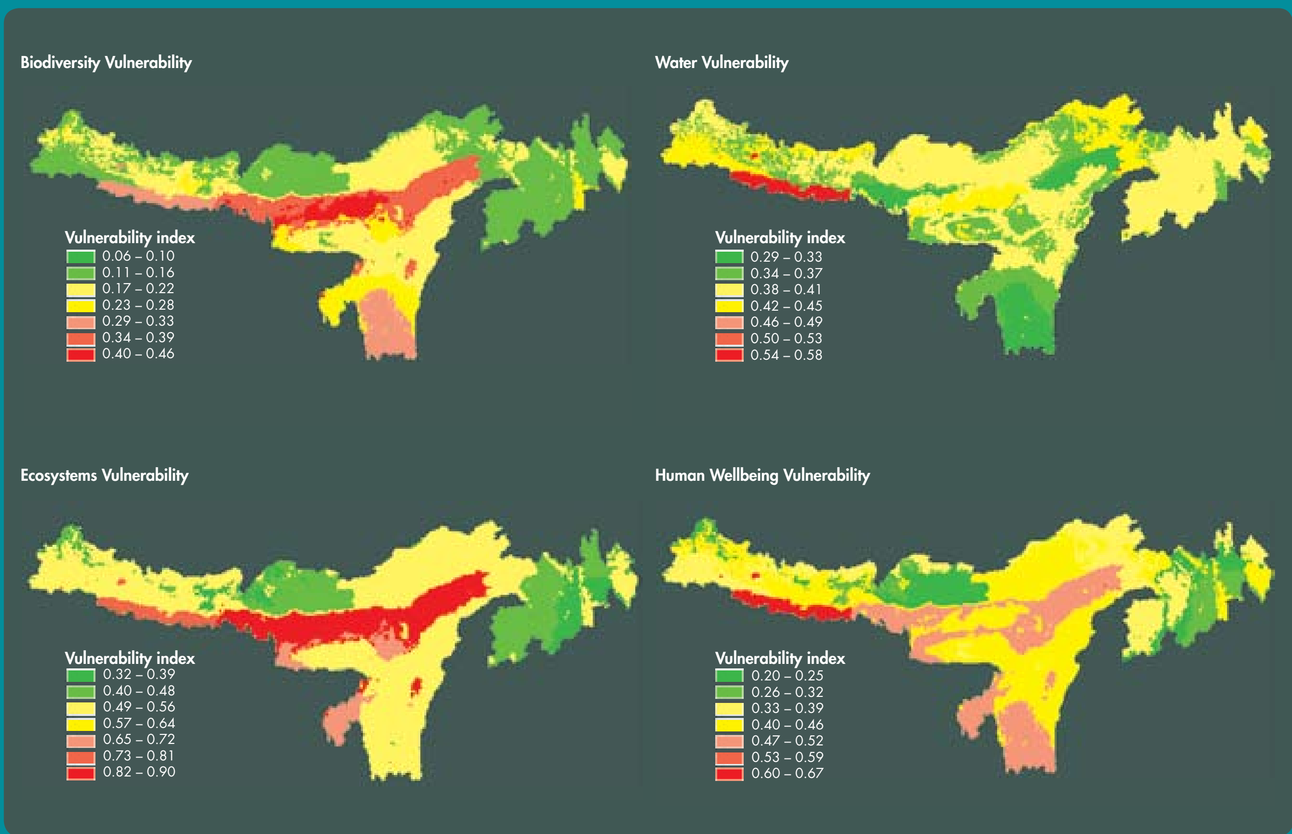
The most vulnerable areas are the whole stretch of the Brahmaputra valley, segments of the lower Gangetic plain falling with the precinct of the Eastern Himalayas, the vicinity of Loktak lake in Manipur, and especially the Terai-Duar tract from southeast Nepal to eastern Bhutan (Figure 9a). Population pressure and the devastation of natural biodiversity are the main factors that make these places highly sensitive to climate change; other factors include low socioeconomic services and productive livelihood assets, poor health and chronic disease outbreaks, land degradation, and deforestation. Although these areas are agriculturally the

Figure 9: **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



most productive in the region, the people living in them have low per capita human development assets. The impacts of the various factors are further aggravated by extremes of weather and climatic variability including recurrent floods. Biodiversity is at enormous risk of being degraded further as resource extraction is intensified to meet food security needs and as an improvised strategy for relief and recovery following each disastrous event. These areas are also sites of potential carbon emissions, which will offset the gains in sequestration offered by the forests in the adjacent mountain areas. Besides intensive agriculture, this stretch of land is also the location of much of the industrial activity in the region, with dense urban settlements and various resource use infrastructure, and is overcrowded with road accessibility. 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 region of China, Chin and Kachin states of Myanmar, Mizoram and pockets in Sikkim in India, and Nepal apart from the Terai belt. Low vulnerability scores in places were the result of values assigned to human pressure, biodiversity, and forest cover.

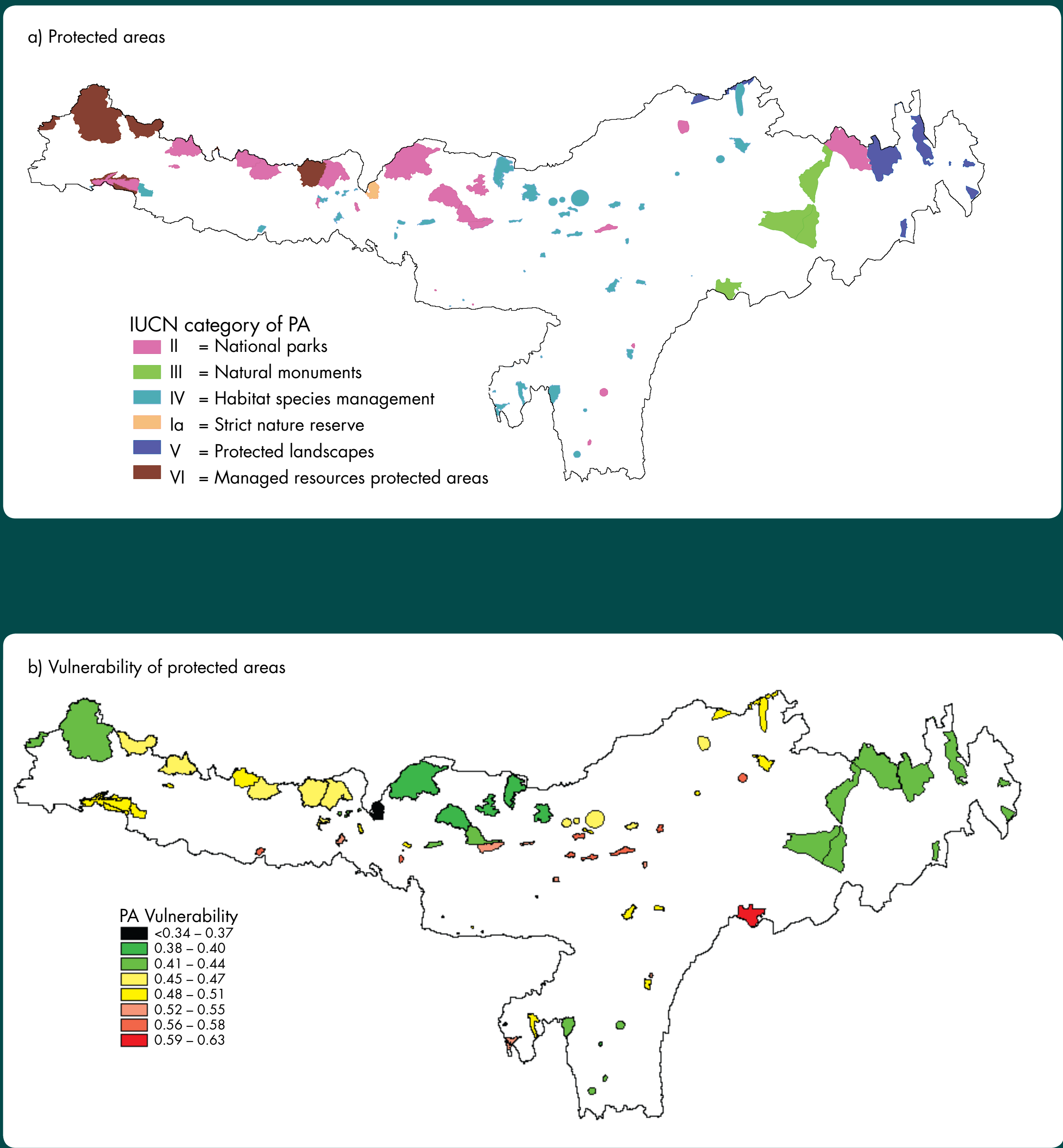
The vulnerability of the existing protected areas network under a changing climate was assessed by overlaying protected areas onto the map of vulnerability (Figure 10) and ranking them according to the degree of vulnerability, following Malcolm and Markham (1997). Rankings are based on the sum of the vulnerability metrics that each protected area system covers. Htamanthi Wildlife Sanctuary in Myanmar was calculated to be the most vulnerable of the protected areas, while other large national parks like Kaziranga, Manas, and Koshi Tappu wildlife reserve are potentially vulnerable to climate change. These conservation areas and other smaller ones are considered to be vulnerable as they are located within the most vulnerable parts of the Eastern Himalayas. Increasing pressure for land and other natural resources from the burgeoning population make these areas susceptible to habitat fragmentation and species total destruction through illegal poaching, hunting, and over exploitation. In addition, they are isolated islands of wild habitats with no prospect for habitat expansion or corridor links to extend the range or for genetic enrichment. Many of these protected areas are too small to remain viable and withstand the pervasive effects of climate change. The vulnerability of the 25 ecoregions in the Eastern Himalayas was assessed in the same way (Figure 11). Of these, the Brahmaputra Valley semi-evergreen forests (India) were identified as the most vulnerable; and the Northern Triangle subtropical and temperate forests (India, China and Myanmar) and Northern Indochina subtropical forests (China) as the least vulnerable. The vulnerability index for the Yarlung Tsangpo (China) arid steppe could not be assessed, as less than 1 per cent of it is in the Eastern Himalayas and probably below sub-pixel level. Other vulnerable areas are the Lower Gangetic Plains moist deciduous forests (India), Meghalaya subtropical forests (India), Terai-Duar savanna and grasslands (India and Nepal), and Northeastern Himalayan subalpine conifer forests (Nepal, China, India and Bhutan).

Research gaps

The assessment showed clearly that there is a considerable gap in our knowledge of the natural resources in the Eastern Himalayas and their vulnerability to climate change; there is no systematic monitoring, documentation, or research to check the status of biodiversity in the region. Despite various projections and observed changes, the region also lacks adequate scientific evidence to understand the impact of climate change on different aspects of human wellbeing. Across the entire region, most of the limited research that is available focuses on the adverse impacts of climate change and overlooks the adaptation mechanisms that local people have developed themselves, and the potential new opportunities. There also appears to be a lack of human and institutional set ups and policy imperatives to tackle climate change issues. The present assessment experienced shortcomings mainly as a result of lack of reliability in observed trends and model projections resulting from the lack of consistent country-wise data in relation to climate change. Three broad areas stand out as knowledge and data gaps that need to be addressed:

1. First, there is much to learn 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 and ecosystems.
2. Second, there is no consolidated handbook of proven biodiversity conservation techniques, or climate adaptation techniques, targeted at this region.
3. Third, detailed analyses need to be developed for each of the priority climate change threats to biodiversity and other natural resources.

Figure 10: **Protected area (PA) coverage and vulnerability in the Eastern Himalayas**

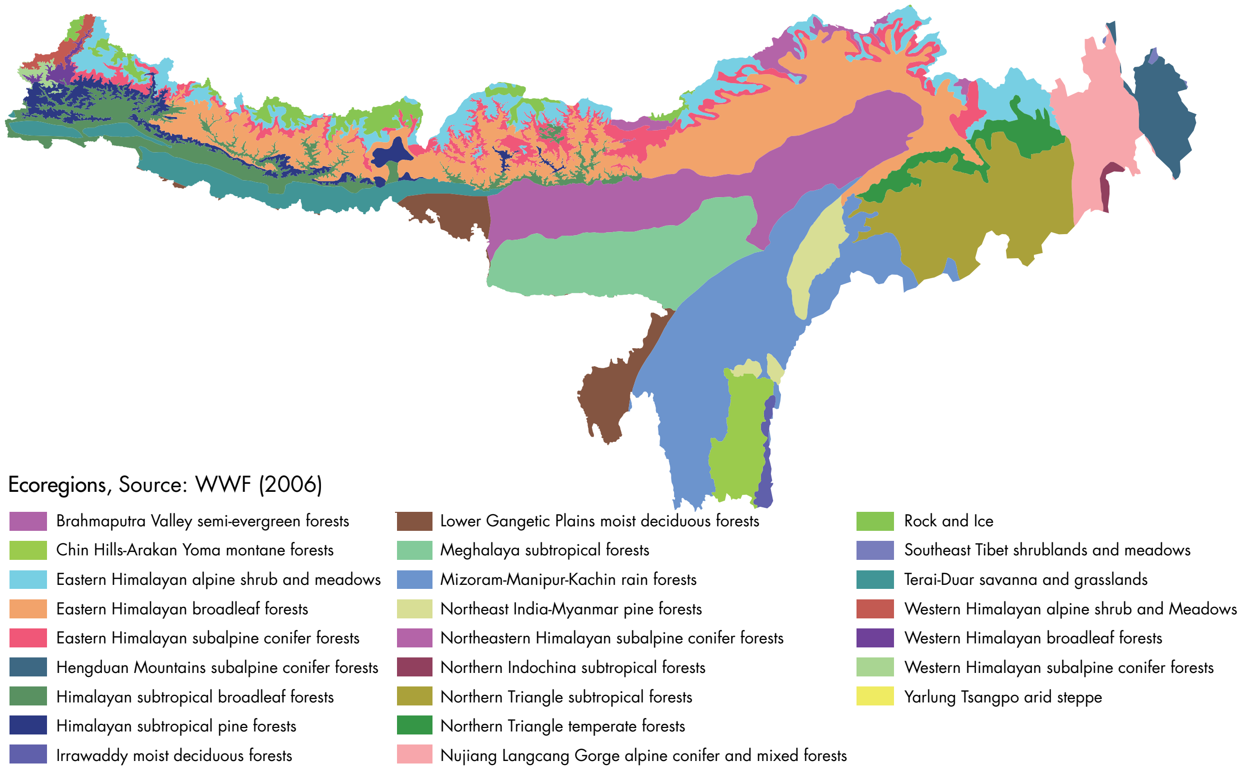


A further strategic approach is needed for detailed research on different ecosystem services and functions to estimate the potential impacts of climate change. Such research could develop adaptation mechanisms and/or highlight mechanisms that have already been implemented by local people in response to the changing environment. Detailed indicative research is also essential to define mitigation strategies at the policy level that need prioritising at the government/ international level.

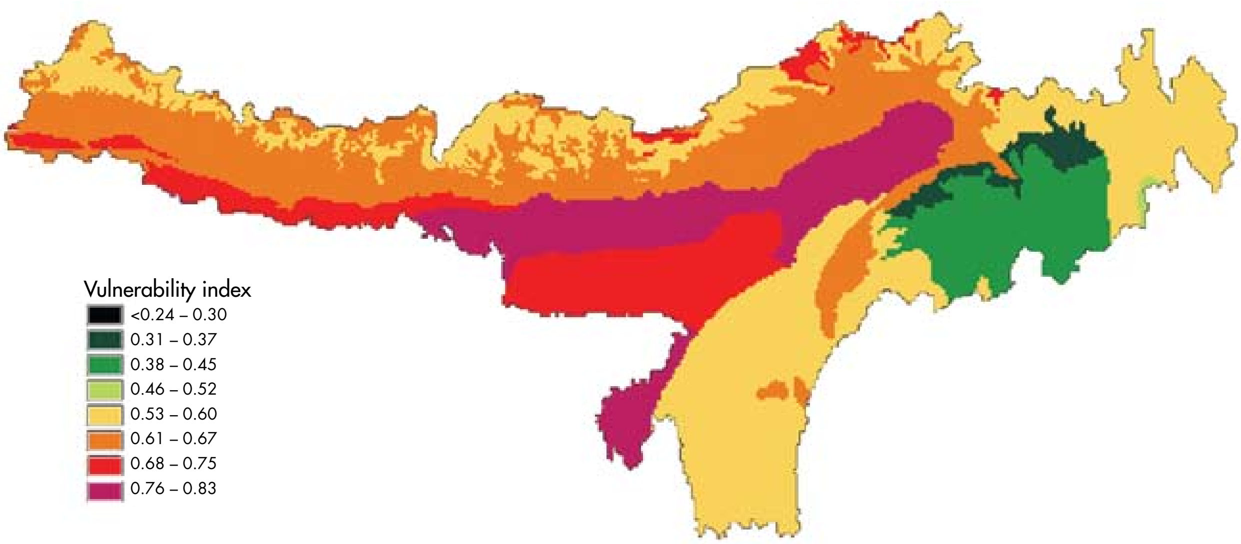
Apart from the above, some potential areas of research that should be considered are the inter-comparison of key physical and biological processes along a series of transects placed over the region; the establishment of a comprehensive regional mountain database; an in-depth study of the mountain cloud forests; and the development of strategies for responding to new health hazards in mountains and addressing human migration in response to adverse climatic and other environmental pressures.

Figure 11: **Ecoregions of the Eastern Himalayas and their relative vulnerability to climate change**

a. Ecoregions



b. Vulnerability of individual ecoregions



Research recommendations

The following are some of the most pertinent policy research needs identified by this assessment.

1. Carry out thorough research on ecosystem structures and functioning, productivity, and delivery of ecosystem goods and services, including piloting. Perform valuation of ecosystem services from biodiversity conservation areas together with an extensive assessment of the movement of climate sensitive and invasive species considering altitudinal and latitudinal aspects, protected area coverage and effectiveness, adaptability of biodiversity entities, and impact on agricultural productivity.

2. Conduct a detailed inventory of wetlands with quantitative data on their ecological characteristics, functions, and services, and assess the effects of temperature and enhanced CO_2 levels on growth, carbon sequestration, and methane emission in different types of wetland.

3. Conduct cross-sector, cross-boundary, and transdisciplinary research on climate change and its impacts on biodiversity and human wellbeing in this region including human health and its relationship with poverty and migration, and the implications for ecosystems.

4. Provide a set of climate change scenarios for the region to address the threats to ecosystems, biodiversity, and human wellbeing.

5. Undertake an assessment of people's vulnerability to natural hazards and document adaptation techniques to both beneficial and adverse impacts of climate change.

6. In future, design and develop programmes in the context of the vulnerability situations of the Eastern Himalayas based on the results of the assessment presented in this paper related to collective vulnerability, and specific vulnerabilities of biodiversity, water, ecosystems, human wellbeing, protected areas, and ecoregions.

7. 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.

References

Alam, M; Regmi, BR (2004) *Adverse impacts of climate change on development of Bhutan: Integrating adaptation into policies and activities. Working paper 3. Nepal CLACC (Capacity Strengthening in the Least Developed Countries (LDCs) for Adaptation to Climate Change),* p 38. Dhaka: International Institute for Environment and Development, and Bangladesh Center for Development Studies

Alam, M; Tshering, D (2004) *Adverse impacts of climate change on development of Bhutan: Integrating adaptation into policies and activities. Working Paper No.2 Bhutan CLACC (Capacity Strengthening in the Least Developed Countries (LDCs) for Adaptation to Climate Change),* p 38. Dhaka: International Institute for Environment and Development, and Bangladesh Center for Development Studies

Anderson, BJ; Akçakaya, HR; Araújo, MB; Fordham, DA; Martinez-Meyer, E; Thuiller, W; Brook, BW (2009) 'Dynamics of range margins for metapopulations under climate change'. *Proceedings of the Royal Society B* 276: 1415-1420

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

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

Beniston, M (2003) 'Climatic change in mountain regions: a review of possible impacts'. *Climate Change* 59: 5-31

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

Brooks, BW; Sodhi, NS; Ng, PKL (2003) 'Catastrophic extinctions follow deforestation in Singapore'. *Nature* 424(24): 420-423

Brooks, TM; Mittermeier, RA; da Fonseca, GAB; Gerlach, J; Hoffmann, M; Lamoreux, JF; Mittermeier, CG; Pilgrim, JD; Rodrigues, ASL (2006) 'Global biodiversity conservation priorities'. *Science* 313: 58-61

Carpenter, C (2005) 'The environmental control of plant species density on a Himalayan elevation gradient'. *Journal of Biogeography* 32: 999-1018

CEPF (2005) *Ecosystem profile: Indo-Burman Hotspot, Eastern Himalayan region*. Kathmandu: WWF, US-Asian Program/ Critical Ecosystem Partnership Fund (CEPF)

Chakravorty, AK (1951) 'Origin of cultivated banana of Southeast Asia'. *Indian Journal of Genetics* 11: 34-46

Chapin, FS III; Zavaleta, ES; Eviner, VT; Naylor, RL; Vitousek, PM; Reynolds, HL; Hooper, DU; Lavorel, S; Sala, OE; Hobbie, SE; Mack, MC; Díaz, S (2000) 'Consequences of changing biodiversity'. *Nature* 405: 234-242

Chase, TN; Sr Pielke, RA; Kittel, TGF; Nemani, RR; Running, SW (1999) 'Simulated impacts of historical land cover changes on global climate in northern winter'. *Climate Dynamics* 16: 93-105

Chaulagain, NP (2006) *Impacts of climate change on water resources of Nepal: The physical and socioeconomic dimensions*. MSc Thesis, University of Flensburg, Germany

Chettri, N; Sharma, E; Shakya, B; Bajracharya, B (2007) 'Developing forested conservation corridors in the Kangchenjunga Landscape, Eastern Himalaya'. *Mountain Research and Development* 27(3): 211-214

Chettri, N; Sharma, E; Shakya, B; Thapa, R; Sharma, M; Bajracharya, B; Uddin, K; Oli, KP; Dasgupta, J; Chaudhury, D (2008) *Biodiversity in the Eastern Himalaya: trends, perception and impacts of climate change,* Study Report, ICIMOD, Kathmandu

Christensen, JH; Hewitson, B; Busuioc, A; Chen, A; Gao, X; Held, I; Jones, R; Kolli, RK; Kwon, WT; Laprise, R; Magaña, RV; Mearns, L; Menéndez, CG; Räisänen, J; Rinke, A; Sarr, A; Whetton, P (2007) 'Regional Climate Projections'. In Solomon, S; Qin, D; Manning, M; Chen, Z; Marquis, M; Averyt, KB; Tignor, M; Miller, HL (eds) *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 and New York: Cambridge University Press

Cruz, RV; Harasawa, H; Lal, M; Wu, S; Anokhin, Y; Punsalmaa, B; Honda, Y; Jafari, M; Li, C; Huu, NN (2007) 'Climate change 2007: Impacts, adaptation and vulnerability'. In Parry, ML; Canziani, OF; Palutikof, JP; van der Linden, PJ; Hanson, CE (eds) *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* pp 469-506. Cambridge: Cambridge University Press

Daily, GC; Alexander, S; Ehrlich, PR; Goulder, L; Lubchenco, J; Matson, PA; Mooney, HA; Postel, S; Schneider, SH; Tilman, D; Woodwell, GM (1997) 'Ecosystem services: Benefits supplied to human societies by natural ecosystems'. *Issues in Ecology* 2: 1-16

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

Dhawan, NL (1964) 'Primitive maize in Sikkim'. *Maize Genetics Co-op Newsletter* 38: 69-70

Du, MY; Kawashima, S; Yonemura, S; Zhang, XZ; Chen, SB (2004) 'Mutual influence between human activities and climate change in the Tibetan plateau during recent years'. *Global and Planetary Change* 41: 241-249

Dyurgerov, MD; Meier, MF (2005) *Glaciers and changing Earth system: A 2004 snapshot*. Boulder: Institute of Arctic and Alpine Research, University of Colorado

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

Eriksson, M; Jianchu, X; Shrestha, AB; Vaidya, RA; Nepal, S; Sandström K (2009) *The changing Himalayas: Impact of climate change on water resources and livelihoods in the Greater Himalayas*. Kathmandu: ICIMOD

Fischer, G; Shah, M; van Velthuizen, H (2002) *Climate change and agricultural vulnerability, special report to the UN World Summit on Sustainable Development, Johannesburg 2002*. Laxenburg (Austria): Int'l Inst. for Applied Systems Analysis

Franco, AMA; Hill, JK; Kitschke, C; Collingham, YC; Roy, DB; Foxs, R; Huntley, B; Thomas, CD (2006) 'Impacts of climate warming and habitat loss on extinctions of species in low-latitude range boundaries'. *Global Change Biology* 12: 1545-1553

Gill, GJ (2003) Annex 7: *Food Security in Nepal*, http://www.odi.org.uk/publications/working paper/wp231/wp231-refrences.pdf ; http://id_cntre.apic.org/apic/influenza/avianflue/news/aug112005tibet.html

Gitay, H; Brown, S; Easterling, W (2001) 'Chapter 5. Ecosystems and their goods and services'. In McCarthy, JJ; Canziani, OF; Leary, NA; Dokken, DJ; White, KS (eds) *Climate change: Impacts, adaptations and vulnerability. Working Group II of the Third Assessment Report of the IPCC,* pp 235-342. Cambridge: Cambridge University Press

GoN/MoFSC (2006) *Sacred Himalayan Landscape - Nepal Strategic Plan (2006-2016) Broad strategy document*. Kathmandu: Ministry of Forest and Soil Conservation, Government of Nepal

Gopal, B; Wolfgang, J; Junk, CM; Finlayson, C; Breen, CM (2008) 'Present state and future of tropical wetlands'. In Polunin, N. (ed.) *Aquatic Ecosystems,* pp 141-154. Cambridge: Cambridge University Press, for the Foundation for Environmental Conservation

Goswami, BN; Venugopal, V; Sengupta, D; Madhusoodanan, MS; Xavier, PK (2006) Increasing trend of extreme rain events over India in a warming environment. *Science* 314: 1442-1444

Grabherr, G; Gottfriend, M; Pauli, H (1994) 'Climate Effects on Mountain Plants'. *Nature* 369: 448

Hamilton, LS (2002) 'Why mountain matters?' *World Conservation: The IUCN Bulletin* 1/2002

Hannah, L; Midgley, G; Andelman, S; Araújo, MI; Hughes, G; Martinez-Meyer, E; Pearson, R; Williams, P (2007) 'Protected area needs in a changing climate'. *Frontier in Ecology and Environment* 5(3): 131-138

Hickling, R; Roy, DB; Hill, JK; Fox, R; Thomas, CD (2006) 'The distributions of a wide range of taxonomic groups are expanding polewards'. *Global Change Biology* 12: 450-455

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

Houghton, RA; Hackler, JL; Lawrence, KT (1999) 'The U.S. carbon budget: Contributions from land-use change'. *Science* 285: 574-578

ICIMOD (2007) *Inventory of glaciers, glacial lakes and identification of potential glacial lake outburst flood (GLOFs) affected by global warming in the mountains of the Himalayan region* (DVD ROM). Kathmandu: ICIMOD

ICIMOD (2009) *Assessment of climate change vulnerability of the mountain ecosystems in the Eastern Himalayas: A synthesis report,* unpublilshed report submitted to MacArthur Foundation

ICIMOD; UNEP (2000) *Inventory of glaciers, glacial lakes and glacial lake outburst floods, monitoring and early warning systems in the Hindu Kush-Himalayan Region, Bhutan*. Kathmandu: ICIMOD

IPCC (2007a) *Climate change 2007: The physical science basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S; Qin, D; Manning, M; Chen, Z; Marquis, M; Averyt, KB; Tignor, M; Miller, HL (eds)]. Cambridge and New York: Cambridge University Press

IPCC (2007b) *Climate change 2007: impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, ML; Canziani, OF; Palutikof, JP; van der Linden, PJ; Hanson, CE (eds)]. 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 Publishing Group

Jain, A; Rai, SC; Sharma, E (2004) 'Terrestrialization of a peat lake in the Sikkim Himalaya, India'. *International Peat Journal* 12: 119-132

Kishan, K (2007) *Climate change and the right to development – Himalayan glacial melting and the future of development on the Tibet Plateau, Human Development Report 2007/2008, Fighting climate change: Human solidarity in a divided world*, Human Development Report Office, occasional paper, UNDP

Kollmair, M; Gurung, GS; Hurni, K; Maselli, D (2005) 'Mountains: Special places to be protected? An analysis of worldwide nature conservation efforts in mountains'. *International Journal of Biodiversity Science and Management* 1: 1-9

Korner, C (2004) 'Mountain biodiversity, its causes and function'. *Ambio Supplement* 13: 11-17

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

Lal, M; Singh, KK; Rathore, LS; Srinivasan, G; Saseendran, SA (1998) 'Vulnerability of rice and wheat yields in north-west India to future changes in climate'. *Agricultural and Forest Meteorology* 89: 101-114

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

Liu, X; Chen, B (2000) Climatic warming in the Tibetan Plateau during recent decades. *International Journal of Climatology* 20: 1729-1742

MA (Millennium Ecosystem Assessment) (2005) *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press

MA (Millennium Ecosystem Assessment) (2003) *Ecosystems and human well-being: A framework for assessment*. Washington, DC: Island Press

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

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

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

Messerli, B; Ives, JD (2004) *Mountains of the world: A global priority*. New York and London: Parthenon Publishing Group

Michmerhuizen, CM; Striegl, RG (1996) 'Potential methane emission from north-temperate lakes following ice melt. *Limnology and Oceanography* 41: 985-991

Mool, PK; Wangda, D; Bajracharya, SR; Kunzang, K; Gurung, DR; Joshi, SP (2001) *Inventory of glaciers, glacial lakes, and glacial lake outburst floods: Monitoring and early warning systems Hindu Kush-Himalayan region: Bhutan*. Kathmandu: ICIMOD

Myers, N; Mittermeier, RA; Mittermeier, CG; da Foseca GAB, KJ (2000) 'Biodiversity hotspots for conservation priorities'. *Nature* 403(24): 853-858

New, M; Lister, D; Hulme, M; Makin, I (2002) 'A high-resolution data set of surface climate over global land areas'. *Climate Research* 21: 1-25

Nogues-Bravo, D; Araujo, MB; Errea, MP; Martınez-Rica, JP (2007) 'Exposure of global mountain systems to climate warming during the 21st Century'. *Global Environmental Change* 17:420-428

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

Pandit, MK; Sodhi, NS; Koh, LP; Bhaskar, A; Brook, BW (2007) 'Unreported yet massive deforestation driving loss of endemic biodiversity in Indian Himalaya. *Biodiversity Conservation* 16: 153-163

Pathak, D; Gajurel, AP; Mool, PK (2008) *Climate change impacts on hazards in the Eastern Himalaya: Assessment of climate change vulnerability of the mountain ecosystems of the Eastern Himalaya,* Study Report, ICIMOD, Kathmandu

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

Peterson, AT (2003) 'Projected Climate Change Effects on Rocky Mountain and Great Plains Birds: Generalities of Biodiversity Consequences'. *Global Change Biology* 9: 647-655

Pimm, S; Raven, P; Peterson, A; Sekercioglu, CH; Ehrlich, PR (2006) 'Human impacts on the rates of recent, present, and future bird extinctions'. *Proceedings of the National Academy of Sciences of the USA* 103: 10941-10946

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; Schroter, D; Patt, A; Gaffin, S; Martello, ML; 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

Pounds, AJ; Bustamante, MR; Coloma, LA; Consuegra, JA; Fogden, MPL; Foster, PN; Marca, EL; Masters, KL; Merino-Viteri, A; Puschendorf, R; Ron, SR; Sanchez-Azofeifa, GA; Still, CJ; Young, BE (2006) 'Widespread amphibian extinctions from epidemic disease driven by global warming'. *Nature* 439: 161-167

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, K V; Goswami, P (2007) 'Reduction in temporal and spatial extent of the Indian summer monsoon'. *Geophysics Research Letters* 34 (23): L23704

Rao, RR; Murti, SK (1990) 'North-east India: A Major Centre for Plant Diversity in India'. *Indian Journal of Forest* 13 (3): 214-222

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

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

Sala, OE; Chapin, FS; Armesto, J; Berlow, E; Bloomfield, J; Dirzo, R (2000) 'Global biodiversity scenarios for the year 2100'. *Science* 287: 1770-1774

Schild, A (2008) 'The case of the Hindu Kush-Himalayas: ICIMOD's position on climate change and mountain systems'. *Mountain Research and Development* 28(3/4): 328-331

Schickhoff, U (2005) 'The upper timberline in the Himalayas, Hindu Kush and Karakorum: A review of geographical and ecological aspects'. In: Broll, G; Keplin, B (eds) *Mountain Ecosystems. Studies in Treeline Ecology,* pp 275-354. Berlin: Springer

Schroter, D; Cramer, W; Leemans, R; Prentice, IC; Arau´jo, MB; Arnell, NW; Bondeau, A; Bugmann, H; Carter, TR; Garcia, CA; de la Vega-Leinert, AC; Erhard, M; Ewert, F; Glendining, M; House, JI; Kankaanpa¨a¨, S; Klein, RJT; Lavorel, S; Lindner,M; Metzger,MJ; Meyer, J; Mitchell ,TD; Reginster, I; Rounsevell, M; Sabate,´ S; Sitch, S; Smith, B; Smith, J; Smith, P; Sykes, MT; Thonicke, K; Thuiller, W; Tuck, G; Zaehle, S; Zierl, B (2005) 'Ecosystem service supply and human vulnerability to global change in Europe'. Science 310: 1333-1337

Sekercioglu, CG; Schneider, SH; Fay, JP; Loarie, SR (2008) 'Climate change, elevational range shifts, and bird extinctions'. *Conservation Biology* 22 (1): 140-150

Sharma, E; Chettri, N; Gurung, J; Shakya, B (2007) *Landscape approach in biodiversity conservation: A regional cooperation framework for implementation of the Convention on Biological Diversity in Kangchenjunga Landscape.* Kathmandu: ICIMOD

Sharma, KP (2003) 'Impact of climate change on water resources of Nepal'. In *Proceedings of the consultative workshop on climate change impacts and adaptation options in Nepal's hydropower sector with a focus on hydrological regime changes including GLOF,* 5-6 March 2003, Kathmandu. Kathmandu: Department of Hydrology and Meteorology and Asian Disaster Preparedness Centre,

Sharma, KP; Adhikari, NR; Karbuja, RG (2002) *Vulnerability and adaptation of water resources to climate changes in Nepal*. Interim report prepared for the United Nations Framework Convention on Climate Change (UNFCCC) Initial National Communication, Central Department of Hydrology and Meteorology, Tribhuvan University, Kathmandu

Shrestha, AB (2004) 'Climate change in Nepal and its impact on Himalayan glaciers'. In Hare, WL; Battaglini, A; Cramer, W; Schaeffer, M; Jaeger, C (eds) *Climate hotspots: Key vulnerable regions, climate change and limits to warming,* Proceedings of the European Climate Change Forum Symposium. Potsdam: Potsdam Institute for Climate Impact Research

Shrestha, AB; Wake, CP; Dibb, JE; Mayewski, PA (2000) 'Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters'. *International Journal of Climatology* 20: 317-327

Shrestha, AB; Wake, CP; Mayewski, PA; Dibb, JE (1999) 'Maximum temperature trend in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971-94'. *Journal of Climate* 12: 2775-2786

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

Sodhi, NS; Koh, LP; Brook, BW; Ng, PKL (2004) 'Southeast Asian biodiversity: The impending disaster'. *Trends in Ecology and Evolution* 19: 654-660

Takhtajan, A (1969) *Flowering plants: origin and dispersal*. Edinburgh: Oliver and Body

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

Thuiller, W; Albert, C; Araujo, MB; Berry, PM; Cabezad, M; Guisan, A; Hickler, T; Midgley, GF; Paterson, J; Schurr, FM; Sykes, MT; Zimmerman, NE (2008) 'Predicting global change impacts on plant species' distributions: Future challenges'. *Perspectives in Plant Ecology, Evolution and Systematics* 9: 137-152

Tong, SL; Ying, LV (2000) 'Global Climate Change and Epidemic Disease'. *Journal of Disease Control* 4(1): 17-19

van Dam, R; Gitay, H; Finlayson, CM (2002) *Climate change and wetlands,* Ramsar COP8 Doc 11. Geneva: Ramsar Secretariat

Vitousek, PM; Mooney, HA; Lubchenco, J; Melillo, JM (1997) 'Human domination of Earth's ecosystems'. *Science* 277: 494-499

Viviroli, D; Weingartner, R (2004) 'Hydrological significance of mountains: From regional to global scale'. *Hydrological Earth Systems Science* 8(6): 1016-1029

Wikramanayake, E; Dinerstein, E; Loucks, CJ; Olson, DM; Morrison, J; Lamoreus, JL; McKnight, M; Hedao, P (2002) *Terrestrial ecoregions of the Indo Pacific: A conservation assessment.* Washington DC: Island Press

Williams, PH; Moore, JL; Toham, AK; Brooks, TM; Strand, H; D'Amico, J; Wisz, M; Burgess, ND; Balmford, A; Rahbek, C (2003) 'Integrating biodiversity priorities with conflicting socio-economic values in the Guinean-Congolian forest region'. *Biodiversity and Conservation* 12: 1297-1320

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

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

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

WWF; ICIMOD (2001) *Ecoregion-based conservation in the Eastern Himalaya: Identifying important areas for biodiversity conservation*. Kathmandu: WWF Nepal

Xu Jianchu; 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

Xu Jianchu; Grumbine, ER; Shrestha, A; Eriksson, M; Yang, X; Wang, Y; Wilkes, A (2009) 'The melting Himalayas: Cascading effects of climate change on water, biodiversity, and livelihoods'. *Conservation Biology* 23(3):520-530

Yao, TD; Guo, XJ; Lonnie, T; Duan, KQ; Wang, NL; Pu, JC; Xu, BQ; Yang, XX; Sun, WZ (2006) 'δ18O record and temperature change over the past 100 years in ice cores on the Tibetan Plateau'. *Science in China: Series D Earth Science* 49(1): 1-9

Acknowledgements

ICIMOD expresses its sincere thanks and gratitude to its regional member countries for their extended support during this study. ICIMOD acknowledges the MacArthur Foundation for supporting the initiative by funding the project and GTZ for co-financing through ECES programme funding. More importantly, the Centre acknowledges the support of all the experts, researchers, and authors who have contributed to the technical papers and helped to strengthen the understanding of the potential impact of climate change on biodiversity and other natural resources in the Eastern Himalayas. In addition ICIMOD is grateful for the assistance provided by the different government agencies, and partners from the RMCs, NGOs, and INGOs, all of whom contributed to developing this valuable information resource.

The assessment team was comprised of Karma Tse-ring, Rita Sharma, Eklabya Sharma, Mats Eriksson, Arun Shrestha, Nakul Chettri, Pradeep Mool, Birendra Bajracharya, Jing Fang, Bandana Shakya, Rajesh Thapa and Rajendra Shilpakar. Technical contributions were received from Dhrupad Choudhury, Manisha Sharma, Kabir Uddin, Krishna P Oli, Joy Dasgupta, Brigitte Leduc, Anupa Lamichhane (all ICIMOD); LP Devkota, D Pathak, AP Gajurel (all Tribhuvan University, Nepal); Kamal Raj Rai (Namsaling Community Development Center, Ilam, Nepal); Nitesh Shrestha and Janita Gurung (both Nepal); Karpo Dukpa (Ministry of Agriculture, Policy and Planning Division, Bhutan); AK Gosain (Indian Institute of Technology, New Delhi, India); Brij Gopal (National Institute of Ecology, New Delhi, India); and SK Barik (North Eastern Hill University, Shillong, India).

Inside front photo: Bhutan, Alex Treadway

Production team
Susan Sellars-Shrestha (Consultant editor)
A Beatrice Murray (Senior editor)
Dharma R. Maharjan (Layout and design)
Punam Pradhan (Layout and design)
Gauri S. Dangol (Map layout)
Asha Kaji Thaku (Editorial assistant)

Printed by Quality Printers (P) Ltd., Kathmandu, Nepal

Publication details

Published by International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Nepal

ISBN 978 92 9115 134 9 (printed)
978 92 9115 136 3 (electronic)

LCCN 2009-341528

This publication is available in electronic form at www.books.icimod.org.

Citation: 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

About ICIMOD

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.

About MacArthur Foundation

The MacArthur Foundation supports creative people and effective institutions committed to building a more just, verdant, and peaceful world. In addition to selecting the MacArthur Fellows, the Foundation works to defend human rights, advance global conservation and security, make cities better places, and understand how technology is affecting children and society.

International Centre for Integrated Mountain Development
GPO Box 3226, Kathmandu, Khumaltar, Lalitpur, Nepal
Tel +977-1-5003222 **email** info@icimod.org www.icimod.org

ISBN 978 92 9115 134 9