Climate Change Impact and Vulnerability in the Eastern Himalayas – Technical Report 2

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FOR MOUNTAINS AND PEOPLE

Biodiversity in the Eastern Himalayas: Status, Trends and Vulnerability to Climate Change

MacArthur Foundation

Biodiversity in the Eastern Himalayas: Status, Trends and Vulnerability to Climate Change

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Introduction

Mountain biodiversity and climate change

Mountains are amongst the most vulnerable and hazardous environments in the world: they also harbour rich repositories of biodiversity. Water and other natural resources are supplied to the lowlands through ecosystem services. Some of the world's most threatened and endemic species are found in mountain areas. The people who live in the mountains are dependent on the biological resources, and face increasing poverty.

Mountains have been recognised as important ecosystems by the Convention on Biological Diversity (CBD) and its special programme on 'mountain biodiversity' which aims to reduce the loss of biological diversity in the mountains at global, regional, and national levels by 2010. There are enormous impediments to this because of various drivers of global change, including climate change (Nogues-Bravo et al. 2007). In the context of climate change, mountains could suffer wide-ranging environmental and socioeconomic impacts, for example on the hydrological cycle, and this in turn would alter the distribution, seasonality, and amount of precipitation and result in changes in river runoff, ultimately affecting not only mountain watersheds but also the lowlands below (Beniston 2003).

There is an evident interconnectedness between climate change and biodiversity, not just in the impacts of climate change on biodiversity but also in concomitant changes occurring in the carbon and water cycles. The Millennium Ecosystem Assessment (MEA) identified climate change as one of the major drivers having adverse affects on biodiversity and associated goods and services (MEA 2005). Studies on climate change in mountain areas are incomplete and scattered (IPCC 2007, Nogues-Bravo et al. 2007),although certain studies from the Hindu Kush-Himalayas (Shrestha et al. 1999; Liu and Chen 2000) do indicate that climate change has an undesirable impact on Himalayan biodiversity and its services. Yet, although there is a global effort to understand the biodiversity and climate change nexus, research in the Hindu Kush-Himalayan region has been limited. To rectify this, the International Centre for Integrated Mountain Development (ICIMOD) with support from the MacArthur Foundation undertook a review of 'Climate Change and Vulnerability of Mountain Ecosystems in the Eastern Himalayas' to produce a state-of-the- art report. This technical report on biodiversity reviews the current status of biodiversity, threats to it, and the impact of climate change on and vulnerability of biodiversity in the Eastern Himalayas.

The Eastern Himalayas

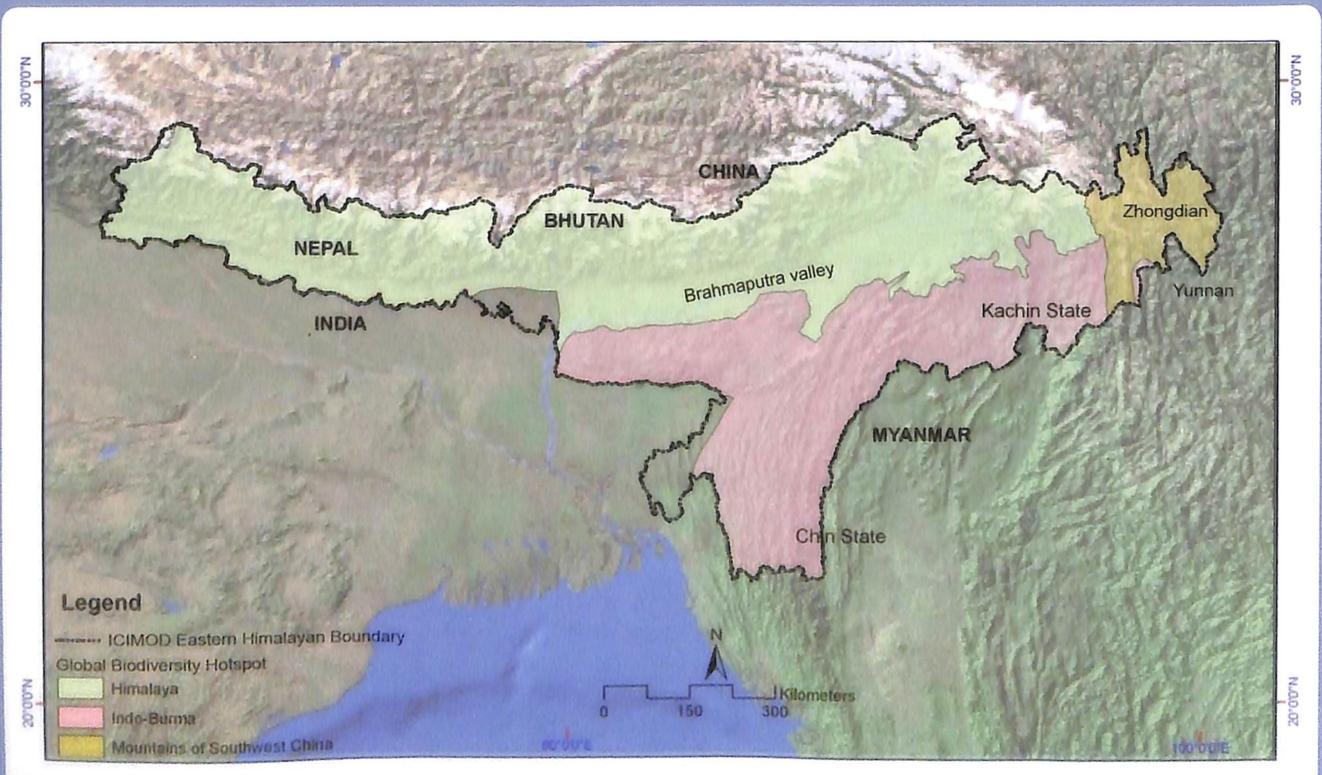
The Eastern Himalayas (EH hereafter) are counted in the 'crisis ecoregions'; 'biodiversity hotspots'; 'endemic bird areas'; 'mega diversity countries'; and 'global 200 ecoregions' (Brooks et al. 2006). The region is also a meeting ground for the Indo-Malayan, Palaearctic, and Sino-Japanese biogeographical realms with diverse ecological and altitudinal gradients and an associated diversity of flora and fauna (CEPF 2005; 2007). Furthermore, the forests of the EH sustain many rivers which are the lifeline for provinces and countries downstream. These rivers and landscapes provide valuable goods and services not only by providing water and biodiversity, but also by providing services such as soil retention, climate regulation, carbon sequestration, and providing reservoirs of pollinators, natural predators, and others. The welfare of millions of people downstream is inextricably linked with the natural resources of the EH.

Geographically, the EH is sandwiched between the two densely populated nations of China and India, both of which have massive demands for resources to fuel economic transformation. Fragmentation of ecosystems is evident as the region faces pressure from migration, economic development, and population growth as well as from climate change (Beniston 2003). Threats to biodiversity from climate change could be acute in the EH which are rich in endemic species that have narrow and restricted ranges of distribution (Root et al. 2003): fragmentation and loss of habitat are already threatening the survival of some endemic species such as golden langur (*Trachypithecus geei*).

Whereas people in the mountain region would be directly affected by changes in climate, there would also be impacts on river basins downstream and eventually the impacts would have global consequences (Malcolm et al. 2006). According to the Intergovernmental Panel on Climate Change (IPCC), at the current rate of climate change, even the most stringent mitigation efforts would be ineffective in counteracting all its negative impacts (IPCC 2007). As yet, there are no concrete studies assessing the magnitude of future warming and its impact on biological resources in the EH, although considerable efforts have been undertaken to conserve the region's unique biodiversity.

The EH region, which is the focus of ICIMOD's work, lies between 82.70°E and 100.31°E longitude and between

Figure 1: **Extent of Eastern Himalayan boundary and ICIMOD's work focus**



21.95°N and 29.45°N latitude and covers a total area of 524,190 sq.km (Figure 1). It extends from the Koshi Valley in Central Nepal to northwest Yunnan in China and includes Bhutan, North East India, Sikkim and the Darjeeling hills of west Bengal, southeast Tibet in China, and northern Myanmar.

Three biogeographical realms meet in the EH Region; namely, the Indo-Malayan, Palaearctic, and Sino-Japanese, and it contains parts of three of 34 global biodiversity hotspots, accounting for 39% of the Himalayan hotspot, 8% of the Indo-Burma hotspot, and 13% of the Mountains of Southwest China hotspot. The complex topography and extreme altitudinal gradients from less than 300 m (tropical lowlands) to more than 8,000 m (high mountains) have led to a variety of vegetation patterns. The geographic complexity exerts considerable influence on the weather patterns in the region, in many instances creating microclimatic conditions that lead to formation of unique assemblages of vegetation and wildlife (Chettri et al.2001). The Himalayan range in the north acts as a barrier to the southwest monsoon from the Bay of Bengal, causing the moisture regime to decrease towards the western side, whereas comparatively more rain is received in the east. Elements of Indo-Chinese subtropical forest are a result of the summer monsoon, which falls from May to September, and of dry conditions from November to March. Climate-dependent vegetation can be found depending on decreasing moisture and increased elevations, for example, tropical seasonal rainforests, tropical montane rainforests, evergreen broadleaved forests, distinctive monsoon forests over limestone from which water is quickly lost, and monsoon forests on river banks where water is available throughout the year. The complex mountain topography creates diverse bioclimatic zones (near tropical, subtropical, lower temperate, upper temperate, subalpine evergreen, alpine evergreen, and alpine shrubs and meadows) and island conditions for many species and populations that are isolated reproductively, thus creating genetic differences among populations and an exceptionally rich assemblage of biodiversity.

Current Status of Biodiversity Resources

Bioclimatic zones and vegetation types

Forest and vegetation are important components of land cover and a climatic expression of biodiversity in terms of spatial coverage. The EH region, with diverse climatic conditions and complex topography, has different types of forest and vegetation. Strict compartmentalisation does not exist in nature and certain parameters such as physiognomy, structure, floral composition, habitat conditions, physiography, and functions have to be considered in classifying vegetation types. Broadly, vegetation types in the EH can be categorised into a) tropical, b) sub-tropical, c) warm temperate, d) cool temperate, e) sub-alpine and f) alpine types (Figure 2).

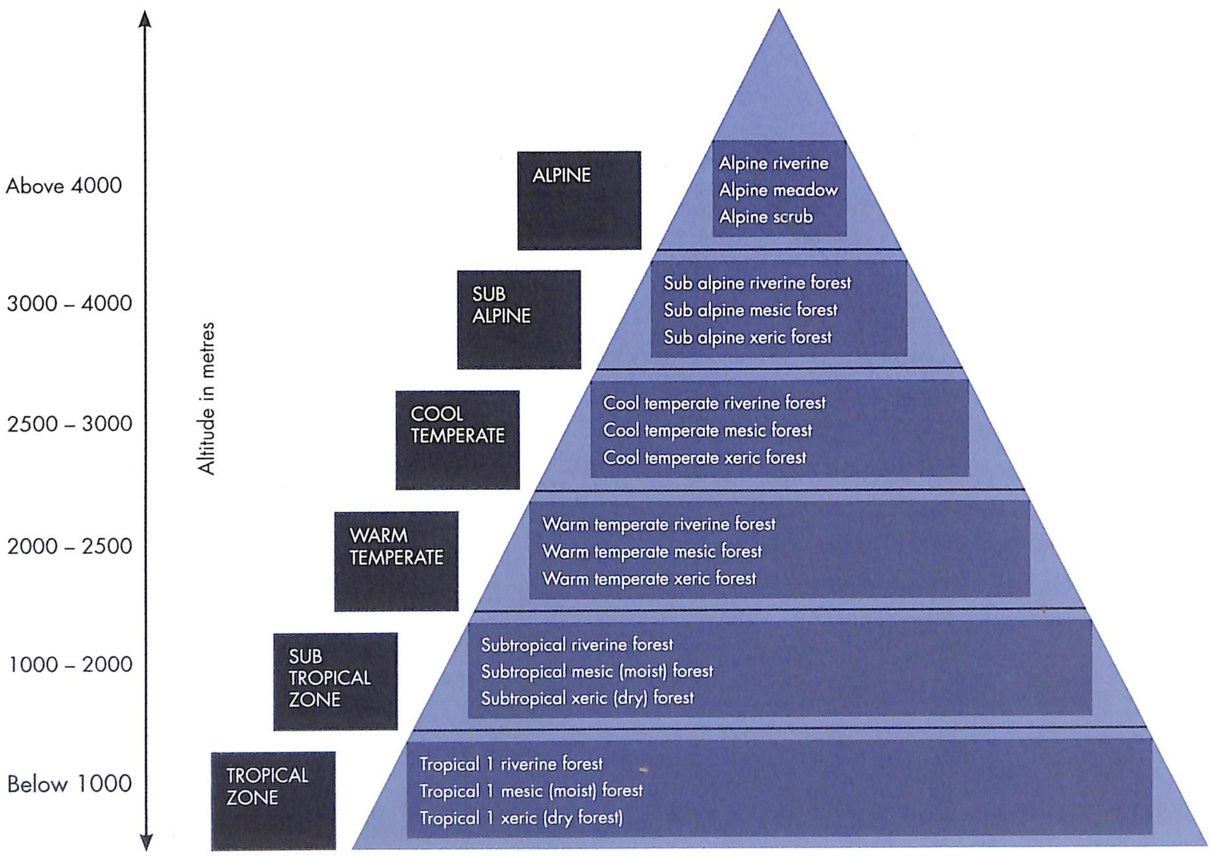
Taxonomic diversity

Several factors contribute to the significant assemblage of unique flora and fauna (WWF and ICIMOD 2001; Guangwei 2002) and exceptional biological diversity in the EH. The Indo-Malayan realm of Southeast Asia contributes many of the tropical taxa whereas the Palaearctic realm brings plant species to the higher elevations in the north. In addition, climatic variability, a result of complex and steep topography across the north-south axis of the Himalayan range, leads to heterogeneity, diverse habitats, and ecosystems that enrich the region with beta and gamma diversity across a vast landscape (Chettri et al. 2009). A recent review by the Critical Ecosystem Partnership Fund (CEPF) revealed that the EH region is home to a number of globally significant mammals (45 species), birds (50 species), reptiles (16 species), amphibians (12 species), invertebrates (2 species), and plants (36 species), and the majority of them, about 144 species, are found in the North Eastern states of India in particular (CEPF 2005).

Floral diversity

The EH region supports one of the world's richest alpine flora; and about one-third of them are endemic to the region (Dhar 2002). There are at least 7,500 flowering plants, 700 orchids, 58 bamboo species, 64 citrus species, 28 conifers, 500 mosses, 700 ferns, and 728 lichens. According to the World Wide Fund for Nature (WWF) and ICIMOD (2001), the temperate broadleaved forests in the region are among the most species' rich temperate forests in the world. Nearly 50% of the total flowering plants recorded in India are from the northeastern region. Takhtajan (1969) regarded the EH as the 'cradle of flowering plants.' The region is well known also for its botanically curious and rare species such as *Sapria himalayana* of the family Rafflesiaceae, discovered in Arunachal Pradesh. There are about 700 species of orchids in the northeastern region of India alone. Of these, 545 species belonging to 122 genera are restricted to Arunachal Pradesh (Chowdhery 1998). Among these, 12 species are endangered, 16 are vulnerable, and 31 are near threatened. Rattan, commonly known as cane, is another species of significance, and the most important non-timber forest

Figure 2: **Altitudinal zonations and dominant forest types found across the Eastern Himalayas**



product (NTFP) in North East India. About 26 species of rattan and 63 species of bamboo are found in North East India, and 25 of the bamboo species are extremely rare (Thomas et al. 1998). The genus Rhododendron of the Ericaceae family is another remarkable group of showy plants with nearly 98% of them being confined to the EH and a substantial number of species being endemic to Arunachal Pradesh, Manipur, Sikkim, and Mizoram (Pradhan and Lachungpa 1990). In addition, families such as Coriariaceae, Nepenthaceace, Turneraceae, Illiciaceae, Ruppiaceae, Siphonodontaceae, Tetracentraceae are each represented by a solitary genus with one or two species (Rao and Murti 1990).

The EH region is rich in endemic flora and many species are used as medicinal or edible plants; for example, *Saussurea obvallata, Nardostachys jatamansi, Neopicrorhiza scrophulariiflora, Aconitum heterophyllum, Circaeaster agrestis,* and *Paris polyphylla* (Sundriyal 1999). Among the insectivorous plants, *Nepenthes khasiana*, which is endemic to Meghalaya, is listed in Appendix I of the Convention on International Trade in Endangered Species (CITES) and placed in Schedule VI of the Wildlife (Protection) Act, 1972. Shrestha (1999) mentioned many focal, subtropical endemic trees from the EH region of Nepal; one example being the *Homalium napaulense* occurring near river courses. Other endemic species from Nepal are *Swertia multicaulis*, a high-altitude medicinal herb; *Cyathea spinulosa* a tree-fern growing in humid gorges; the curious *Saussurea gossypiphora* found at 4,000 m; and the very rare *Tetracentron sinense* found in the temperate deciduous forest of eastern Nepal and which is in considerable need of conservation.

Faunal diversity

Faunal diversity is relatively better documented than floral diversity. Notwithstanding, most of the information available is on vertebrates, mainly large mammals (Borang and Thapliyal 1993; Avasthe and Jha 1999; Gupta 2001; Chetry et al. 2003; Mishra et al. 2006) and birds (Chettri et al. 2001; Choudhury 2003; Birand and Pawar 2004; Barua and Sharma 2005). Small mammals, reptiles, amphibians, and fish have been much less studied, although they form the most abundant taxonomic group, and insects have been virtually ignored. In the recent past, studies on Lepidoptera (Mani 1986, Haribal 1992, Yonzon 1991) reptiles, and amphibians (Pawar et al. 2007) have taken place. Overall, the EH region is home to many globally significant animal species (CEPF 2005): the Indo-Burma hotspot alone is home to approximately two per cent of global endemic vertebrates (Myers et al. 2000). One hundred and seventy-five species of mammal and over 500 species of bird are known from the region (WWF and ICIMOD 2001). Among these 175 vertebrates, 45 are threatened among which 14 are endangered, 29 vulnerable, and two are critically rare (CEPF 2005).

Because the Himalayas are of relatively recent origin, fauna endemism is low, especially among the better-known higher taxonomic groups. There are altogether 28 endemic mammals recorded in the EH and these are distributed among 14 ecoregions, of which 18 are strictly endemic to their respective ecoregion types (Table 1). The golden langur (*Trachypithecus geei*) is restricted to the patch of semi-evergreen and tropical forest on the northern bank of the Brahmaputra River between the Sankosh and Manas rivers which flow south from the mountains. The pygmy hog (*Sus salvanius*) and hispid hare (*Caprolagus hispidus*) are restricted to the alluvial grasslands and the Namdapha flying squirrel (*Biswamoyopterus biswasi*) is restricted to the temperate broadleaved forests of the region. Endemism among birds in the region is higher than that among mammals. Some species restricted to the region include the Manipur bush quail (*Perdicula manipurensis*), chestnut-breasted partridge (*Arborophila mandellii*), Blyth's tragopan (*Tragopan blythii*), Temminck's tragopan (*Tragopan temminckii*), Sclater's monal (*Lophophorus sclateri*), Tibetan-eared pheasant (*Crossoptilon harmani*), and rusty-bellied shortwing (*Brachypteryx hyperythra*).

Recently 353 species were discovered in the EH (Thomson 2009) among them a new bird – Bugun liocichla (*Liocichla bugunorum*) – by Mishra and Dutta (2007); two new species of Arunachal macaque (*Macaca munzala*) by Sinha et al. (2005); and a Tibetan macaque (*Macaca thibetana*). In addition, a new species of Ranid frog (*Paa annandalii*) was discovered by Bordoloi et al. (2001); and two new fish species in Arunachal Pradesh by Tamang et al. (2007). Range extensions of the Chinese goral (*Nemorhaedatus caudatus*) and leaf deer (*Muntiacus putaoensis*) have also been recorded as cited by Chatterjee et al. (2006). All of these highlight the need for more extensive research and systematic documentation of biodiversity in the EH.

Agrobiodiversity

Most people living in the EH depend on agriculture and agroforestry for their livelihoods. Based on the agro-climatic zones and farming practices, the EH can be categorised broadly into five major systems and, in each of these specialised systems, there are variations in crops

Table 1: **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. (2001)

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

and cropping patterns (Table 2). Each farming system supports a wide range of agrobiodiversity which is the source of food, nutrients, and economic wellbeing. In addition, the EH region is also known as the 'centre of origin of cultivated plants' as original locations of over 50 important tropical and sub-tropical fruits, cereals, and rice are in this region (Vavilov 1926; Chakravorty 1951; Dhawan 1964; Hore 2005): in addition, out of an estimated 800 species used for food in India, about 300 species occur in North East India alone (Rao and Murti 1990).

Ecosystem diversity

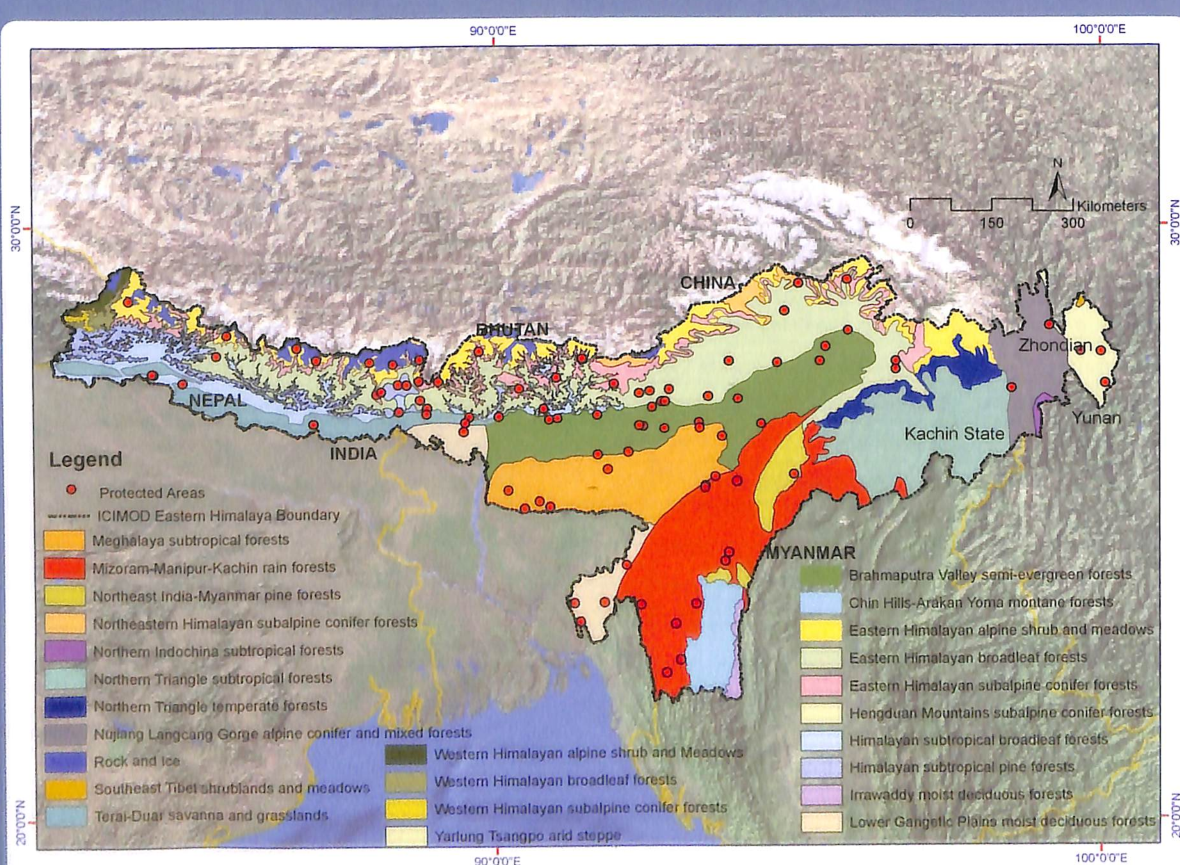
Myers (1988) brought the EH region into the limelight in terms of global conservation by including it among the Global Biodiversity Hotspots (GBH). The EH region within its boundary of 524,190 sq.km includes three of the 34 global biodiversity hotspots. According to the global ecoregion analysis (WWF 2006), there are 25 ecoregions within the EH boundary, among which 12 are spread across the Himalayan hotspots, eight in the Indo-Burma, and five in the Mountains of Southwest China (Figure 3). Among these, four are Global 200

Table 2: **The major agro-farming systems and crops cultivated in the Eastern Himalayas**

Major agro-farming systems	Specialised practices	Specialised crops/products
Specialised pastoralism	Purely livestock-based, high-altitude transhumance subsistence livelihoods	Sheep, yak, cattle, and milk products
Mixed mountain agro-pastoralism	Livestock, agriculture, and agroforestry-based midhill livelihood	Cereals, maize, potatoes, vegetables, goats, cattle, and milk products
Cereal-based hill farming system	Agriculture-based low and midhill livelihoods	Rice, maize, cereals, potatoes, vegetables, goats, cattle, and milk products
Shifting cultivation	Livelihoods based on rotational agroforestry with slash and burn practices	Rice, maize, cereals, vegetables, and spices
Specialised commercial system	Livelihoods based on monoculture and other commercial crops	Tea and large cardamom

Source: Sharma and Kerkhoff (2004)

Figure 3: **Ecoregions and protected area distribution in the Eastern Himalayas**



Ecoregions found within the EH boundary, therefore they are quite significant in terms of conservation and have been well covered under the PA network (Figure 3). Within the ecoregions (WWF and ICIMOD 2001) are 175 key biodiversity areas and five landscape complexes (Terai Arc Landscape, the Bhutan Biological Conservation Complex, the Kangchenjunga-Singhalila Complex, the Kaziranga-Karbi Anlong Landscape, and the North Bank Landscape), which are of great significance in the context of conservation (CEPF 2005).

Climate-Change Scenario, Threats, Vulnerabilities and Potential Impacts on Biodiversity

Climate-change trends and projections

The Himalayan region, including the Tibetan Plateau, has shown consistent warming trends during the past 100 years (Yao et al. 2006). Current knowledge of the climatic characteristics of the EH region, however, is limited by both paucity of observation and the insufficient theoretical attention given to the complex interaction of spatial scales in weather and climate phenomena in mountain areas. Despite these limitations, studies of the 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 EH region in part or as a whole.

Our analysis of spatial distribution of annual and seasonal temperature trends is illustrated in Figure 4 (Shrestha and Devkota 2010). It is clear that most of the region is undergoing warming trends. The annual mean temperature is increasing at the rate of 0.01°C/yr or more. In general, for annual and seasonal trends there is a diagonal zone with a southwest to northeast trend of relatively less or no warming. This zone encompasses the Yunnan Province of China, part of the Kachin State of Myanmar, and the northeastern states of India and Assam. The zone to the upper left (Figure 4), which includes eastern Nepal and eastern Tibet AR of China, shows relatively greater warming trends. Though warming in the winter (DJF) is much greater and more widespread in area, the warming trend has been greatest during the post-monsoon season and at high elevations. The analysis shows progressively greater warming rates with increasing elevation (Table 3). The zone where warming is less is significantly small and limited to Yunnan and Arunachal Pradesh. The past trend 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 EH region do not present a drastic deviation from the IPCC outcomes for South Asia; they reinforce the scientific basis for the contention that the EH region is undergoing a warming trend (Sharma et al. 2009).

Table 3: **Temperature trends by elevation zones for the period from 1970-2000 (°C per year)**

	Annual	DJF	MAM	JJA	SON
Level 1: (<1 km)	0.01	0.03	0.00	-0.01	0.02
Level 2: (1 km-4km)	0.02	0.03	0.02	-0.01	0.02
Level 3: (>4 km)	0.04	0.06	0.04	0.02	0.03

Source: Sharma et al 2009

The analysis of the region suggests the following.

- The Eastern Himalayas are experiencing widespread warming and the rate is generally greater than 0.01°C per year.
- Using usual seasonal dichotomies, the highest rates of warming are in winter and the lowest, or even cooling, are in summer.
- There is progressively more warming with elevation, with areas higher than 4,000 m experiencing the greatest warming rates.

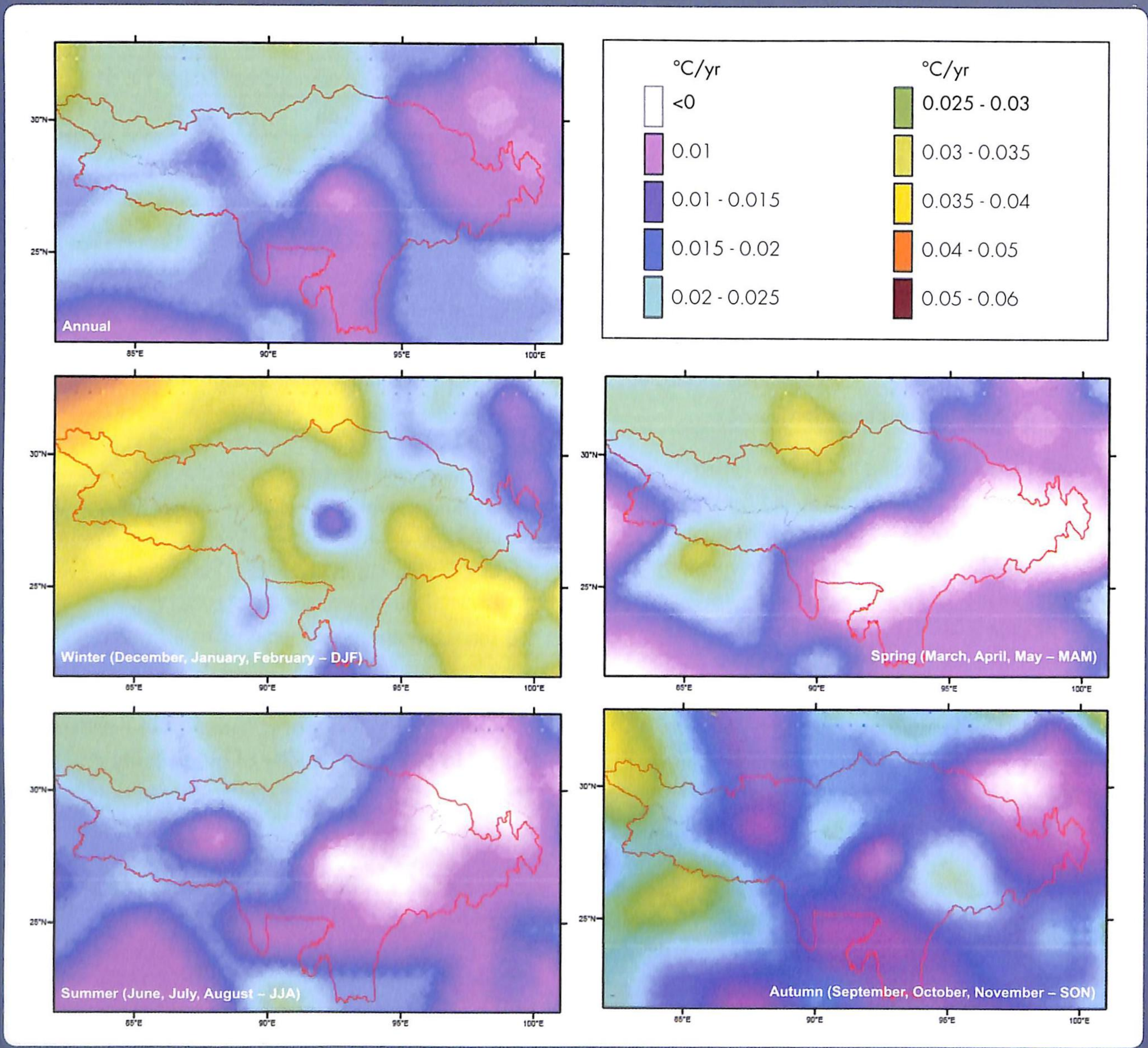
Threats to and vulnerability of biodiversity

Assessing the consequences of climate change in the EH region is indeed a big challenge mainly due to limited data availability, uncertainties associated with the climate scenarios, and the existence of non-linear feedbacks between impacts. Nevertheless, through various review and consultative processes we have focused on some thematic indicators such as land-use and land-cover change, critical habitats and ecoregions, bioclimatic zones and phenology, agrobiodiversity, and threatened and endemic species, that throw light on the potential impacts and vulnerabilities of biological diversity due to climate change.

Land-use and land-cover changes

Changes in land cover (biophysical attributes of the earth's surface) and land use (human purpose or intent applied to these attributes) are among the most important drivers of climate change as they relate to carbon sequestration and nitrogen deposition (Lal 2004; Foley et al. 2005). Land-use and land-cover changes contribute to local and regional climate changes (Chase et al. 1999) and global climate warming (Penner et al. 1994; Houghton et al. 1999); and they have a direct impact on biodiversity (Chapin et al. 2000; Sala et al. 2000), influencing the reduction in species' diversity (Franco

Figure 4: **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.)



et al. 2006). These changes also affect the ability of biological systems to support human needs (Vitousek et al. 1997). Such changes also determine, in part, the vulnerability of places and people to climatic, economic, or sociopolitical changes (Kasperson et al. 1995).

There are several enumerations on land use and land cover from the EH (Champion and Seth 1968, NARMSAP 2002; Gautam and Watanabe 2004); however, there is little documentation on changes over time (Khan et al. 1997). Land-use change from forest to other usages in the EH has been quite conspicuous in the last few decades, causing depletion of natural resources in the Himalayas (Singh and Singh 1992). The quests for rapid economic development and expanding agricultural activities have increased the exploitative pressures on forests leading to habitat alternation and forest fragmentation (Pandit et al. 2007). Shankar Raman (2001) revealed that the North Eastern states of India lost 378 sq.km of forest due to human-induced activities between 1989 and 1991; 488 sq.km between 1991 and 1993; and 175 sq.km between 1993 and 1995. Other information from the North Eastern Indian states from 1991-2005 shows an increase in forest cover in Assam, Meghalaya and Tripura and either mixed or decreasing trends elsewhere. The gross forest cover of these seven states increased by 1,250 sq.km (0.7%) in total between 1991 and 2001, and 19 sq.km (0.01%) between 2003 and 2005 (Table 4).

Assam	78,438	24,751	24,061	23,688	27,714	27,826	27,645
Manipur	22,327	17,685	17,558	17,384	16,926	17,219	17,086
Meghalaya	22,429	15,875	15,714	15,633	15,584	16,839	16,988
Mizoram	21,081	18,153	18,576	18,338	17,496	18,430	18,684
Nagaland	16,579	14,321	14,291	14,164	13,345	13,609	13,719
Sikkim	7,096	3,041	3,127	3,118	3,193	3,262	3,262
Tripura	10,486	5,535	5,538	5,745	7,065	8,093	8,155
Total	**262,179**	**168,118**	**167,486**	**166,917**	**169,368**	**173,297**	**173,316**

An analysis was made of overall land cover in the 1970s and 2000s, based on six broad categories, using satellite images. The analysis of overall land-cover types showed that land-cover types in the EH changed significantly over 25 years between the1970s and 2000s (Figure 5). The data revealed a substantial increase of 17,394 sq.km (40.4%) of shrubland, which accounts for 3.3% of the total area of the EH. Forest cover decreased by 9,314 sq.km (3.4% of the same class and 1.8% of the whole EH) and grassland decreased by 3,261 sq.km (8.2%), accounting for 0.6% of the EH. Cultivated area changed by only 594 sq.km (0.5% of the same class and 0.1% of the EH). The area of denuded and uncultivated land increased by 1,369 sq.km (6.1%), accounting for 0.3% of the EH. No significant change took place in water bodies which show a decrease of 10 sq.km.

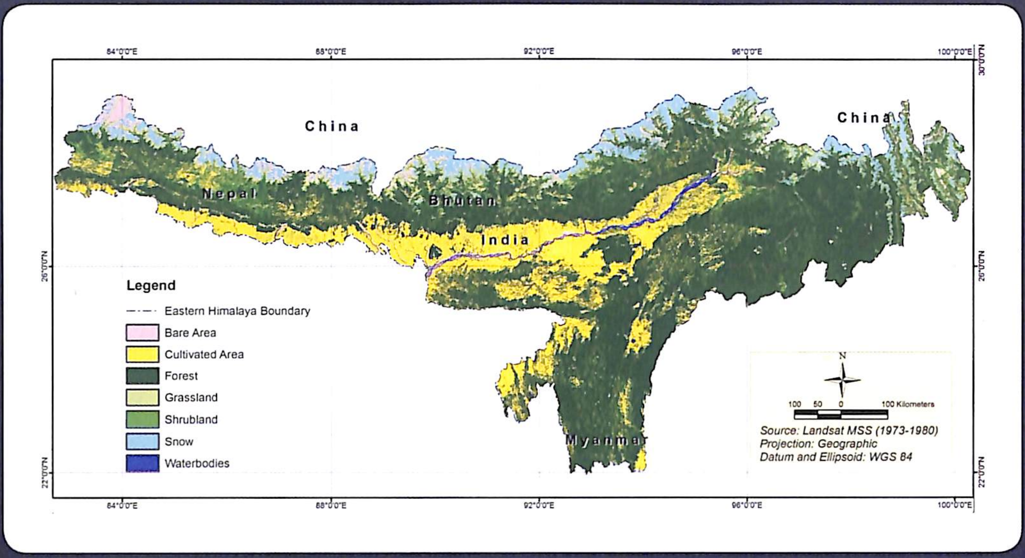
Snow cover decreased by 6,756 sq.km (24.6% of the same class and 1.3% of the EH). The interpretation of snow cover needs careful consideration as the analysis has not differentiated between seasonal and permanent snow. The analysis from the 1970s included Landsat MSS images from 1973 to 1979 with 32 out of 45 images from 1974 to 1977. Similarly, the land cover in the 2000s included Landsat ETM+ images from 1999 to 2002, with 30 out of 40 images from 2000 and 2001. Most of the images (75% for both periods) were acquired in winter from November to February. The figures should be taken as indicative rather than absolute values due to inherent limitations in the analysis caused by differences in sensors and time of image acquisition. The areas covered by seasonal snow may appear as different land-cover types in the images from other dates, and these are not true land-cover transformations.

Vulnerable habitats and ecoregions

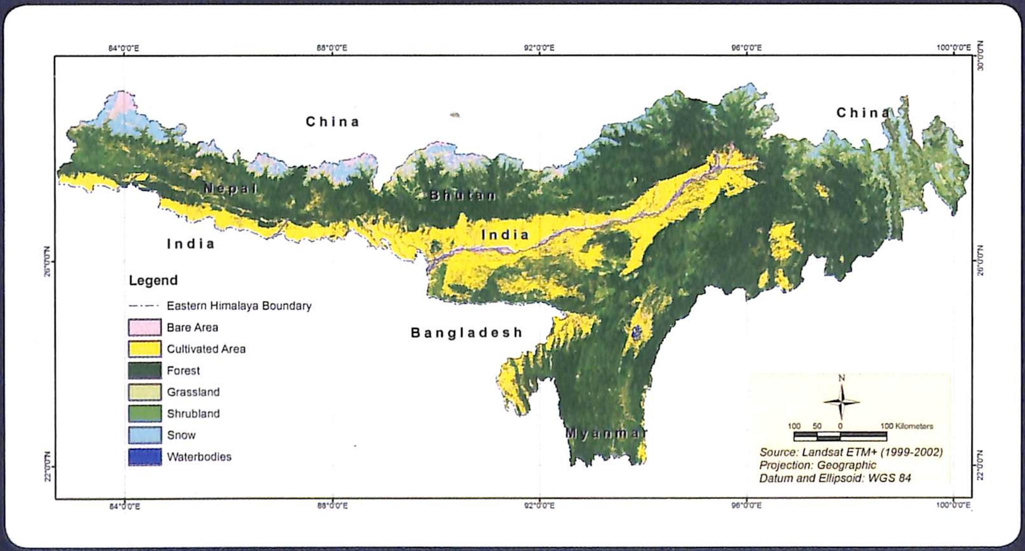
The EH region is known for diverse habitats and ecoregions that are subject to a high level of human-induced threats (Myers et al. 2000; CEPF 2005; 2007). Conservationists from across the globe have realised that the prevailing climate change trend and projections could mean that there will be substantial changes in critical habitats and the species therein because of the limited scope for expansion as the habitats outside protected areas are subject to intense fragmentation (Pounds et al. 1999; Wilson et al. 2005). Among the 25 ecoregions, 17 protected area complexes, and 41 candidate priority areas in the EH are many which are extremely important for biodiversity conservation (WWF and ICIMOD 2001). Among the ecoregions, Eastern Himalayan broadleaved forests, Brahmaputra Valley semi-evergreen forests, and Himalayan subtropical pine forests have the greatest conservation values because of the number of mammals, birds, and plants found in them (WWF and ICIMOD 2001). Similarly, the alluvial grasslands that stretch across the tropical forests in the EH support some of the highest densities of tigers in the world (Karanth and Nichols 1998), while the greater one-horned rhinoceros is restricted to several small, isolated populations within protected areas; the EH region is the last mainstay for this charismatic mega herbivore. The Brahmaputra and Ganges rivers flowing through the Himalayan foothills support globally important populations of Gangetic dolphin (*Platanista gangetica*), a freshwater dolphin with two endangered subspecies and which is endemic to the river system that flows through the foothills of the Himalayan mountain range. The region is also well known for amphibians and reptiles, mostly found in moist forests and ephemeral freshwater habitats (Pawar et al.

Figure 5: **Land cover change in the EH over thirty years (1970s to 2000s) with details of change forest** (for details see text)

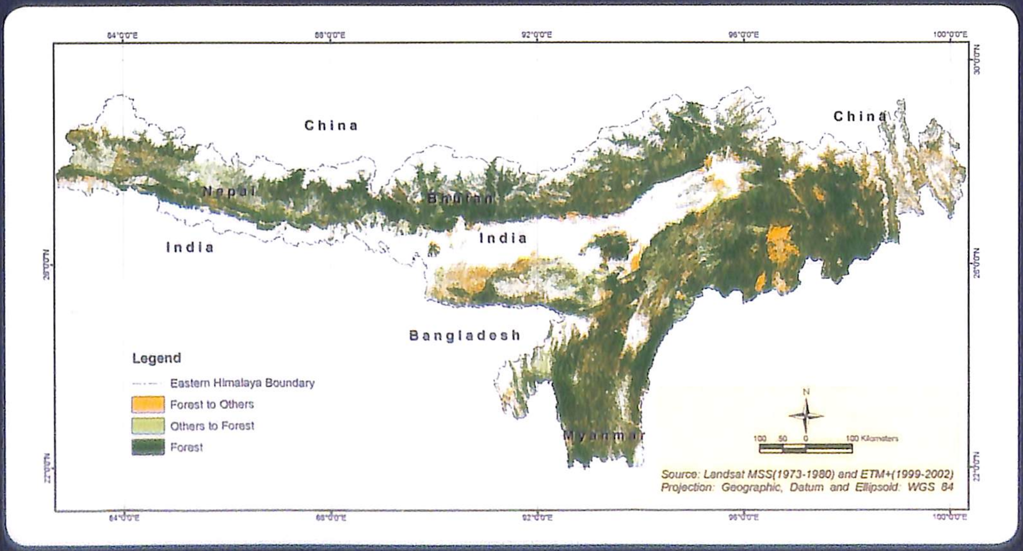
Land cover (1973-1980)



Land cover (1999-2002)



Forest cover change



2007) that are subject to impacts from climate change (Pounds et al. 2006). Thus, considering the vulnerable biodiversity entities and the potential change indicators, seven ecosystems or habitats in the EH have been identified as critical (Table 5).

Bioclimatic zones and phenology

Although there is no strict compartmentalisation of vegetation along altitudinal gradients in the EH region, elevation has important implications for its ecology, evolution, physiology, and conservation and is highly relevant to species' composition and phenology patterns (Chettri et al. 2001; Carpenter 2005). As a result of microclimatic variations, most organisms found in the EH are confined to specific habitats such as highland pastures, forests, and so on. This is a special risk factor for highland species that are sensitive to climate change (Pounds et al. 2006) and more likely to be at risk of extinction. Globally, there is evidence of the shift of species towards the north in latitude (Hickling et al. 2006) or higher elevations (Wilson et al. 2007), especially for species in the transition zone between subalpine and alpine which are more vulnerable to climate change as they have limited scope for movement. Analyses for the EH are few and limited to certain pockets of areas (Carpenter 2005). Observations have been made about the change in events related to plant and animal phenology and also to shifting of tree lines and encroachment of woody vegetation into alpine meadows. Phenological changes, such as early budding or

Table 5: **Critical ecosystems in the Eastern Himalayas with respect to climate change, as revealed during the consultation processes**

Critical habitat	Change indicator	Example of observed changes	Vulnerable entities
Alpine/sub-alpine ecosystems nestled between the treeline at 4,000 m to the snowline at 5,500 m	• Changes in ecotones • Desertification • Declining snowfall, glaciation events • Changes in species' composition • Growth in unpalatable species, decreasing productivity of alpine grasslands	Transformation of earlier *Quercus-Betula* forest into the 'Krummholz-type' of vegetation comprising species of Rhododendron, *Salix, Syringia*	Ungulate species, Himalayan pika, high-value medicinal plants, botanically fascinating species (bhootkesh and Rhododendron), curious species (succulents, Ephedra), alpine scrub flora
Cool-moist forests	• Changes in ecotones • Loss of habitat • Blockage of migration routes	Decline in population of *Mantesia* sp. *Ilex* sp. and insectivorous plants	Habitat specialists such as red panda, blood pheasant, microflora and associated fauna
Cloud forests at temperate elevations where moisture tends to mix with other particles and remain in the air	• Less precipitation and cloud formation during warmer growing season • Loss of endemics /specific flora and fauna • Upward range shift • Desertification of soil, affecting the water-retention capacity of forests	-	Endemic epiphytes and lichens, wildlife dependent on cloud forest vegetation (diversity of insects)
Areas with intensive agriculture	• Reduced agrobiodiversity (monoculture) • Low employment rate/gradual loss of traditional knowledge • Degradation of soil quality • Potential increase of greenhouse gas (GHG) emissions	Loss of traditional varieties such as upland varieties of rice, indigenous beans, cucurbits, and citrus varieties Pest increase in citrus species	Crops, cereals, and vegetables
Freshwater wetlands	• Loss of wetlands due to sedimentation, eutrophication, drying, drainage • Successional shift to terrestrial ecosystems • Increased salinity in aquifers	Decrease in population of *Sus salvanius*; 'beels' and associated biodiversity are changing	Large mammals such as crocodiles, river dolphins, wild-buffaloes; wetland plant species; migratory avian species
Riparian habitats nurtured by silt deposited by overflowing rivers	• Damage or destruction of riparian habitats by floods/glacial lake outburst floods (GLOFs)/ river-bank erosion. • Degradation due to increased / little deposition of sediments • Reduced stream flow • Disrupted successional stage	Loss of pioneer species such as *Saccharum spontaneum* and other tree species leading to a change in species' composition of the alluvial grasslands	Ibis bill (has nesting habitats in riparian zones), market-value tree species found in riparian zone; e.g., sisso, simal
Ephemeral stream habitat	• Loss of ephemeral stream habitats. • Increased salinity • Riverine system impacted	Riverine island ecosystems, such as Majuli in Assam, are being threatened	Ephemeral stream species, especially herpetofauna

flowering and ripening of fruits in plants, and hibernation, migration, and breeding in animals, could have adverse impacts on pollination patterns. Consequently, this may have an impact on the population of pollinators, leading to changes in ecosystem productivity and species' composition in high-altitude habitats (Thuiller et al. 2008).

Vulnerable species

Climate change increases the risk of extinction in species that use narrow geographic and climatic ranges (Hannah et al. 2007). According to the prevailing extinction theory, the larger and more specialised species are likely to be lost due to habitat destruction (Sodhi et al. 2004). This might be significant for the EH region as habitat and forest destruction were seen to have increased although the quality of increasing and decreasing forests has not been assessed (Pandit et al. 2007). With regard to climate change, since ecosystems in the three hotspots in the EH are layered as narrow bands along a longitudinal axis of the mountain range, they are greatly influenced and easily impacted by climatic variations. For example, alluvial grasslands are nurtured by silt deposited by rivers overflowing during the monsoon, and various species are accustomed to the flood plains. For example, *Saccharum spontaneum* and pioneer trees *Trewia nudiflora, Dalbergia sissoo, Acacia catechu*, and *Ehretia laevis* facilitate the rapid regeneration of other grassland species, and changes in the weather pattern followed by changes in the river flow would disrupt the successional stage of alluvial grasslands and eventually impact the existence of those species restricted to this ecosystem such as *Sus salvanius* which is already a critically endangered species. Similarly, the central plain of the Irrawaddy in Myanmar has rich moist deciduous forest that supports few but persistent and high- level endemic species which can easily be affected by changes in the patterns of the river system induced by climate variations.

Some of the ecoregions located within the EH harbour many threatened mammal species, some of which are greatly threatened (Table 6) or restricted endemic species with a narrow habitat range (Table 1). The golden langur (*Trachypithecus geei*), for example, is restricted to a patch of semi-evergreen and temperate forest on the north bank of the Brahmaputra River between the Sankosh and Manas rivers which flow southwards from the mountains; the pygmy hog (*Sus salvanius*) and hispid hare (*Caprolagus hispidus*) are restricted to the alluvial grasslands; and the Namdapha flying squirrel (*Biswamoyopterus biswasi*) is restricted to the temperate broadleaved forests of the EH. Others from the EH, particularly in the sub-tropical and temperate forests

Table 6: **Some of the critically threatened mammals recorded in the EH**

Common name	Scientific name	Threatened categories*
Anthony's pipistrelle	*Pipistrellus anthonyi*	CR
Argali	*Ovis ammon*	NT
Asian elephant	*Elephas maximus*	EN
Asiatic black bear	*Ursus thibetanus*	VU
Assamese macaque	*Macaca assamensis*	VU
Back-stripped weasel	*Mustela strigidorsa*	VU
Capped leaf monkey	*Trachypithecus pileatus*	VU
Cheetah	*Acinonyx jubatus*	VU
Clouded leopard	*Neofelis nebulosa*	VU
Eld's deer, Thamin	*Rucervus eldii*	VU
François leaf monkey	*Trachypithecus francoisi*	EN
Ganges river dolphin	*Platanista gangetica*	EN
Gaur	*Bos frontalis*	VU
Gee golden langur	*Trachypithecus geei*	EN
Golden snub-nosed monkey	*Rhinopithecus roxellana*	VU
Himalayan tahr	*Hemitragus jemlahicus*	VU
Hispid hare	*Caprolagus hispidus*	EN
Hoolock gibbon	*Hoolock hoolock*	EN
Irrawaddy squirrel	*Callosciurus pygerythrus*	VU
Joffre's pipistrelle	*Pipistrellus joffre*	CR
Kozlov's shrew	*Sorex kozlovi*	CR
Markhor	*Capra falconeri*	EN
Namdapha flying squirrel	*Biswamoyopterus biswasi*	CR
Parti-coloured flying squirrel	*Hylopetes alboniger*	EN
Pig tailed macaque	*Macaca nemestrina*	VU
Pygmy hog	*Sus salvanius*	CR
Red goral	*Naemorhedus baileyi*	VU
Red panda	*Ailurus fulgens*	EN
Serow	*Capricornis sumatraensis*	VU
Smooth-coated otter	*Lutrogale perspicillata*	VU
Snow leopard	*Uncia uncial*	EN
Stump-tailed macaque	*Macaca arctoides*	VU
Swamp deer/ Barasinga	*Rucervus duvaucelii*	VU
Takin	*Budorcas taxicolor*	VU
Tiger	*Panthera tigris*	EN

Source: CEPF (2005, 2007)
* CR = critically endangered; EN = endangered; VU = vulnerable; LR = lower risk; NT = near threatned

(broadleaved, coniferous, and mixed), include the tiger (*Panthera tigris*) and other members of the cat family (Felidae) which would be extremely vulnerable to climate change as would narrowly endemic taxa, such as Mishmi takin (*Budorcas taxicolor taxicolor*) and Hoolock gibbon (*Hoolock hoolock*), which are likely to face challenges to their conservation in the forests of the region. There are habitat specialists from the tropics, such as five deer species – swamp deer (*Rucervus duvaucelii*), sambar (*Rusa unicolor*), axis deer (Axis axis), hog deer (*Axis porcinus*), and barking deer (*Muntiacus muntjak*) – from the Terai-Duar savanna and grasslands; pygmy hog (*Sus salvanius*) and hispid hare (*Caprolagus hispidus*) from the semi-evergreen forests of the Brahmaputra valley; Himalayan tahr (*Hemitragus jemlahicus*) from the open, steeper hills and woodland habitats; red panda (*Ailurus fulgens*), which are limited to patches of mature fir forests with bamboo understoreys; and, at high altitudes, colonial marmots. The brow-antlered deer (*Cervus eldi*), locally known as sangai, is endemic to the Manipur wetlands, especially Loktak lake, and is the rarest and most localised subspecies of deer in the world.

Agrobiodiversity and food security

The most vulnerable agro-ecological zone in the EH region is the specialised pastoralist system in the high-altitude areas of Eastern Nepal, Sikkim, Bhutan, Arunachal Pradesh, and the Tibet Autonomous Region of China. The vulnerability of the system is due to land use change caused by shifts in rainfall patterns and loss of vegetation cover. Other agro-ecological zones, such as mixed mountain agro-pastoralism systems; cereal-based hill farming systems; and shifting cultivation areas could also be impacted with changes in precipitation and temperature regimes. In the EH, large tracts of secondary forest have been established and maintained through shifting cultivation practices; and this traditional farming and agroforestry practice, which used to be subsistence based but sustainable (Kerkhoff and Sharma 2006), is facing numerous challenges from widespread, modern agricultural development, increasing population pressure, and decreasing fallow cycles (Ramakrishnan 1992). Many indigenous crop varieties are under serious threat, therefore, and this is manifest in commercialisation of agriculture, weak policy and regulatory frameworks, increased accessibility, changes in cropping patterns and land-use practices, social inequality, population growth, and technological advancement: all of these contributing to loss of agrobiodiversity (Upreti and Upreti 2002).

The prevailing rise in temperature and changes in precipitation patterns leading to increased incidence of extreme weather events and an increase of greenhouse gases in the atmosphere, carbon dioxide (CO_2) being the most prominent, are principal factors that could lead to diminishing crop and livestock diversity and have direct implications on agrobiodiversity and food security in the EH. Changes in weather patterns would make it difficult to determine sowing and harvesting schedules and would hamper selection of suitable crops. Erratic rainfall, in particular, would affect regions already suffering from water shortages. Extreme rainfall events would lead to increased loss of water through runoff. Another negative impact would be a pervasive decrease in soil fertility through loss of carbon from the soil through erosion, reduced soil moisture, and moisture storage capacity. All this could result in reductions in crop yields and agricultural productivity because of the loss of soil fertility and decrease in pollinator populations, with subsequent threats to food security. Complete loss of crops resulting from extreme events, such as prolonged drought and torrential rain, is also possible. In addition, a fall in livestock productivity from heat dissipation and declining availability of feed and fodder; and increased risk of pests and diseases to both crops and animals (as well as humans) would bring about changes in the agro-ecological environment. Threats from new invasive plant and animal species would be inevitable. The combined effect of all the factors described could lead to a reduction of agrobiodiversity.

Peoples' perceptions

Peoples' perceptions and first-hand experiences of the communities dealing with nature give important insights into the potential impacts of climate change (Byg and Salick 2009). Unfortunately no studies examine the extent to which climate change matters to people and society. Feedback from a national stakeholders' consultation and analysis of a questionnaire survey carried out in the EH region showed that people's perceptions about the impact of climate change on biodiversity varied. Grassroots' communities do experience changes in the climate, and they talk about changes in weather patterns and in their immediate physical surroundings; but they are unsure what linkages these have with global warming or climate change. People are mostly concerned about changes in the benefits the ecosystems provide and perceive differences in food production, water storage systems, and influence on tourism and related services, rather than the impact on biodiversity elements per se. The survey had 182 respondents, of which 75% were educated. Their level of awareness on issues related to climate change was fairly high because of their exposure to the print and electronic media. Impacts on the physical environment, such as drying of ponds, forest fire, drought, and land erosion, were reasonably well understood and most of the respondents emphasised that there would be impacts on livelihoods, on human mortality, and on biodiversity. In the context of adaptation or mitigation strategies, the nature of the response emphasised the need for joint efforts to combat the impacts of climate change, alternatives to forest resources, and recycling (Table 7).

Most farming communities in North East India and Bhutan are aware of variations in growing seasons of certain crops, inability of certain crops to flourish during the growing seasons, loss of pollinators, extensive drought, changes in the monsoon pattern, reduced or delayed snowfall, and lack of snowfall (which affects winter crops). Many communities have even tried to adapt by either changing crop varieties or cropping patterns or by migrating to a suitable crop habitat. One example given was the withering of bananas in Manipur before maturity because of water shortages. In Senapti in Manipur, soya beans were planted during water shortages, but in 2004/05, soya bean crops failed due to excessive rainfall.

Introduction and extensive growth of invasive species are least thought to be the impact of climate change, as invasive species are perceived as adaptive to any physical environment. There is widening concern, however, about loss of genetic diversity, which in turn may reduce the capacity of species to adapt to climate change. For example, in western Bhutan, the introduction of exotic brown trout (*Salmo trutta morpha fario*) to cold-water regions has had negative impacts on the indigenous fish, the asla (*Schizothorax* sp). The brown trout is a voracious competitor to Asla as it is carnivorous and feeds on the Asla young. In other places, wild leafy vegetables and mushrooms are growing in new locations

Table 7: Perceptions about coping with climate change

Action required	Percentage of respondents
Intensify afforestation and reforestation programmes	12
Find alternatives to forest products	14
Awareness campaign and multi-media education	8
Land and water management	8
Local participation to mitigate effects of hazards	8
Recycling of waste materials	14
Reduction in settlement expansion	10
Reduction in use of firewood	6
Partnership, cooperation, and collaboration to combat climate change	20

leading to a decrease in places for livestock forage, thus necessitating that pack animals be stall fed.

With regard to forest fires, although perceived as a human-induced threat, people think that increased frequency of forest fires could be due to a rise in atmospheric temperature. On the positive side, farmers (Helipong village in Tuensang) say that there is an increase in areas that are warm enough to cultivate cereal crops and that the productivity of oranges has increased. Such experiences can give important insights into the potential impacts of climate change.

Existing Policies and Governance Structures

Worldwide both nations and local communities are undertaking two primary actions in response to climate change: viz., mitigation – the process of reducing greenhouse gas emissions and, thereby, associated climate change; and adaptation – the process of adjusting in response to, or in anticipation of, climate change. Actions that adapt to and mitigate the effects of climate change enhance the resilience of vulnerable systems and reduce the risk of damage to human and natural systems from climate change and variability. Some of the key mitigation and adaptive practices and potentials found in the region – and the challenges faced therein – are discussed in the following passages.

Mitigation

Carbon dynamics is an important phenomenon that is directly linked to the carbon budget in the atmosphere: a potential causal agent of climate change. It is estimated that deforestation contributes more carbon dioxide emissions than the total emissions coming from the transport sector. Therefore forestry and diverse agricultural and agroforestry practices are among the most promising means of carbon management because of their potentials for carbon sequestration, hence supporting mitigation (Montagnini and Nair 2004). There are ample practices and opportunities for mitigation of greenhouse gases in the EH. Community-based forest management systems help increase carbon stock, for example, participatory forest management such as joint forest management (JFM) in India, community-based natural resource management (CBNRM) in Bhutan, and community forestry (CF) and leasehold forestry (LF) in Nepal are well-known successes in the regeneration of degraded forests (Sharma and Chettri 2003). Community-managed forests in the Himalayan region are becoming an important carbon pool, since previously deforested areas have started to regenerate. The mean carbon sequestration rates for community forests in India and Nepal are close to 2.79 $tCha^{-1}\ yr^{-1}$, or 10.23 $tCO_2ha^{-1}yr^{-1}$ under normal management conditions and after local people have extracted forest products to meet their sustenance needs (Banskota et al. 2007). Nevertheless, these efforts have not been recognised in the international tradeoff of forests within the Clean Development Mechanism (CDM) of the Kyoto Protocol. Strong negotiations in the international forum on carbon trade are needed so that such practices can be scaled up and incentives introduced.

Adaptation

Adaptation is not a new concept. Traditionally employed by ecologists, it refers to the evolutionary process by which living organisms fit into a new environment. At the simplest level, the process of adaptation is seen as a response to vulnerability. In the context of adaptation, research and policy communities have had to understand the potential impacts of climate change and the range of vulnerabilities to them in order to translate good practices into adaptation measures. The EH region is facing numerous vulnerabilities because of climate change at regional (e.g., biome, hotspots, and ecoregions); ecosystem (e.g., mountains, wetlands, forests, grasslands, and agro-ecological systems); and species (e.g., threatened and endemic) (also see Sharma et al. 2009) levels. In some areas these vulnerabilities are addressed by traditional knowledge with conservation ethics at the community (Rai et al. 1994; Sherpa 2003; Devi et al 2005; Arora 2006; Salick et al. 2007) and landscape levels (Ramakrishnan 1996, 2003). These traditional practices are adapting to various resource crises through conservation ethics governed by customary laws and institutions (Box). Adaptation mechanisms based on ecosystems which bring about socioeconomic and cultural benefits along with ecological integrity can facilitate the resilience of biodiversity in the EH.

Conservation measures and policies

The conservation of biodiversity in the EH region has been progressive in terms of establishment of protected areas. The first PA to be established was the Pidaung Wildlife Sanctuary in Myanmar which was established in 1918. There are about 99 protected areas of different sizes covering more than 79,000 sq.km (15% of the total area) across the region (Table 8). This is quite significant in terms of protected area coverage compared to the global percentage of 11.5% for mountain protected areas (Kollmair et al. 2005). The trend in protected areas show that they grew considerably within the 80 years from

Box **Adaptive capacities of pastoralist communities in western Bhutan**

Pastoralism is a traditional means of earning a living practised by different castes and ethnic groups in the EH and it makes a significant contribution to the economy by providing employment and income and by supplying nutrition to the rural poor. The implications of climate change for pastoral livelihoods are yet to be understood and, indeed, two quite different opinions seem to prevail. Some see pastoral groups as 'canaries in the coalmine' of ongoing processes, as rangelands will tend to become drier and existing water shortages will worsen, thus affecting the overall sustainability of pastoralism. Others see pastoralists as the most capable of adapting to climate change, since pastoral livelihoods are shaped to deal with scarce and variable natural resources and to tackle difficult and uncertain agro-ecological conditions. Climate change could conceivably lead to the extension of territories in which pastoralism could have comparative advantages. It is important to know 'why people do what they do' especially in traditional societies that have remained relatively unchanged by the forces of modern technology.

In the high altitude areas of western Bhutan above 3,000 m, yak production has been and continues to be the main source of livelihood for a nomadic people inhabiting this rugged landscape, known as 'bjops.' The 'bjops' use tents made of yak hair called bja, known to the outside world as the one hundred peg tent. The tent weighs about 30-53 kg depending on size. A 'zow' (a skilled weaver) normally designs the tent in two pieces, so that it can be carried on two horses when transporting it from one pasture to another. A good, strong 'bja' may last 20-25 years in spite of its use in a harsh climate. These tents withstand heavy snowfall, rainfall, and wind and are comfortable enough to cope with extreme climates as they do not leak nor sustain damage from the wind. The tent has a100 pegs to hold it upright and the angle maintained prevents leakage. The herders help each other erect the tents, and this normally needs four strong hands. Livestock are looked after by a hired herder or member of the family owning the herd; and they sometimes live together in one 'Bja.' Thus the social structure and mechanisms for mutual sharing of resources and their livestock assets seem to be intact. It is quite evident from the lifestyle of these people that they can withstand the extreme cold and harsh climate in alpine pastures and in trans-Himalayan areas. These pastoralists have shown themselves to be very resilient and capable of adapting to an extreme climate. (Adapted from Chettri 2008)

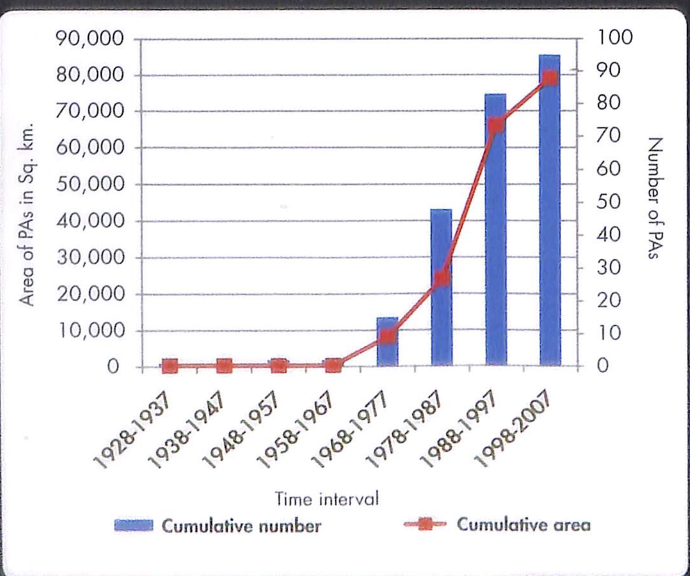
Table 8: **Number and coverage of protected areas within the Eastern Himalayan (EH) boundary (% with respect to total PAs and their area coverage in the respective countries)**

Country	Total area of the country (sq.km)	Total area within EH (sq.km)	Total number of PAs in EH	PA area coverage within EH (sq.km)	% of PA coverage with respect to area of EH in country
Bhutan	46,500	39,862	9	11,195	28
China	9,596,960	32,864	9	11,918	36
India	2,387,590	272,707	67	28,379	10
Myanmar	676,577	93,855	3	8,379	9
Nepal	147,181	84,339	11	19,510	23
Total	**12,854,808**	**523,627**	**99**	**79,381**	**15**

1927 to 2007 (Figure 6). The last two decades show exponential growth in both the number and coverage of these protected areas: the cumulative area has increased from 23,379 sq.km (1977-1987) to 71,972 sq.km (1997-2007) and the number increased from 46 to 99.

Contemporary conservation approaches; such as establishment of protected areas and the concepts of conservation corridors and landscape approaches; have also brought about a significant paradigm shift by soliciting community participation in protected areas and buffer zone management. Such approaches bring critical habitats and ecoregions and their species into new, evolving conservation measures (Sherpa et al. 2004; Chettri et al. 2007). They allow species to move from otherwise confined protected areas; and they make it possible for conservationists and development workers to plan conservation action in an integrated manner (Williams et al. 2005; Hannah et al. 2009). Most of these new conservation approaches are still in the early stages of development and need appropriate actions and policies to implement them effectively.

Figure 6: **Cumulative number and coverage of protected areas in the Eastern Himalayas from 1928 to 2007**



Research Gaps and Training Needs

Gradually, as international legal instruments were implemented, many national policies and legal instruments to protect the environment and minimise the impact of global climate change emerged. With regards to the EH region, Bhutan, China, India, and Myanmar have all put efforts into developing adaptation policies to reduce their country's vulnerability to climate change either by minimising the exposure to impacts (adoption of an ecosystem approach) or by maximising the adaptive capacity (reducing non-climatic stresses, reversing trends that increase vulnerabilities, and increasing social awareness). These countries are in different stages of developing their policies and laws to manage their ecosystems in the face of climate change, however.

There is wide-scale awareness in the region, but there has been little in the way of research or analysis despite this awareness. Efforts to involve governments, the private sector, non-government organisations, and scientists in providing an integrated assessment of the consequences of ecosystem change for human wellbeing and to analyse options for conserving ecosystems and their contributions to meet human needs are scattered and inadequate. Climate change is an interdisciplinary issue, hence individual and fragmented efforts are insufficient. The efforts of various local, regional, and global organisations operating in the EH and providing capacity-building interventions must be coordinated and collective partnerships with governments and local people developed so that the entire EH region is able to cope with the present and future impacts of climate change.

In terms of research gaps, research into policies linking conservation with livelihoods and climate change is limited. Policies based on sound scientific analysis need to be strengthened and made suitable for addressing the challenges imposed on biodiversity by climate change and other drivers of change. Research into climate change, vulnerability of ecosystems, and the extent of impacts on biodiversity based on collaborative modelling is insufficient. Comprehensive inventories of species and their population within many of the protected areas in the EH are scarce and limited in their coverage. Assessment of the spread of invasive and exotic species; establishment of critical landscape linkages for flagship species; analysis of population trends of flagship and threatened species; strengthening of the effectiveness and extent of coverage of protected areas; and fire management strategies are needed urgently.

Agrobiodiversity and wetlands' ecosystems are in need of extended research: for agroecological systems, for example, it is particularly important to find out how farming systems are evolving under drivers like globalisation, climate change, and changes in land cover and land use. Many questions have yet to be answered about how cropping patterns in the mountains and lowlands are affected or changed and what implications such changes are having on rural food security. Similarly, wetland biodiversity and services from them are barely explored. In the climate change context an understanding of the dynamics of wetland ecosystems and their significance as either sources or sinks for carbon is essential.

There is a gap in research related to the historical migration patterns of biodiversity and historical coping patterns of humans. It is of extreme importance to establish long-term monitoring of several biodiversity entities in the EH such as hotspots of flora and fauna; vulnerable ecosystems; flagship species; endangered, endemic, and restricted range species; lower plants, rangeland vegetation; amphibians, insects, and other pollinators.

The inadequacy of data and information on biodiversity in the EH is often related to the capacity of individuals, institutions, and nations to carry out long-term scientific research and to their ability to share and use information. There are disparities in infrastructure, knowledge, and resources among the EH countries. Often failure to establish proper information-sharing mechanisms hinders effectiveness and exchange of scientific data and information. More importantly, common regional research protocols that can produce long-term comparative data across the EH are minimal. The capacity of individuals and institutions to analyse the significance of biodiversity management at the regional level; to identify collaborative conservation action; and to prioritise national measures to reduce human dependency on biodiversity, also needs to be strengthened. ICIMOD has been raising strategic awareness through various regional workshops and, for example, through formulation of a regional cooperation framework for implementation of the Convention on Biological Diversity (Sharma et al. 2007). Capacity in terms of conducting actual research on the ground; in particular to understand climate change vulnerabilities and hazards; resiliency of habitats and species; short- and long-term impacts on vulnerable ecosystems and their services; improving livelihoods through options linked to conservation for communities dependent on biodiversity resources; economic dimensions of biodiversity; and indigenous adaptation mechanisms should be established at the regional level. ICIMOD is trying to strengthen human resources to carry out specific research on taxonomy and conservation biology; and to carry out interdisciplinary impact assessment through integrated regional training.

Recommendations and Future Strategies

While acknowledging the significant diversity of biological resources in the EH region and the existence of a fair understanding of the important drivers of change, it is recognised that concerted efforts to monitor and research the impacts of climate change on biodiversity in the region are essential. Four priority thematic areas for focus were identified and are discussed in detail in the following.

Long-term consistent monitoring of both climate change and biodiversity

The importance and need for establishing long-term, consistent monitoring of climate change and its impact on biodiversity is clearly realised. Permanent plots and/or units need to be established on an altitudinal transect spanning the tropics to the alpine regions in order to monitor diverse ecosystems. An institutionalised monitoring system, however, requires standardisation of monitoring parameters. In this respect a consistent, uniform methodology and a network of collaborative partners should be developed in order to collect and analyse data and information regularly and distribute it to partners. Realising the need for a facilitating institution, ICIMOD has taken on the coordinating role by consensus. Academic and research institutions were identified as collaborative partners: their responsibilities are to establish and maintain the permanent research plots, carry out the regular monitoring, and generate and analyse the data. The involvement of communities in the respective areas was seen to be critical in maintaining the plots, in participatory action research, and in carrying out observations and sharing perceptions.

Guidelines for the research areas could be the following:

- Monitoring climatic variables by establishing stations as necessary to facilitate generation of precise and long-term climate data for mountain regions in the EH and also for improved access to climate data
- Assessing ecosystem functions of vulnerable species and understanding the relationship between ecosystem structure, its productivity, and the delivery of ecosystem goods and services
- Assessing the economic value of goods and services provided by the conservation areas to raise awareness about the importance of the EH with respect to the global biodiversity tradeoff from their goods and services
- Understanding second generation problems, such as land-tenure complexities, food security, resource use rights, and devolution of power in decision-making processes, which affect environmental sustainability, and identifying management options to increase the resilience of communities
- Identifying best practices adopted by traditional resource management systems in the EH and formulating supportive policy guidelines to support scaling up through enhancement of institutional and financial commitments from national and international communities
- Identifying species that are tolerant and have greater resistance than others to insect damage from diseases, natural phenomena, and forest fire

Focused research on impacts, coping mechanisms and adaptation to climate change

Documentation on impacts is, as yet, anecdotal for the most part – there is a need, therefore, to document impacts as well as coping mechanisms of communities to change systematically. The most promising indicators seem to be agrobiodiversity, followed by other forms of biodiversity (both flora and fauna). Documentation of changes in crops and their performance, and coping mechanisms of communities, focusing on changes in cropping patterns, crop shifts, and cropping system management, should be carried out on a priority basis. One important aspect requiring documentation and monitoring is the change in nutritive value of crops as a result of the impacts of climate change. Systematic documentation and monitoring, however, will need a framework of institutional support and re-orientation of existing government research programmes and institutions in regard to adaptive research.

The monitoring activities should focus broadly on the following issues:

- Historic coping mechanisms of relevant agrobiodiversity (evolutionary and adaptive mechanisms), together with an understanding of gender-based knowledge and know-how pertaining to domestic crop management and crop genetic resource management
- Current adaptive responses of species and/or biodiversity
- Current local and/or indigenous practices and coping mechanisms of communities
- Interaction between climate change and systematic analysis of land-use and land-cover changes and their impacts on biodiversity
- Effects of atmospheric CO_2 enrichment on the productivity, species' composition, and carbon dynamics in different ecosystems, and on ecosystem resistance and resilience.

Assessment of critical habitat linkages, protected area effectiveness, and ecological and social vulnerabilities

In addition to the functional responses of existing protected areas (PAs) to climate change (which could provide critical information about responses of natural systems to change and hence provide benchmark parameters), new critical habitats and the necessity for linkages of such habitats to existing ones need identifying. Existing PAs will require constant monitoring to document changes in vegetation, identification, and census of indicative species (to monitor population dynamics as a function of changing climate impacts). The effectiveness of PA management will have to be central to all research and feed into evolving responsive management approaches and technologies. Findings and conclusions from the above should provide insight into adaptive responses and the resilience of natural systems; and these will become critical elements in evolving decision-support systems and hence require priority. Research on institutional frameworks and their effectiveness in governance and assessments of good practices with examples of community-led conservation have to be central to formulation of an effective and responsive governance system. Strong emphasis has to be placed on indigenous knowledge systems, particularly in regard to natural resource management approaches and institutional frameworks, drawing upon traditional practices of management and governance especially in regard to sacred landscapes.

Monitoring should focus broadly on the following:

- Developing connectivity between protected areas and ensuring promotion of well-managed agroforestry systems in order to increase the potential of forests to sequester carbon, reduce soil erosion, improve water quality, and provide goods and services to local people
- Managing PAs and their governance mechanisms effectively
- Vulnerable ecosystems such as grasslands and ecotones and their associated species
- Local and/or indigenous conservation practices and their effectiveness
- Supporting development of appropriate databases on biodiversity and climate change scenarios

Policy analysis on climate change, adaptation and coping mechanisms; and relevant adjustments to existing policies

An enabling policy environment is essential to support and strengthen community efforts to cope with change. Documentation and assessments indicate the need for policy dialogue focusing on areas identified. Policy dialogues would need to focus on areas where adjustments in existing policies are required, particularly in regard to economic benefits, governance frameworks, and local-level policy adjustments. A clear concern was the multiplicity of policy actors governing natural resource management and livelihood support and the need for convergence of different (often conflicting) policies under one forum for ease of implementation. Dialogues need to focus on this required convergence before moving on to sectoral details. There is a critical role for scientific institutions in regard to policy formulation concerning natural resource management, livelihood support, and climate change. Policy makers require authentic data inputs and, more often than not, these are not available or not in a comprehensible form. Scientific institutions need to fill this gap so that policy making can be based on scientific findings.

Monitoring should focus broadly on the following:

- Policy reviews and policy briefs
- Facilitating dialogue among experts and policy makers
- Developing a framework for implementation if necessary
- Liaising with stakeholders at local, national, and regional levels for implementation

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Acronyms and Abbreviations

CBD	Convention on Biological Diversity
CBNRM	community-based natural resources management
CDM	clean development mechanism
CEPF	Critical Ecosystem Partnership Fund
CF	community forest
CITES	convention on International Trade in Endangered Species
CO_2	carbon dioxide
CR	critical
DJF	December-January-February season
EH	Eastern Himalayas
EN	endangered
GBH	Global Biodiversity Hotspots
GHG	greenhouse gas
GLOF	glacial lake outburst flood
HKH	Hindu Kush-Himalayas/n
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JFM	joint forest management
JJA	June-July-August season
LF	leasehnold forest
LR	lower risk
MAM	March-April-May season
MEA	Millennium Ecosystem Assessment
NDVI	normalized difference vegetation index
NTFP	non-timber forest product
PA	protected area
PRECIS	Providing Regional Climates for Impacts Studies
RMC	regional member country
SON	September-October-November season
TAR	Third Assessment Report
Tibet AR	Tibetan Autonomous Region
VU	vulnerable
WWF	World Wide Fund for Nature