Dancing on the Roof of the World: Ecological Transformation of the Himalayan Landscape

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That the Himalaya contain the basins of major rivers, regulate regional climate, and harbor rich biodiversity and varied ecosystems is well known. The perennial waters and biodiversity are closely linked to the livelihoods of over a billion people. The Himalaya are stressed because of a burgeoning human population and the escalating pressures of deforestation; urbanization; hunting; overexploitation of forests; and, more recently, intensive dam building. The cumulative effects of these forces have led to biotic extinctions and an increased frequency of hazards threatening human lives, livelihoods, and property. However, there is largely no comprehensive account of these challenges facing the Himalaya. We review and discuss the importance of the Himalaya and the need for their conservation by exploring four broad themes: (1) geobiological history, (2) present-day biodiversity, (3) why the Himalaya are worth protecting, and (4) drivers of the Himalayan change. We suggest scientific policy interventions, a strengthening of institutions, and proactive institutional networking to reverse the trend.

Keywords: biodiversity loss, climate change, dams, Himalaya, institutional networking.

***Kumarsambhava*, the epic poem of fifth century** Sanskrit poet, Kalidasa, is perhaps the oldest and the most fitting written tribute to the Himalaya. The poet describes the Himalaya as the "measuring rod of the Earth" and as "the roof and refuge." In purely geological terms, the Himalaya represent the youngest and the highest mountain chain of the world (estimated at 45–55 million years old) and is located on the Asian subcontinent. The formation of the Himalaya was a major geophysical event that led to the disappearance of the Tethys Sea, which separated the Eurasian Plate in the north and the Indian Plate in the south. The birth of the Himalaya had far reaching effects on the climate of Central and East Asia (Zhisheng et al. 2001). As this new geophysical system took shape, it became a source of a variety of natural resources that have, for millennia, molded and sustained human civilizations across South and Southeast Asia.

Located between 26 degrees (°) north (N) and 41°N latitude (about 1700 kilometers [km] north to south) and between 70° east (E) and 105°E longitude (about 3200 km across), the Himalaya have an east–west orientation and are spread across different nations. The geographical extent of the Himalaya reported in the literature varies (see Royden et al. 2008, Bolch et al. 2012). Some authors have included the hills of the northeastern hill states of India in their definition of the Himalaya (see Johansson et al. 2007) because of the geographic continuity of the two regions, but their geological and evolutionary histories are likely to be different. In this study, *the Himalaya* refers to the mountainous region of the Indian subcontinent, encompassing 10 major river basins and spread across seven nations (figure 1). The nations that share the Himalayan landscape, from west to east, are Afghanistan (11.39%), Pakistan (11.79%), India (14.09%), Nepal (4.29%), Bhutan (1.12%), the Tibetan Autonomous Region (TAR) and China (48.06%), and northern Myanmar (9.26%). On the Indian subcontinent, the Himalaya are broadly classified into the Eastern Himalaya (EH) and the Western Himalaya (WH). The EH stretch from eastern Nepal, crossing the northeastern Indian states of West Bengal, Sikkim, Arunachal Pradesh, and Bhutan into northern Myanmar, whereas the WH extends from west of the Kali Gandaki valley in Nepal through the Indian states of Uttarakhand, Himachal Pradesh, Jammu and Kashmir and to the Hindu Kush areas of northern Pakistan and Afghanistan. The major parts of the trans-Himalayan belt (the arid area in the rain shadow of the Himalaya, with an average elevation of 3000 meters [m]) lie in the TAR and China. The greater Himalayan region contains the origins of some the world's major rivers—namely the Ganga (Ganges), the Brahmaputra, the Indus, the Irrawaddy, the Salween, the Mekong, the Yangtze, and the Yellow River (figure 1), with nearly 1.4 billion people inhabiting their basins.

Despite its geological, hydrological, biological, and cultural significance, an integrated systematic analysis of the

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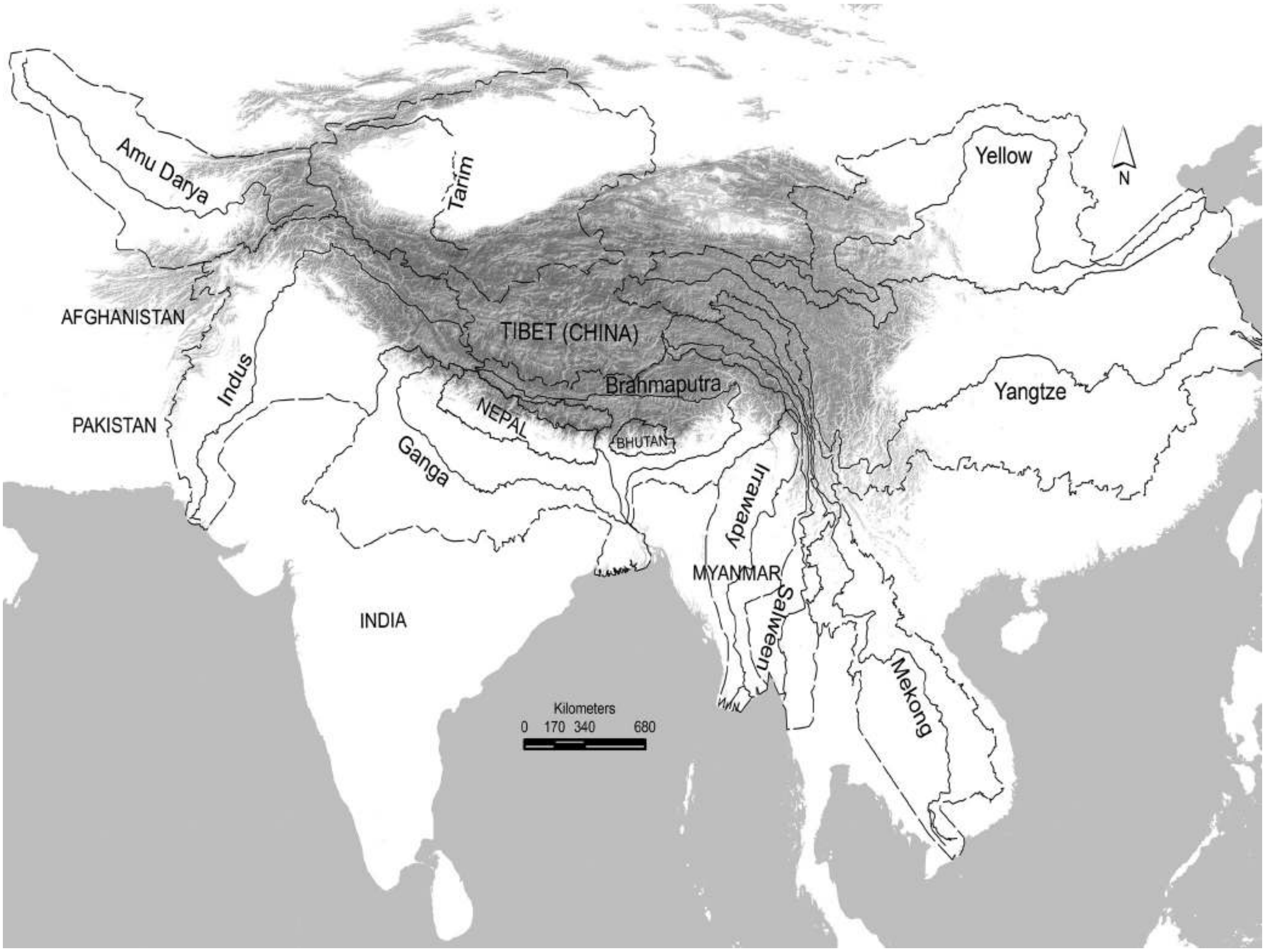

Figure 1. Geographic spread of the Himalaya across various nations, encompassing 10 major river basins. These river basins sustain a human population of nearly 1.4 billion across these nations.

Himalayan region is largely missing from the scientific literature (but see Xu et al. 2009). The manifold changes in the Himalaya brought about by human communities during the Anthropocene warrant an integrated assessment. Here, we present an overview of the geobiological history of the Himalaya; their significance in terms of providing numerous ecosystem services, such as water supply, climate regulation, and biodiversity; and the challenges faced by the region. We identify and discuss a number of drivers of the ecological transformation of the Himalaya, which include deforestation, urbanization, hydropower development, hunting of wildlife, and climate change (see figure 2). We also discuss the need for balancing conservation and economic development and highlight the role of various national and international agencies therein.

A geobiological overview

The formation of the Himalaya began in the early Cenozoic Era, around 50–55 million years ago, with the collision of the Indian and Eurasian Plates. The mountain building culminated around the late Tertiary or Middle Miocene (c. 15–10 million years ago; Royden et al. 2008), even though the final uplift is reported to have occurred at the end of Pleistocene glaciation. The periodic orogenic events and the ensuing environmental effects (e.g., the evolution of the Southeast Asian monsoon) likely served as a major driving force for the establishment and modification of the newly formed Himalayan ecosystems. A relatively nascent terrestrial ecosystem replaced the marine Tethys and brought about contiguous landmass connectivity of the Indian subcontinent with the Sino-Japanese regions in the north and east, the Caucasian region extending to the Alps in the west, and the Indo-Malayan region in the southeast. The sediment fossil record of the WH foothills well illustrates close affinities to the extant members of Indo-Malayan floral elements (*Dipterocarpus tuberculatus*, *Hopea wightiana*, *Sterculia coccinea*, *Sterculia urens*, *Bursera serrata*, *Euphoria longana*, *Dialium indum*, *Diospyros candolleana*, *Artocarpus heterophylla*, and *Ficus benghalensis*; Prasad 1993). Likewise, a comparative study of the Tertiary flora of southwest China

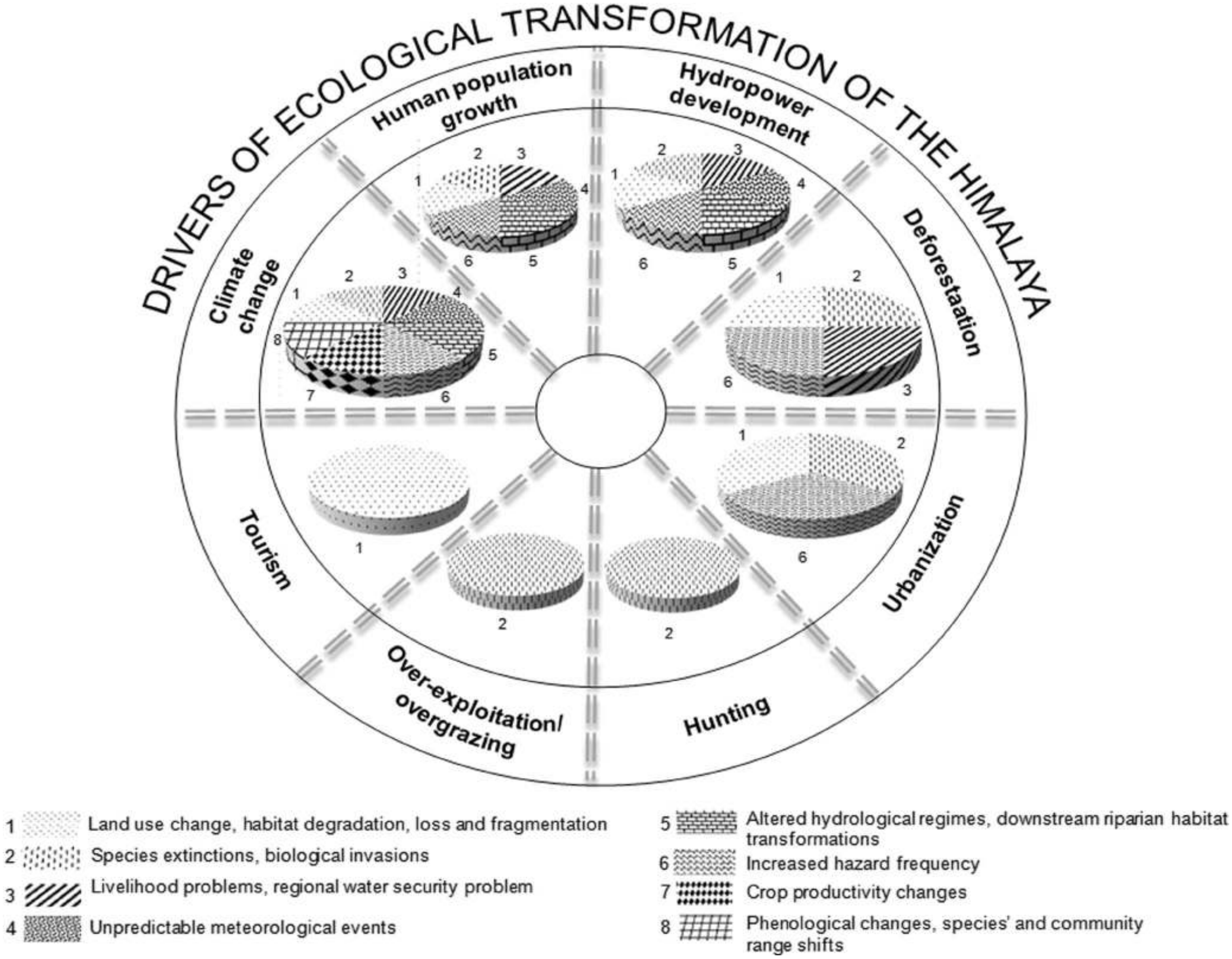

Figure 2. The major drivers of ecological transformation in the Himalaya. The effects of the respective drivers are represented in the form of pie charts, and the numerical annotations alongside the pie charts give the different effect categories. Each effect has been assigned an equal weight. On the basis of the cumulative number of effects, climate change can be considered the predominant driver of change, followed by human population growth.

and that of the EH suggests migration of Chinese elements (e.g., *Acer*, *Alnus*, *Betula*, *Celtis*, *Myrica*, *Salix*, *Viburnum*) into the northeast Himalaya via the WH corridor (Mehrotra et al. 2005). These migrant elements found new opportunities to colonize the evolving ecosystems and to diversify in the Himalaya. The geobiological dynamics initially ensured species' range expansion because of lower physical barriers followed by the formation of new elevated barriers promoting vicariance. A recent study of spiny frogs inhabiting Tibet, South China, and the Indo-Chinese region presents notable evidence of how the geological events of the Himalaya shaped the evolutionary history of the region's biota (see Che et al. 2010). Che and colleagues (2010) reported that the split of the subgenera *Nanorana* and *Paa* occurred around 19 million years ago, which coincided with the uplift of southern Tibet and the Himalaya about 20 million years ago. Diversification of the subgenus *Nanorana* on the Tibetan plateau took place about 9 million years ago, therefore associating the species' formation with geological events—the uplift of Tibet nearly 8 million years ago (see Che et al. 2010 and the references therein). The recent discovery of the oldest big cat fossil, *Panthera blytheae*, from the Tibetan Himalaya (Tseng et al. 2014) emphasizes the importance of the regional uplift as a backdrop for the diversification of the earliest living cats. Tseng and colleagues (2014) suggested that the Tibetan Plateau acted both as a training ground for Ice Age megaherbivores and as a refuge for different mammalian lineages.

The tectonic events, before and after the Miocene, resulted in the disruption and disturbance of barely stabilized Himalayan ecosystems and aided their colonization by better-adapted taxa. It is conceivable that frequent ecosystem disturbances in the formative periods of the Himalayan ecosystems and prevalent glaciation toward the

Table 1. A comparative account of the Himalayan biotic diversity and endemism with respect to India.

Taxonomic group	India			Himalaya		
	Total	Endemic	Percentage endemism	Total	Endemic	Percentage endemism
Angiosperms	17,000	5700	33.53	8–10,000	4000	40–50
Gymnosperms	64	8	12.50	44	7	15.91
Pteridophytes	1022	250	24.46	600	150	25
Bryophytes	2700	783	29.00	1737	556	32.01
Lichens	1950	–	–	1159	–	–
Fungi	13,000	–	–	6900	0	0
Mammals	372	44	11.83	300	12	4
Birds	1228	55	4.48	900	20	2.22
Reptiles	428	187	43.69	175	48	27.43
Amphibians	204	110	53.92	>100	42	~42
Fish (freshwater)	674	284	42.14	290	35	12.1

Source: Adapted from Pandit and Kumar (2013).

final phases paved the way for widespread colonization by exotic polyploids among plant species. A not-so-exhaustive analysis of the present-day relatives of 113 Himalayan fossil angiosperm taxa inhabiting the tropical and temperate zones, with Mediterranean, Malayan, Malesian-Decannian, and Sino-Japanese affinities (see Prasad 1993, Mehrotra et al. 2005), revealed that more than 72% of these species were polyploids. The remaining 28% were diploids with somatic chromosome counts of 24 or more and may have undergone at least one event of genome doubling, which is well documented in angiosperms (De Bodt et al. 2005). Recent research shows that the majority of genome duplications in angiosperms occurred around the Cretaceous–Tertiary boundary and that polyploids possess a greater facility in adapting to and colonizing disturbed habitats (Fawcett et al. 2009, Pandit et al. 2011).

Present-day biodiversity

With the final phase of the Himalayan uplift and the establishment of alpine and subalpine ecosystems, *Quercus semecarpifolia*, *Betula utilis*, *Salix* spp., *Juniperus* spp., and *Rhododendron* spp. represented the main components of the timberline forests and alpine shrub communities. Broadly speaking, floral elements, with predominant Euro-Caucasian-Mediterranean affinities, inhabit the WH region, and the Sino-Japanese, North American, and Malesian elements inhabit the EH region (Singh SP and Singh 1987, Pandit and Kumar 2013). A quantitative estimate of the present-day biodiversity of the Himalaya vis-à-vis the Indian subcontinent is given in table 1. High plant endemism, ranging from 30% in the WH to 40% in the EH, reveals the significant conservation value of the Himalaya (see Pandit et al. 2007). The Himalayan region houses four of the 34 global biodiversity hotspots (see Xu et al. 2009); 60 ecoregions, including 30 critical regions and 12 of the total 200 ecoregions across the globe; and 330 important bird areas. It also forms the primary center of diversity for numerous plant taxa, such as *Geranium, Meconopsis*, *Potentilla*, *Primula*, *Rhododendron*, *Sorbus*, and many others with high species diversity and endemism (Pandit and Kumar 2013). Even though high endemism is reported in the Himalayan plant species, this is not true for other taxa, such as birds. Johansson and colleagues (2007) suggested that, despite the high number of bird species (8% of the world's avifaunal taxa) in the Himalaya, the absence of isolation barriers is responsible for the limited endemism of the Himalaya avifauna (Trevor Price, Department of Ecology and Evolution, The University of Chicago, Chicago, personal communication, 17 June 2014). Birds show around 2% endemism at the species level but much higher endemism at the subspecies level because the Himalaya are a relatively young mountain range, and most of the taxa found there are invasive to the area, mainly from the East (Martens et al. 2011).

A generalized contemporary biodiversity profile of the Himalaya is summarized as follows: The Himalayan foothills up to 900 m in elevation are inhabited by tropical semideciduous forests of *Shorea robusta* (sal), *Terminalia tomentosa*, *Acacia catechu*, and *Dalbergia sissoo*. This region harbors some of the most charismatic flagship large mammalian species, such as the elephant, the tiger, several deer species, the wild dog, and other carnivores. A common mammal in the tropical and subtropical zones in the EH is the Hoolock gibbon (*Hoolock hoolock*). The Himalayan treepie (*Dendrocitta formosae*), the Himalayan woodpecker (*Dendrocopos himalayensis*), and the yellow-eyed babbler (*Chrysomma sinense)* are also commonly found in this region. To the immediate south, contiguous with these forests, lies the Terai (lowland) area, dominated by marshy scrubs and grasslands that harbor diverse fauna, including the one-horned rhinoceros, the Bengal tiger, the Asian elephant, and the Indian leopard. Some of the prominent conservation areas of the Indian subcontinent—namely

India's Dudhwa and Jim Corbett National Park in the west; Kaziranga, Manas, and Namdapha National Park in the east; and Nepal's Chitwan and Bardiya National Parks—are located in the Terai zone. At around 2000 m in elevation, forests of subtropical chir pine (*Pinus roxburghii*) and oak (*Quercus leucotrichophora*) dominate. Wild boar (*Sus scrofa*), Indian muntjac (*Muntiacus muntjak*), Himalayan griffon vulture (*Gyps himalayensis*), and kalij pheasant (*Lophura leucomelanos*) are the characteristic faunal species of this zone. The temperate regions of the Himalaya (2000–3800 m) are characterized by moist temperate coniferous forests of blue pine (*Pinus wallichiana*), deodar (*Cedrus deodara*), spruce (*Picea* spp.), and silver fir (*Abies pindrow*) and broad-leaved forests of oak–rhododendron, Indian horse chestnut (*Aesculus indica*), and maple (*Acer* spp.). The EH at higher elevations is also dominated by coniferous forests of *Abies densa*, *Tsuga dumosa*, *Juniperus recurva*, and *Larix griffithii* across the Indian, Nepalese, and Bhutanese Himalaya. Notably, the temperate WH forests have been dominated by the Mediterranean *C. deodara* since the Pliocene (around 3.5–2.5 million years ago), whereas a different conifer, *Larix griffithiana (= L. griffithii)* dominates the EH landscape. Himalayan musk deer (*Moschus leucogaster*), Mishmi takin (*Budorcas taxicolor taxicolor*), koklass (*Pucrasia macrolopha*), and Himalayan monal (*Lophophorus impejanus*) are typical faunal elements of the temperate region. The alpine vegetation of the Himalaya harbors more-diverse communities than does the temperate region. Between 3800 and 4500 m in elevation, the subalpine vegetation is dominated by various species of *Rhododendron* in the shrublands and in the meadows. The alpine zone, between 4500 and 5000 m, primarily consists of a dwarf *Rhododendron–Cassiope* community and dry alpine scrubs of *Juniperus communis*. The major faunal species of the temperate-alpine zone include the Himalayan brown bear (*Ursus arctos isabellinus*), the Himalayan blue sheep (*Pseudois nayaur*), the Himalayan tahr (*Hemitragus jemlahicus*), the Himalayan pika (*Ochotona himalayana*), the Himalayan snowcock (*Tetraogallus himalayensis*), and the snow leopard (*Uncia uncia*). In addition to these animals, the EH region harbors some distinct species, such as Mishmi takin (*B. taxicolor taxicolor*), and the red panda (*Ailurus fulgens*).

The aquatic biodiversity of the Himalayan freshwaters is unique and diverse. The rivers of the Brahmaputra and Ganga basins are home to endemic and endangered species such as the Gangetic dolphin (*Platanista gangetica*), the gharial (*Gavialis gangeticus*), and the golden mahseer (*Tor putitora*). There are nearly 298 species of fish in the Himalayan rivers, with as many as 29 endemic species (Bhatt et al. 2012). Bhatt and colleagues (2008) showed that the majority of the rivers in the Brahmaputra and Indus basins are dominated by a giant diatom, *Didymosphenia geminata*. The diatom has been described as a noxious invasive of the freshwaters in the Northern and Southern Hemispheres (Kumar et al. 2009, Kilroy and Unwin 2011). Studies on the Himalayan rivers have so far not indicated that *D. geminata* is an invasive species, as it has been reported to be in other parts of the world, but extensive dam building on the Himalayan rivers may soon alter this scenario (see Bhatt et al. 2008, Pandit and Grumbine 2012).

Why are the Himalaya worth protecting?

Some of the major geophysical changes following the formation of the Himalaya include the inception of the monsoon system, the development of glaciers, and the birth of a wide network of rivers. The origins of these rivers lie in nearly 54,000 glaciers, holding ice reserves of about 6100 cubic kilometers (km^3); therefore, the region is aptly described as the "water tower of Asia." The estimated glacier cover for the region is around 43,178–49,650 square kilometers (km^2), which constitutes the most extensive glacier cover outside Alaska and the Arctic (Bolch et al. 2012). The total water flow from the Himalaya to the plains is estimated to be around 8700 km^3 per year. In a recent study, Immerzeel and colleagues (2010) showed that snow and glacier meltwater accounted for 151% of the total discharge in the downstream areas of the Indus basin, followed by the Brahmaputra (27%), the Ganga (10%), the Yangtze (8%), and the Yellow (8%) river basins. Although some of the largest rivers flow through the region, the vast number of Himalayan inhabitants depend on the innocuous springs for their daily water needs. In recent years, numerous springs have dried because of reduced groundwater recharge, which has been attributed to climatic change and a shift in precipitation patterns, water diversion and withdrawals by dams, increased population pressure, deforestation, and top soil erosion, which are collectively detrimental to the water security of the rural Himalaya (see Tambe et al. 2012).

The ecosystem and biodiversity services for the local communities in the Himalaya include timber, medicinal plants, spices and condiments, fodder and pastures for livestock rearing, and irrigation and manure for agriculture. Studies on the link between biodiversity and the economy of an Indian Himalayan valley revealed that the income from agriculture accounted for 32%–36%, woollen products accounted for 18%–24%, the sale of livestock was 28%–38%, and the sale of medicinal plants was 12%–13% of the residents' total earnings (Farooquee and Saxena 1996). At regional scale, the Himalayan forests are responsible for maintaining soil fertility, hydrological balance, erosion control, and food security in the region (see Singh SP 2002). The ecosystem services of alder (*Alnus nepalensis*) for providing high soil nitrogen to cardamom plantations and other croplands in EH have been documented (Sharma et al. 1996). In the WH, the important ecosystem services of oak (*Q. leucotrichophora*) have been described in terms of soil development, the protection of nutrients, water retention, and the longevity of springs in a watershed (see Singh SP 2002). A review of the carbon sequestration dynamics in the Himalayan region suggests that the land-use changes and forest or soil degradation affect carbon pools significantly (Upadhyay et al. 2005). Besides several ecosystem services, the natural forests also act as a reservoir of high genetic diversity and local agrobiodiversity (see Singh SP 2002).

Drivers of Himalayan change

The following sections detail the drivers of Himalayan change.

Deforestation and ecosystem degradation. Commercial deforestation in the Himalaya on the Indian subcontinent started in the nineteenth century, during the British rule. In the last three to four decades, commercial exploitation of forests has continued unabated across the Himalayan nations as an easy source of revenue and for agriculture expansion and urbanization (see Pandit and Kumar 2013 and the references therein). Studies on the Indian Himalaya using satellite data projected that deforestation will reduce the total forest cover in the region from 84.9% of the value in 1970 in 2000 to 52.8% in 2100 (Pandit et al. 2007). Moreover, the dense forest areas are likely to decline from 75.4% of total forest area in 2000 to just 34% in 2100, resulting in the extinction of 23.6% of the species across various taxonomic groups. Similarly, the Pakistani Himalaya have lost 30% of their forest cover in the last three decades, which is ascribed mainly to commercial harvesting and mismanagement by the administration; the highest losses have been reported for the Basho Valley in the WH region of Pakistan, where the forests have been reduced by at least 50% since the valley opened to the world after the construction of a link road in 1968 (Ali et al. 2005). The data on deforestation in the Nepalese Himalaya has been equivocal, with World Bank estimates that suggest a reduction in forest cover by 50% over three decades (between the 1960s and the 1990s) and with others indicating a 1.3% forest cover loss per year in the 1990s (see Ives and Messerli 1989 and the references therein). The official data of the Department of Forestry indicates that Bhutan lost nearly 1300 hectares of forests in barely 4 years (2001–2005) from various infrastructure development activities. Studies have provided credible evidence of the presence of trees at 4000 m of elevation and above, and thick peat deposits in the Tibetan Plateau and the Hengduan Mountains at one time, which reveals that the region has lost extensive forest cover over the past 1200 years (see Ives and Messerli 1989).

Grazing by mounting livestock populations in the Himalaya is a potent threat to alpine pastures and their community structure. In a recent study, Bagchi and colleagues (2012) showed that grazing by domestic cattle promotes the dominance of grazing-tolerant species and lowers species richness and community evenness relative to the native herbivore populations.

Invasion by exotic species is yet another ecological change related to deforestation, habitat degradation, agriculture expansion, overgrazing, and climate change in the Himalaya (Telwala et al. 2013). The Himalayan foothills are fast being colonized by exotic invasives such as *Parthenium hysterophorus*, *Lantana camara*, and *Lagascea mollis*, whereas the subtropical and temperate elevations are being colonized by *L. camara*, *Ageratina adenophora*, *Polygonum hydropiper*, with members of Poaceae, Asteraceae, and Brassicaceae outnumbering other taxa (see Khuroo et al. 2007). Even though the alpine regions of the Himalaya, at present, may be relatively free from exotic invasions, mainly because of their geographic isolation, two important trends are clearly noticeable: (1) The native herbaceous species dominate and reduce species richness under the influence of domestic grazers (Bagchi et al. 2012), and (2) the native shrub communities are expanding and invading into alpine herbaceous communities in meadows, which is resulting in the shrinking and loss of those communities (Brandt et al. 2013, Telwala et al. 2013).

A variety of management frameworks have been suggested to curb the problems of deforestation and degradation in the Himalaya, ranging from joint forest management to community forest management. These mechanisms have not yielded the desired results because of a number of factors, including problems of scale and the efficacy of the institutional apparatus (Ives and Messerli 1989). The state's role of safeguarding and the local communities' role in the region's exploitation need to be altered in order to reverse the problem (see Ives and Messerli 1989). The United Nations–backed program Reducing Emissions from Deforestation and Forest Degradation (REDD) is one such mechanism that can ensure the participation of local communities as stakeholders with economic benefits. The efforts of national and international institutions such as the International Centre for Integrated Mountain Development (ICIMOD), in Kathmandu, in facilitating communication and negotiation regarding REDD across the Himalayan nations need to be widened and strengthened for better results.

Urbanization and infrastructure development. The Himalaya, in the last four decades, have witnessed the widespread growth of human settlements, with small villages transforming into huge towns and erstwhile towns converting into major cities (Pandit 2009). Rapid urbanization and the accompanying infrastructure development have followed high population growth across the Himalayan nations. The Afghani and Pakistani Himalaya have reported a near quadrupling of the human population in the last half century, whereas the Chinese and Indian regions have grown by 2 and 2.8 times, respectively (see figure 3). The human population density in the Indian Himalayan states increased 4.5 times from 1950 to 1992 (Pandit 2009). The official records of Bhutan's Ministry of Works and Human Settlement indicate that the capital city, Thimpu, grew at an average annual growth rate of 12.6% between 2000 and 2005. Moreover, more than 40% of the urban population of Bhutan is concentrated in the two major cities of Thimpu and Phuentsholing. Nepal's Central Bureau of Statistics has reported a 25% increase in population, from 24 million in 2000 to 30 million in 2012, with a nearly 8% increase in the population density; the urban population in Nepal increased by 16 times over the last five decades.

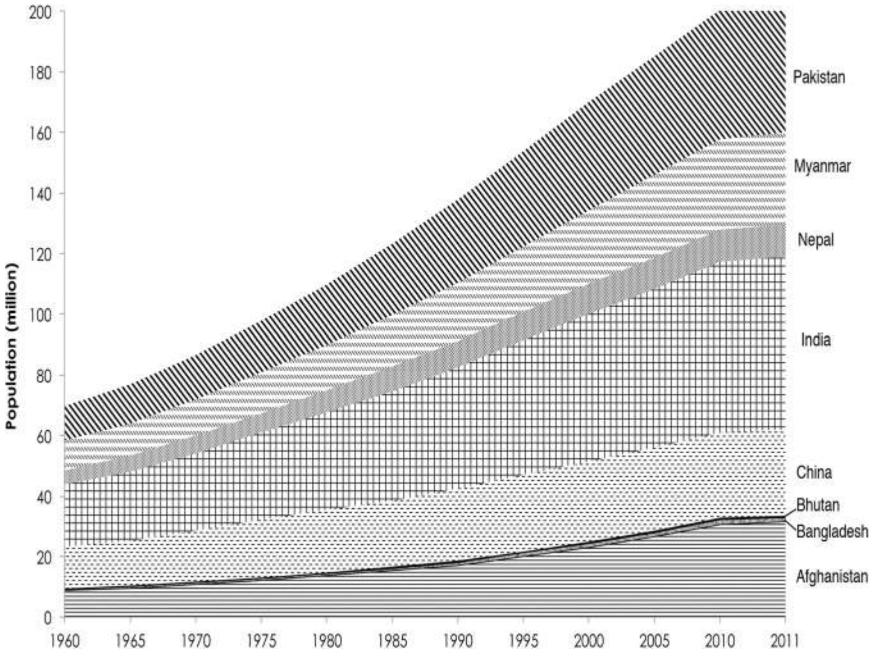

Figure 3. Country-wise human population growth in the Himalaya in the last half century (1960–2011). Note that the most rapid growth (nearly 400%) has occurred in the Himalayan areas of Pakistan and Afghanistan, as opposed to 200% and 280% in the Chinese and Indian regions, respectively.

There is little published information on rural-to-urban migration in the Himalayan region, but the available evidence suggests that it is fast emerging as a major livelihood strategy for various communities (Goodall 2004). Historically, the rural Himalayan populations have lived in widespread poverty because of the isolation induced by topography and inclement weather and because of limited avenues of economic growth. However, the rapid expansion of road networks across the Himalaya during the last couple of decades for strategic reasons, such as military operations, mining, and hydropower, has facilitated increased migration and tourism in the region. The Himalayan nations added about 10,000 km of highways in the two decades between 1960 and 1980 (Ives and Messerli 1989). The total length of roads has nearly doubled in Nepal, from 4740 km in 1998 to 9400 km in 2006–2007. Likewise, the highway and road network in Bhutan increased by 43% between 2001 and 2010. Reports in the grey literature suggest the construction of a 58,000-km road network by China in Tibet that includes five major highways. With respect to migration, the official estimates from 2005 suggest that, in Bhutan, 111,770 people had moved from rural to urban areas, compared with 19,992 people who had undertaken the reverse migration. The 2001 census from Nepal reported 25.5% rural-to-urban migration within the country. Likewise, the Indian census reports of 2001 revealed that the work or employment factor was a major cause of rural-to-urban migration in the Himalayan states (28.9% in Jammu and Kashmir, 40.9% in Himachal Pradesh, 25.9% in Uttarakhand, 41.8% in Sikkim, and 29.7% in Arunachal Pradesh).

A steep growth in tourism for leisure and pilgrimage has been a significant driver of urbanization and anthropogenic pressure on the Himalaya; tourism has become a mainstay of the local Himalayan economies (see Pandit 2013). The number of tourists visiting Tibet increased by 29 times between 1990 and 2001; a total of 686,000 tourists visited Tibet in 2001 (Baiping et al. 2004). In the Annapurna Conservation Area of Nepal, the number of lodges increased by a factor of 9.3 between 1980 and 2002, with the annual consumption of fuel-wood and kerosene estimated to be about 3600 tons and 475,000 liters, respectively (Nepal 2008). The tourism-driven ecological footprint of Manali, an important national and international tourist destination in India, showed an increase of over 450% between 1971 and 1995 (Cole and Sinclair 2002). India's WH states have witnessed abrupt growth in the number of pilgrims during the last two decades, with over 2 million annual visitors. In India, the majority of religious shrines are located in the alpine Himalayan areas, in the close vicinity of glaciers. Therefore, a huge congregation of pilgrims presents a potent threat to these fragile Himalayan ecosystems and, at times, results in grave human tragedy, as was witnessed in the Kedarnath Temple region on 17 July 2013 because of a cloudburst and lake breach, which killed several thousand devotees and destroyed the town around the shrine. Reports in the grey literature, quoting officials of the Pakistani Ministry of Tourism, have indicated a huge (4.5-fold) increase in tourists visiting the Neelum Valley of Pakistan-administered Kashmir between 2010 (130,000) and 2012 (600,000).

These surging tourist numbers to the Himalaya call for a proactive response, including curbs on tourist arrivals, the imposition of an environmental tax on tourists, and controls and sanctions against rampant and haphazard urbanization, as has been elaborated elsewhere (see Pandit 2013). On the positive side, there are several success stories that promote conservation and help alleviate the economic conditions of local communities in the Himalaya; these initiatives need to be replicated. The efforts of the Sikkim government, enunciated in their ecotourism policy document of 2011, provide policy guidelines and financial incentives for practicing socially and culturally embedded tourism. The policy incentivizes local communities to host tourists in their traditional homes, which are built using locally available material, and to offer meals made from locally grown crops and vegetables (see Pandit 2009). Similarly, Himalayan Homestay, in Indian Ladakh, is a novel community-based ecotourism initiative by the Snow Leopard Conservancy that links tourism and conservation through culture and environment-friendly homestays for tourists. The generated income supports the local Himalayan communities and protects the endangered and endemic snow leopard.

Overharvesting and hunting. Of the more than 10,000 angiosperm species found in the Himalayan region, nearly 1800 have been reported to be of medicinal importance, and 700 are of edible value. Cultivated medicinal plants (approximately 20% of the local species) and those harvested from the wild (around 80%) are known to constitute a sizeable economic activity of the Indian Himalayan communities (Kala et al. 2004). In India, the medicinal-plant-related trade is estimated to be approximately US$1 billion per year, and nearly 30% of these medicinal plant products are of Himalayan origin (Kala et al. 2004). A conservative estimate of the annual medicinal plant trade in the alpine and subalpine Nepalese Himalaya range from 480 to 2500 tons, valued at US$0.8–3.3 million (Olsen and Larsen 2003). Markets in Tibetan Lhasa and Dechen support an extensive trade in several threatened species (e.g., *Fritillaria* spp., *Panax* spp., *Saussurea* spp.; Salick et al. 2006). Medicinal plant poaching in the Himalaya has flourished afterin market-dominated economies, which has resulted in a shrinking of those plants' natural populations (Pandit and Babu 1998).

The rising demand for the animal products, such as cashmere wool, in the western markets is increasingly affecting the Himalayan native biodiversity. The economic motivation of a billion-dollar cashmere industry pushed the population of cashmere goats to a whopping 123 million in the mid-1990s in China, which has emerged as the largest producer of cashmere wool. The consequences are being felt in terms of the ecological degradation of the trans-Himalayan highlands. In a recent study on the globalization of the cashmere market, across seven study areas in Mongolia, India, and China's Tibetan Plateau, Berger and colleagues (2013) reported a decline in the native large mammalian species, including at least eight Asian endemic species: the saiga, the chiru (*Pantholops hodgsoni*), the Bactrian camel (*Camelus bactrianus*), the snow leopard (*Panthera uncia*), the khulan (*Equus hemionus*), the kiang (*Equus kiang*), the takhi (*Equus przewalski*), and the wild yak (*Bos mutus*).

Recognized as the second most important driver of species extinctions after habitat destruction, hunting in the Himalayan region is carried out for subsistence needs and for quick and higher economic gains. The poaching of species of high economic value, which include wild cats for skin and rhinos for horns, is carried out by organized hunting. However, opportunistic hunting and routine snaring are mainly intended for subsistence requirements, food, and cultural practices (Kaul et al. 2004). Chinese official records show that between 1994 and 1997, about 40% of the illegal wildlife trade took place in the Himalayan region. In the Indian Himalaya, the hunting of mammals is more prevalent in the EH, where over 94 species are targeted, than in the WH, where 22 species are reported to be hunted (Velho et al. 2012). Traditionally, hunting in the Nepalese Himalaya was carried out by hunter–gatherer communities known as *Raute*, who hunted in groups and led a nomadic life. The hunting of wildlife was banned in 1991 by the Nepalese government, with the exception of the Himalayan blue sheep (*Pseudois nayaur*), the tahr (*Hemitragus jemlahicus*), the Indian muntjac (*M. muntjak*), the hog deer (*Hyelaphus porcinus*), and the wild boar (*S. scrofa*). In the Bhutanese Himalaya, human–wildlife conflicts are emerging as a new challenge for wildlife conservation in the region. Local communities across the Himalaya, including in Bhutan, carry out retaliatory killing of wild animals because of damage to farmers' crops and livestock by wild boar (*S. scrofa*), Himalayan black bears (*Ursus thibettanus*), sambars (*Cervus unicolor*), and dholes (*Cuon alpinus*). Realizing the criticality of these conflicts and in order to address this mounting problem, the Bhutanese Nature Conservation Division has made a set of recommendations to be included in the Bhutanese tenth 5-year plan (2008–2013).

Multilateral and bilateral cooperation across the Himalayan nations is central to conserving the unique biodiversity of this global biodiversity hot spot. Cooperation between India and Nepal in the conservation management of protected areas such as Kanchandzonga National Park (Sikkim, India) and the Kanchenjunga Conservation Area (Eastern Nepal) and among India, China, and Myanmar such as Namdapha National Park (Arunachal Pradesh, India), the Gaoligongshan National Nature Reserve (Yunnan Province, China), and Hkakabo Razi National Park (Kachin state, Myanmar) can become model sites for transboundary cooperation in conservation. A notable experiment in Nepal is underway in which local communities have been managing the Kanchenjunga Conservation Area since 2006. The responsibility of managing and monitoring the Kanchenjunga Conservation Area rests with the management council, which represents all local stakeholders in the region, instead of with state institutions, and local traditional knowledge is being effectively employed to formulate sustainable livelihood practices. An equally important role in conservation could be played by religious institutions, given their profound impact on various activities of the local communities. A notable suggestion by Li and colleagues (2014) that Buddhist monasteries could help potentially conserve 80% of the global range of snow leopards needs serious consideration from state conservation authorities.

Hydropower development. The Himalaya are spread over 10 river basins, including the Ganga, the Indus, and the Brahmaputra, which largely flow into and within Indian territory (figure 1). Because of their perennial nature, the Himalayan rivers have been visualized as important sources of hydropower generation. The cumulative hydropower potential of the Himalayan rivers is reported to exceed 500 gigawatts. The Nepalese, Pakistani, Bhutanese, and Indian Himalayan regions are reported to have over 550 hydropower projects already in existence or under construction.

Figure 4. One of the largest reservoirs in the Himalaya, created by the damming of the Ganga river in the middle Himalaya. Dams and reservoirs are identified with preventing floods but also with inundating vast areas of forests, which can lead to the loss of habitat and species extinctions. Photograph: Maharaj K. Pandit.

In sharp contrast to the proposed 292 dams in the Indian Himalayan region, China is planning over 700 projects in Tibet alone. Dam construction in the Indian Himalaya over the next couple of decades is likely to result in one of the highest average dam densities in the world, with one dam for every 32 km of river channel (Pandit and Grumbine 2012). Although the spatial distribution of the proposed dams spans from tropical areas to alpine valleys, 88% are located in the subtropical and temperate ecosystems that are considered to be the most vulnerable to species losses driven by land-use changes (Pandit et al. 2007). In addition, over 27% of these dams would be located in relatively pristine forests. Hydropower infrastructure is likely to submerge and affect nearly 1700 km^2 of the Himalayan forests (see figure 4). The habitat fragmentation caused by such projects is likely to reduce tree species richness by 35%, tree density by 42%, and tree basal cover by 30% in the remaining undisturbed forests (Pandit and Grumbine 2012). The study showed that by 2025, dam-building activities alone are likely to result in the loss of 22 angiosperm and 7 vertebrate taxa. The neighboring Three Gorges Dam (not in the Himalaya), on the Yangtze River, is reported to have caused massive impacts on the river's ecosystem, including adverse effects on more than 40 fish species, 19 of which are endemic (Fu et al. 2003). The dam is reported to pose extinction risk to endemic fish species such as the Chinese sturgeon (*Acipenser sinensis*), the river sturgeon (*Acipenser dabryanus*), and the Chinese paddle fish (*Psephurus gladius*) and to living fossils such as the Chinese river dolphin (baiji, *Lipotes vexillifer*; Wu et al. 2003). A large-scale reduction of biodiversity and ecosystem services, including damage to food security and human livelihood, are anticipated or have already been experienced in the Mekong River Basin across China, Myanmar, Laos, Thailand, Cambodia, and Vietnam (Xu et al. 2009). The dams on the Mekong are specifically reported to have negatively affected native endemic species such as the migratory Mekong giant catfish (*Pangasianodon gigas*), the elephant ear gourami (*Osphronemus exodon*), the thicklip barb (*Probarbus labeamajor*), and the Laotian shad (*Tenualosa thibaudeaui*). Mathematical models suggest that 27 dams constructed on the Mekong River and its tributaries would result in a loss of 20% of the migratory fish biomass (Ziv et al. 2012).

The conflict between dam-building activities and the Himalayan ecology needs serious attention from policymakers. Although there is need for a trade-off between conservation and development, the Himalayan nations would do well to carry out urgently needed reforms in their hydropower policies. These modifications include the exploration and development of alternative sources of electricity generation, a reduction in transmission and distribution losses, power-sharing and exchange, improvements in the environmental impact assessment processes of the member countries, reforms in dam resettlement rules, and a proposal for the establishment of a transboundary river basin management system throughout the Himalaya (see Grumbine and Pandit 2013). Biodiversity losses can be minimized if dams in and around already degraded forest areas are prioritized and those around dense forests are deferred, given up, or at least investigated in detail.

Climate change. Recent studies show that the Himalaya are warming three times faster than other regions of the Earth; an annual increasing trend of 0.06° Celsius (C), as opposed to the global average of 0.02°C, has been reported (Shrestha et al. 2012). The Chinese Himalaya showed an increase of 0.015–0.059°C per year between the 1960s and 2006 (Xin et al. 2012), whereas the increase on the Yunnan Plateau was 0.3°C per decade over the last four decades (Fan et al. 2011). The Nepalese Himalaya temperatures are likely to increase by 1.2°C, 1.7°C, and 3.0°C by 2030, 2050, and 2100, respectively (see Shrestha and Aryal 2011). The WH region, including many Indian states, Pakistan, and Afghanistan, is reported to have experienced a temperature increase of 0.46°C per decade between 1971 and 2007 (Kothawale et al. 2010). The high-elevational ranges in the EH state of Sikkim, in India, provide the first evidence of warmer winters in the region relative to those of the last two centuries. The mean temperatures of the warmest and the coldest months have increased by 0.76°C and 3.65°C, respectively (Telwala et al. 2013). It is feared that the cumulative effects of warming may affect the nature and intensity of monsoons and the associated precipitation in South and East-Central Asia.

The warming has affected the Himalayan glaciers significantly; the loss of glacier cover due to warming ranges from 1.5%–2% over the last three decades in China and of 16% over the last four decades in India (Kulkarni et al. 2011). The loss of glacier cover in India's WH region (Garhwal and Ladakh) ranges from 4.6% to 14% over the past four decades (Schmidt and Nüsser 2012). That the Himalayan glaciers are in a state of peril because of recent warming is evident from studies using ice cores from Naimona'nyi Glacier in the Tibetan Himalaya (6050 m in elevation), which suggest no net accumulation of ice since at least 1950 (Kehrwald et al. 2008). Kehrwald and colleagues (2008) noted the possibility of the loss of other glaciers in the Himalaya, under influence of warming, and pointed to a grim scenario of water resources for the vast human population dependent on the Himalayan rivers.

Biologically, the most manifest effects of warming and altered precipitation scenarios in the Himalaya include changes in plant phenology, shifts in species' geographic ranges and tree lines, and the spatial contraction of plant communities. Studies indicate that species of *Rhododendron* flower a month earlier than their previous known flowering period (see Xu et al. 2009). Telwala and colleagues (2013) showed that range shifts have occurred in 87% of the 124 endemic plant species over the last two centuries, with a mean upward displacement rate of 27.53 m per decade. Likewise, tree lines in the Tibetan Plateau are reported to have shifted upward by 67 m and tree limits by 45 m, a result based on a comparison of repeated photographs in 1923 and 2003 (Baker and Moseley 2007). Endemic species, in particular, are at greater risk because of their limited geographical ranges. Climate change is therefore likely to result in widespread species extinctions in the Himalayan region, where plant species endemism is high. The alpine meadows are shrinking under the impact of the upward march of woodland species, and endemic species are being replaced by exotic invasives in the Himalaya (see Telwala et al. 2013 and the references therein).

Besides affecting biodiversity, climate change is increasingly being reported to affect agriculture and human health. The local farming communities in the Himalaya attribute a decline in crop productivity and quality to the increased temperature levels (Basannagari and Kala 2013). Climate change resulting in reduced water availability is likely to threaten the food security of approximately 63 million people in the Himalayan riven basins (Immerzeel et al. 2010). The spread of vector-borne diseases, such as diarrhea, malaria, and dengue fever, to previously unsuited higher elevations in the Himalaya is likely to unfold as a consequence of climate change, and the effects of malaria, Japanese encephalitis, kala-azar, dengue fever, and filariasis are likely to be exacerbated in the region in the near future (Sharma 2012).

Although steps are being taken by governments, with help from national and international institutions and nongovernmental organizations (NGOs), in research and adaptation to face the challenges of warming on crop productivity, similar efforts to conserve natural biodiversity in the wake of the Himalaya warming are largely nonexistent. Protected areas can serve as an important land-use tool in resilience thinking and adaptation to climate change. ICIMOD has estimated that there are a total of 483 protected areas in the Himalaya, with a geographic coverage of 1,667,391 km^2, representing about 39% of the region's terrestrial area. However, most of these protected areas are isolated from each other, with little interconnectivity. Therefore, transnational cooperation in managing conservation areas through linking national parks with continuous physical boundaries and varying elevational profiles will help create natural corridors for uninterrupted species migrations influenced by climate change.

Natural hazards. The geological nature of the Himalaya and the related tectonic activities make the region highly vulnerable to natural hazards. Earthquakes, landslides, floods, and glacial lake outburst floods (GLOFs) are some of the natural hazards that induce ecosystem transformations and portend far-reaching consequences for millions of people (Pandit 2013). Major earthquakes of magnitude 8 and above on the Richter scale have been predicted for the Himalaya, which are likely to affect about 40 million people and 3000 settlements, potentially killing between 15,000 people in the sparsely populated Western Nepal and 150,000 near Dehra Dun in India (Wyss 2005). Landslides, a common feature of the Himalayan landscapes, are primarily caused by various geological discontinuities but are also induced by human activities, such as road construction and infrastructure-building activities such as dams. The major impacts of landslides in the Himalaya range from the loss of human lives and property to a triggering of flash floods by the formation of temporary dams, with devastating effects. A recent study based on a thousand-year geological record of floods in the upper Ganga valley, in the Himalaya, underscores the crucial role of landslides in floods and projects that floods will possibly worsen with the increasing intensity of monsoons over the next century (Wasson et al. 2013). GLOFs are a major potential natural hazard in the Himalaya. ICIMOD has reported as many as 200 dangerous glacial lakes as potential causes of GLOF and the ensuing devastation in the Himalayan region. An ICIMOD report (*www.unisdr.org/files/14048_ICIMODGLOF.pdf*) documented 34 known GLOF events in the Himalayan region so far (4 in Bhutan, 16 in China and the TAR, and 14 in Nepal). The Chinese Academy of Sciences reported that, in August 2000, a GLOF event on the Tibetan Plateau destroyed more than 10,000 houses and 98 bridges and caused financial losses of about US$75 million. The threatening consequences of GLOFs in the Himalaya are exemplified by a recent study of the Shako Cho glacial lake, in the Sikkim Himalaya, whose margin, if it is breached, could release 16 million cubic meters (m^3) of water at an astounding rate of 7000 m^3 per second (Worni et al. 2012). The frequency of GLOF events could greatly increase in the near future because of the combination of a projected increase in rainfall and warming in the Himalaya.

In view of the likelihood of an increased frequency of natural hazards in the Himalaya, mitigation measures through effective monitoring and research are needed to prevent or at least reduce the scale and intensity of the losses of human lives and property. A transnational framework for effective monitoring, forecasting, and information sharing of these events and hazards, along the lines of tsunami warning systems, needs to be put in place (see Pandit 2013). The recent efforts of ICIMOD to focus the attention of policymakers in the Himalayan nations on the looming threats from GLOFs and other floods are timely but the acceptance of its directions and advice remains a formidable challenge.

Conclusions

Conservation programs in the Himalayan region are mandated by government agencies, but there is little transnational coordination. Cooperation among the Himalayan nations is vital for designing a robust conservation strategy and in meeting the numerous recent challenges threatening the Himalaya. Various regional research institutions and NGOs are engaged in research and raising awareness on the conservation of the Himalaya and its natural resources. India's Almora-based Govind Ballabh Pant Institute of Himalayan Environment and Development and the Centre for Inter-Disciplinary Studies of Mountain and Hill Environment at the University of Delhi, through their multiple research and development programs, aim to balance environmental conservation and economic development. Outreach activities of regional NGOs, such as the Ashoka Trust for Research in Ecology and the Environment, in India's EH; the Himalayan Wildlife Foundation, in Pakistan; Bird Conservation Nepal; the Royal Society for Protection of Nature, in Bhutan; and the Bhutan Trust Fund for Environmental Conservation are some of the leading efforts in conservation and socioeconomic development in the Himalaya. International institutions such as ICIMOD and NGOs such as the MacArthur Foundation, the World Wildlife Fund, the International Union for Conservation of Nature, and BirdLife International actively contribute to conservation and development initiatives in this region.

Finally, because the entire Himalayan region remains a highly militarized zone, a pragmatic assessment will indicate heavy odds against multilateral efforts unfolding soon. The limited carrying capacity of the Himalaya demands that all efforts be made to ensure state and public participation in enforcing various sustainable policies on land use, administrative accountability, river regulation and use, and biodiversity conservation. That said, the cumulative efforts of public and private enterprise will yield limited desired results unless urgent steps are taken to curtail the burgeoning human population in the Himalaya. The role of primary, secondary, and tertiary educational institutions in teaching more Himalayan-region-based curricula and increased funding for quality research is a long-term but crucial ingredient in achieving results for a safe space for the Himalaya.

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