High-Altitude Ecosystem Interfaces in the Hindu Kush Himalayan Region

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Mountains harbour an extremely high level of biological diversity as a result of the compression of eco-climatic zones along sharp altitudinal gradients, the diversity of habitats produced by micro-topographic variation, and a variable directional orientation with rapid changes in aspect. Understanding the nature of high-altitude ecosystems, their interfaces, and their response to climatic and non-climatic drivers will be crucial for long-term conservation and development planning. The development of landscape ecology has introduced the concept of boundaries (together with patches) as the essential structural and functional components of landscape mosaics. Over the last decade, the term 'ecosystem interface' has been used more frequently in a comprehensive context by conservationists and planners, while considering transboundary landscapes and anthropogenic disturbances and taking into account crosscutting issues related to policy, governance, and regional dataset sharing. The terms 'ecosystem interface' and 'ecotone' and are virtually synonymous, but ecotone is more commonly used by traditional community ecologists and ecosystem interface by natural resource managers and landscape ecologists. In this paper, the authors try to give a clearer definition of the term ecosystem interface; discuss the associated patterns, structures, and specialities; and analyse the challenges and perspectives of ecosystem interfaces in the Hindu Kush Himalayan region.

Keywords: ecotone; high-altitude ecosystem; interface; transboundary landscapes

Introduction

Mountains occupy nearly 24% of the global land surface and directly support over 12% of the world's population that lives within these regions (Sharma et al. 2010). One-fifth of humankind derives a vast array of ecosystem goods and services from the mountains, including freshwater, energy, timber, a wide variety of bioresources, and opportunities for recreation and spiritual renewal. Mountains harbour an extremely high level of biological diversity, which results from the compression of eco-climatic zones along sharp altitudinal gradients, the diversity of habitats produced by micro-topographic variation, and the variable directional orientation with rapid changes in aspect (Koerner 2003). Nearly half of the world's 34 biodiversity hotspots are located in mountain areas. Owing to their geographical isolation and singular biophysical setting, many mountain areas exhibit high levels of endemism and rapid evolutionary processes. At the same time, mountains are home to a multitude of ethnic communities who have inherited and nurtured rich cultural practices, farming systems, and related traditional knowledge (CBD 2010). However, mountain ecosystems are among the most fragile in the world and are under severe threat from climate change, invasive alien species, globalization, urbanization, and other anthropogenic pressures.

The Hindu Kush Himalayan (HKH) region is one of the largest and most assorted mountain settings in the world, embracing 4.3 million square kilometres of land with several parallel mountain ranges, such as the Karakoram, the Hengduan Mountains, the Himalayas, the Hindu Kush, and the Tibetan Plateau, all comprising diverse landscapes of mountains, plateaus, river valleys, and adjoining foothills. The region is well known for geo-hydrological, biological, cultural, and aesthetic values. The eco-climatic conditions range from tropical (<500 masl) to high alpine and nival zones (>6,000 masl), with a principal vertical vegetation regime representing tropical and subtropical rainforests; temperate broadleaf, deciduous, or mixed forests; temperate coniferous forests; alpine moist and dry scrub; meadows; and desert steppe (Pei 1995; Guangwei 2002).

The HKH region is inhabited by more than 210 million people representing diverse ethnic and sociocultural groups. In addition, 1.3 billion people living in the downstream areas depend on the ecosystem goods and services flowing from the region. Based on the physical features, the HKH region is divisible into two sub-regions: the mountainous area, which is rugged and varies in altitude and aspect, thereby harbouring extremely diverse forest types known on earth; and the vast Tibetan plateau, also known as the 'Roof of the World', generally located above 4,000 masl, and encompassing grasslands, desert steppe, and high-altitude wetlands. The region hosts all or part of four Global Biodiversity Hotspots: the Himalayas, Indo-Burma, Mountains of South-West China, and Mountains of Central Asia (Mittermeier et al. 2004; Chettri and Shakya 2008). In terms of land cover, recent estimates show that the HKH region is 14% forest, 26% agriculture (including areas with a mixture of natural vegetation), 54% rangeland, 1% water bodies, and 5% permanent snow and glaciers. Approximately 39% of the area is included in a protected area network. This results in a new interface for ecosystems, i.e., the transitional zone between protected areas and other land use categories.

The past few decades have witnessed unprecedented changes in the patterns of resource use and developmental activities in the HKH region under the influence of globalization and socioeconomic transformation of the societies. These, coupled with a rapidly changing climate, pose serious threats to the sustainability of the ecosystems, especially at higher altitudes, which are ecologically fragile and extremely sensitive. With the exception of a few empirical studies (such as Maharana et al. 2000a, 2000b; Baral et al. 2007, 2008; Badola et al. 2010; Chen and Jim 2010), there have been no serious efforts to enhance scientific understanding of the significance of ecosystem interfaces and the value of the ecosystem services of the HKH region. Thus, there is an increasing need to promote in-depth research on high-altitude ecosystem interfaces and develop sound methodologies for monitoring, restoring, and valuing them in order to ensure that their value is realized. In terms of ecosystem services, the high-altitude environments are crucial as they form the upper catchments of the Himalayan rivers that serve as lifeline for both the mountain people and those living downstream. However, owing to the physically challenging and hostile environment and limited growing season, these areas offer limited livelihood opportunities. Planned developmental activities, rapid changes in land use practices, and overexploitation of natural resources in such areas can severely affect the flow of ecosystem goods and services from the mountains and the wellbeing of human populations both within and outside the region (Sharma and Yonzon 2005; Sharma et al. 2010; Tse-ring et al. 2010). Understanding the nature of high-altitude ecosystems, their interfaces, and their response to climatic and non-climatic drivers, will be crucial for long-term conservation and development planning.

This article deals with the concept and salient features of high-altitude ecosystem interfaces in the HKH region, the key issues and challenges for managing the interface areas, and strategies for participatory action research and monitoring.

From Ecotone to Ecosystem Interface

Modern concepts in landscape ecology recognize the significant role of heterogeneity in space and time. Heterogeneity in the landscape is created mostly at the junctions of two or more ecosystems. Traditionally, the junctions between different ecosystems or biomes have been termed 'ecotones', a term first proposed by FE Clements in 1905, and subsequently used widely by a large number of ecologists across the globe (Clements 1905; Tansley and Chipp 1926; Odum 1983). The study of ecotones gained increased momentum after the 1970s. The most recent and best accepted definition of ecotone comes from the Scientific Committee on Problems on the Environment (SCOPE) meeting held at the International Council of Scientific Unions, Paris, France in 1987, according to which the ecotone is a "zone of transition between adjacent ecological systems, having a set of characteristics uniquely defined by space and time scales and by the strength of the interactions between adjacent ecological systems" (Holland 1988). The term 'ecological systems' makes the definition scale independent and the concept is useful as an abstract framework for organizing the descriptive characteristics and properties of ecotones in general (Risser 1995). The reference to "strength of the interactions" stresses that interfaces are sites of exchange of energy, materials, and organisms between adjacent ecosystems or habitat patches.

In nature, the boundaries between two different ecosystems are usually gradual and seldom abrupt. The physical width of the boundary area may vary from a few metres to several kilometres depending on the systems considered, but the mutual influences may reach much further. Examples of distinct boundaries of ecosystems include the timberline in alpine belts, and the riverine boundary between terrestrial and aquatic ecosystems. In many cases, the physiologically determined limits of species occur within ecotones. These transition zones may be sensitive to environmental changes; thus monitoring of ecotones might offer a way to detect effects such as immediate biotic responses to climatic changes. The transitional belts may also act as buffer zones between adjacent communities, serving as semi-permeable barriers across which energy, nutrients, and propagules flow, or as landscape boundaries that potentially confer stability to adjacent communities (Holland 1988). Understanding the structure, function, and dynamics of these belts is critical to developing objective criteria for measuring changes in the attributes of ecological boundaries that reflect environmental change. Thus ecological boundaries can be viewed not only as a signal amplifier for outside interference, but also as an important zone for research on global change.

The terms 'ecotone' and 'ecosystem interface' are almost synonymous, but ecotone is generally used by academics and traditional community ecologists, whereas ecosystem interface is used more by natural resource managers and landscape ecologists. The use of 'ecotone' was prevalent until the 1960s among plant ecologists who worked in a somewhat isolated manner at distinct scales such as along the boundaries of forests, rangelands, and woodlands (Risser 1995). For most classic ecological research, ecotone is still defined purely as a transition zone between plant communities. Within this, ecozones are considered to be intermediate zones between two or more plant communities where the processes of exchange or competition between neighbouring communities or subunits of communities occur.

The development of landscape ecology brought the concept of boundaries (together with patches) as essential structural and functional components of landscape mosaics (Cadenasso et al. 2003). Climate, topography and aspect, soil characteristics, species interactions, physiological parameters, and even population genetics are important considerations at ecological boundaries, depending on the scale. Recently, researchers on landscape boundaries suggested that it would be desirable to broaden the term ecotone. In the past decade, conservationists and planners who adopted an 'ecosystem approach' in landscape conservation, more frequently used the term 'ecosystem interface' to reflect the comprehensive context used when considering transboundary landscapes and taking into account crosscutting issues related to policy, governance, and regional data sharing (Sherpa et al. 2003; GoN/MoFSC 2006; Chettri et al. 2007; Sharma et al. 2007). Generally speaking, 'ecosystem interface' shares similar ecological characteristics and functions with 'ecotone', especially the geographical spatial dimension, but can be viewed as an integrated context with both biological and anthropogenic dimensions on a landscape scale, and as a dynamic, multidimensional transition zone that exhibits greater internal heterogeneity than adjacent biomes. It can also be defined as the transition zone where one biome changes to another and the land use practices change accordingly. For example, in the HKH region, an alpine treeline is not only the ecotone between an alpine meadow and sub-alpine forests, it is also the 'interface' between pastoral transhumance and other land use practices, although the width of the belt is variable across the region.

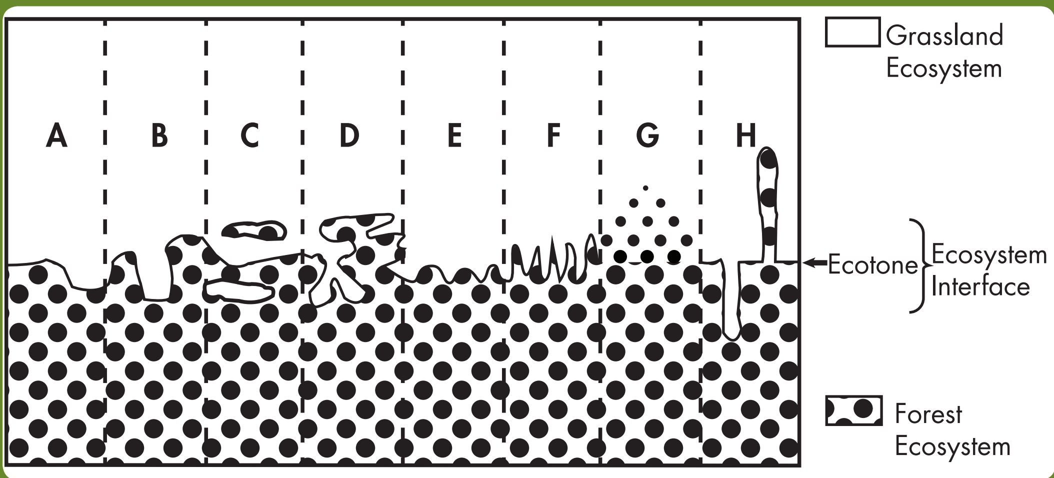
Ecosystem Interface Patterns

An ecosystem interface is often characterized by a transition from one biome to the other, and is not necessarily marked by changes in the physical or topographic features. It is scale dependent and variable in space and time. When the resolution is finer, every boundary becomes blurred (Erdos et al. 2011). In reality, most natural boundaries represent transition zones along an environmental gradient (Armand 1992). Depending upon the steepness of the gradient and the scale, lines may be sharp or indicative. Even along the most prominent natural boundaries such as riverine forests and alpine timberlines, two or more parallel lines can be visualized when viewed at fine scale, depending upon the micro-habitat parameters. Thus factors related to the environment and availability of resources may change along a transition zone depending upon the micro-habitat preference. Daubenmire (1968) recognized four general types of boundaries between plant communities:

i) Abrupt transitions caused by discontinuities in an underlying environmental gradient;
ii) Gradual blending of vegetation due to smooth environmental gradients;
iii) 'Mosaic' interfaces where peninsulas and islands from each community extend into the other, probably as a result of local heterogeneity in soil or microclimate; and
iv) Sharp transitions even on smooth environmental gradients due to biotic interactions among organisms.

The first three are based on community distribution being closely related to controlling factors in the environment e.g., soil moisture. Each is then distinguished by the abruptness and the degree of spatial heterogeneity within the interface. The fourth type is unique in having the control of environmental factors usurped by biotic interactions such as competition or mutualism (Armand 1992). Figure 1 illustrates graphically some different types of boundaries between natural ecosystems, in this case the interface between forest and grassland ecosystems.

Figure 1: **A generalized model showing different forest-grassland interfaces:** A, B), simple interfaces with equal and homogeneous surfaces; C) inclusion of one type into the other, creating multiple interfaces; D) complex interfaces, E, F) different patterns of interface which lengthen the total edge; G) diffusion of one interface into the other without a prominent boundary; H) interface that could be formed as a result of a peculiar topographic or biotic interference.



The shapes of the ecosystem interfaces are idealized models interpreting the natural transitions; real natural transitions can be more complicated. Changes in the physical environment may produce a sharp boundary, as in the case of the alpine timberlines, especially between the krummholz (the stunted forest characteristic of a timberline) zone and alpine meadows. Elsewhere, more gradually blended interface areas can be found together in various proportions. The complexity of ecosystem interfaces has encouraged ecologists to use different theoretical tools to explore their properties. Recently, ecological boundaries have frequently been examined using a structural or functional approach (Yarrow and Salthe 2008). Salthe (1985) emphasizes the role of structural units as parts of hierarchical systems. Such units have boundaries that constrain what states they can assume and what processes occur within. A structural approach is conceptually in line with the majority of edge detection methods currently used in boundary studies (Fagan et al. 2003). Furthermore, patterns in spatial heterogeneity are often distinct at different scales and different structuring processes can also emerge at different scales (Peterson 2000). Recently, Erdos et al. (2011) provided yet another elaborated definition of the spatial boundary. They distinguished between the gradient (transition) and the space-segment (transitional zone), and identified the main difference between the two types of gradients: cline and tone. Furthermore, they discussed the meanings of synonyms such as the boundary line, boundary zone, edge, margin, and border.

Mountain ranges often create more complicated interfaces, due to a wide variety of climatic conditions combined with the influence of topography and degree of slope. In mountains, two conditions favour the formation of ecosystem interfaces: the steep gradients in the physical environment, for example topography and climate, that directly affect key ecological processes and the distribution of organisms; and aspects of mountain slopes, for example, shady slopes and sunny slopes, which directly affect the distribution of dominant species and different disturbances in ecosystems. The Himalayan region provides ample opportunity to study interface ecology as it houses a large number of ecosystems along altitudinal gradients. In mountains, ecosystem interfaces differ significantly from their neighbouring systems in terms of spatial scale, structural attributes, and processes. Thus, interfaces and neighbouring systems can be seen as discrete ecological units when studying the changes of ecosystem services driven by climatic or anthropogenic pressure.

Key Specificities of Ecosystem Interfaces

The ecosystem interface possesses many unique natural attributes such as the distinctiveness of edge effects (Clements 1905; Hardt 1989), non-continuity of vegetation distribution, heterogeneity in a landscape structure (Walker 1979, 1985), and fragility of the ecological environment. These attributes, uniquely defined by space and time scales, guide the study of ecosystem interfaces and play an important and irreplaceable role in the exploration of natural ecological laws and the protection of the ecological environment. For this reason, the ecosystem interface has received increasing attention from scientists and governments (Di Casstris and Hansen 1992; Wang et al. 2000; Kevin and Thomas 2006; Temuulen 2005).

Rich biodiversity

One reason for studying ecosystem interfaces is that these areas harbour particularly rich biodiversity due to proximity of contrasting habitat types. Interfaces may also serve as barriers or corridors between gene pools as they represent unique habitats optimal for some species and inhospitable for others. An interface controls energy and material flux, thereby allowing a potentially sensitive site for interactions between biological populations and their controlling variables, providing critical habitat for rare and threatened species, and serving as source area for pests and predators. Some interfaces may also be sites for longitudinal migration (e.g., along windbreaks or riparian zones) and genetic pools or sites for active microevolution (e.g., forest/agricultural interfaces). Thus the effects of an interface on biodiversity are evident at the genetic, species, habitat, and landscape levels of organization.

The presence of an increased variety of plants and animals at the ecosystem interface is called the 'edge effect' and is essentially due to a locally broader range of suitable environmental conditions or ecological niches. Plants in competition extend themselves on one side of the interface as far as their ability to maintain themselves allows. Beyond this, competitors of the adjacent ecosystem take over. As a result the interface represents a shift in dominance. Ecosystem interfaces are particularly significant for mobile animals, as they can exploit more than one set of habitats within a short distance. The interface may also include a number of highly adaptable species that tend to colonize such transitional areas (Smith 1974). This can produce a high diversity along the boundary line, with the area displaying a greater than usual overall diversity.

Not all kinds of landscape boundaries show an increased number of species. In some cases, the ecosystem boundary contains fewer species than either of the adjacent patches. This can result if the interface is subject to great fluctuations in resource levels (as in the salt lake/lakeside interfaces on the Tibetan Plateau) or experience extreme levels of disturbance (e.g., the boundary of a protected area). It is also possible for the overlap of disturbances at an interface to create synergetic effects that are adverse to many species. Finally, edge specialists may be few if the interface is too narrow to provide a unique habitat.

Noss (1993) found that whereas the density of nesting birds was highest on habitat edges, nesting success was lowest there due to increased predation rates. He suggested that narrow, man-made habitat edges may function as 'ecological traps' by concentrating nests and thereby increasing density-dependent mortality. Also, there is increasing evidence that some patch interior species cannot tolerate habitat edges and become extinct in highly fragmented habitats (see Neilson 1993). Consequently, the strategy of maximizing local diversity by increasing the abundance of interfaces may lead to a reduction in regional diversity due to the loss of edge-avoiding species (Noss 1983). There is a need to develop predictions on the factors that influence biodiversity in patch boundaries and to test these predictions against patterns in nature. Moreover, there is a need for more consideration of the consequences of human alteration of landscape boundary structures on biodiversity and abundance.

Strong sensitivity

The ecological boundaries are particularly sensitive to rapid changes in climate and anthropogenic impacts, thus they could be a good indicator to use in environmental monitoring. Organisms in the transition zones between ecosystems may be near their tolerance limits and thus quick to respond to environmental change. For this reason, scientists involved with the International Geosphere-Biosphere Programme (IGBP) are interested in monitoring ecosystem interfaces as early indicators of global change. Over the last two decades, many researchers have emphasised the role of ecological boundaries as monitors of global climate change, and several models of their dynamics have been established (Solomon 1986; Neilson 1993; Noble 1993). The relationship between boundary dynamics and climatic change, however, is complicated due to individualistic responses of species, the interaction of species, and the time-lag of vegetational development during climatic change (Liu et al. 2001). Equally, non-climatic factors, such as fire, soil, topography, and grazing can also lead to shifts in ecosystem interfaces (Wu and Liu 1998).

Ecosystem interfaces are not only sensitive to climate change but also to other external disturbances. For example, interfaces between terrestrial and freshwater ecosystems are particularly sensitive to drainage, pollution, and land-use change. Examples include riparian forests, marginal wetlands, littoral lake zones, floodplain lakes and forests, and areas with groundwater-surface water exchanges. Peatlands have been studied worldwide due to their sensitivity to global warming and their contribution to greenhouse gas emissions as a result of exploitation for agriculture, grazing, peat mining, and forestry and decline in biodiversity (Joosten et al. 2012).

High vulnerability

Geological instability, steep topography, extreme climatic conditions, and turbulent rivers make the HKH region vulnerable to various kinds of disturbances and sensitive to natural disasters. Interventions, positive and negative, may change the composition and function of ecosystem interfaces and result in a space/range shift and structural change of ecological boundaries. At present, most high-altitude ecosystems and their interfaces are suffering from degradation, desertification, and soil erosion, which are further aggravated by climatic and anthropogenic factors. Mountain areas are prone to landslides and landslips in the rainy season and avalanches in winter. Moreover, during recent decades, population growth and anthropogenic pressures have been increasingly affecting the irreplaceable biodiversity of the landscapes. The influence of globalization and climate change on the stability of the fragile mountain ecosystems and the livelihoods of mountain people is increasing. Vulnerable physical conditions interwoven with anthropogenic pressures aggravate the straitened circumstances in the HKH region. Lack of livelihood options, together with modern changes in lifestyle, have made the indigenous communities of the landscape extremely vulnerable. Under the global climate change scenario, the landscapes and their people and biodiversity are likely to face acute threats to their continued sustenance and long-term sustainability.

Protection of high-altitude ecosystems and their interfaces can play a significant role in retaining the most needed services such as water, biodiversity, and carbon sequestration and creating an opportunity to diversify the livelihoods of local communities based on the available natural resources.

Challenges and Perspectives of Interfaces in the HKH

Although the area occupied by interfaces in the HKH region is small compared to the total area of landscapes or habitats, their role is extremely important because they control the flow of organisms, materials, energy, and information (Wiens et al. 1985). Risser (1995) in his review of the study of ecotones suggests that the most important current studies on ecological boundaries are those on the dynamic impact of boundaries on active landscapes, the significant role in supporting a high level of biological diversity, and the role of boundaries as a source of high levels of primary and secondary productivity. Interfaces frequently intensify or concentrate the flow of materials, as well as the movement of organisms across the landscape. Providing important components of wildlife habitat, interfaces of protected areas also act as sensitive indicators of efficient conservation and management.

The distinction between a biome and an interface is more than ecological semantics. It influences strategies for preservation and restoration, and it may affect animals more than plants. The mountain protected areas in the HKH, and associated faunal communities in particular, have typical interface characteristics, and therefore present special challenges for conservationists. The persistence of marginal populations in an ecosystem interface may depend crucially on immigration from source populations nearer the centres of the species' range in adjacent biomes. If the source populations are not thriving, centrifugal dispersal movements may be inadequate to maintain peripheral populations in the interface. As a result, the presence and persistence of a species in an interface may depend as much, or more, on the conditions in the adjacent biomes as on the conditions in the interface itself (Wiens et al. 1985).

Knowledge on ecosystem interfaces plays a significant role in the field of landscape management, as well as in nature conservation. Increased fragmentation due to human activity results in more boundaries. The response of interfaces to global changes, especially to global climate change, will probably be one of the most important research questions in upcoming decades. The International Centre for Integrated Mountain Development (ICIMOD), a regional knowledge-based organization, has a long history of working with ecosystem management, especially on the Himalayan rangelands, wetlands, and forests, and their interfaces, and has been promoting the improvement of ecosystems and the conservation of transboundary landscapes in the HKH region with a view to identifying opportunities for equitable development strategies for high-altitude ecosystem-dependent people. However, there is a lack of knowledge and information on the ecological role of ecosystem interfaces for conservation and sustainable management at a regional or even global scale. An ecosystem interface is a spatial analogue of vegetation change over time at a fixed location.

There is a rich theoretical literature on thresholds in ecological system dynamics, where a minor perturbation may push a relatively stable system to a new and very different state (Walker et al. 1979). Exploring this concept of 'interface in time' seems especially important now, when human-induced climate change may cause rapid alteration of many components of the biosphere (Dyer et al. 1988). We will examine three topics that we consider to be among the most important reasons for further study on ecosystem interfaces: (1) interfaces may influence ecological flows between ecosystems; (2) unique patterns of biodiversity may occur in an interface; and (3) humankind is substantially altering interface patterns without knowledge of the consequences. These topics will also be covered to some extent by various articles in this volume.

In terms of the conservation and management of transboundary landscapes, ecosystem interfaces are important in influencing ecological flows and biodiversity in the whole landscape; where human activities are dramatically altering these boundaries, management actions are clearly desirable. One approach is to attempt to halt those activities that have negative consequences and to develop management strategies that mitigate the negative impacts. Unfortunately, there is limited knowledge about the dynamics and functions of high-altitude ecosystem interfaces, and little is known about how to manage these boundaries in remote mountain areas.

The role of ecosystem interfaces in transboundary landscapes is especially important at present because human activities are having an unprecedented impact on mountain ecosystems at the local and regional levels. In the HKH region, man's imprint on the landscape structure has become ever more pronounced as human land use has broadened and intensified. In many places, human activities appear to be replacing natural agents of change as the primary determinants of landscape structure. Agricultural development, deforestation, and urban expansion have dramatically transformed upland and riparian vegetation and wildlife across geographic and political boundaries. In semi-arid areas, such as the Tibetan Plateau and Karakoram-Pamir Landscape, these activities have contributed to desertification and reductions in landscape productivity. Anthropogenic activities have also greatly accelerated the rate of species extinction, forest loss, and wetland shrinking. Thus, there is a real concern that such changes will contribute to alterations in regional and global climate. Furthermore, these climatic alterations are expected, in turn, to induce further changes in terrestrial and aquatic systems.

References

Armand, AD (1992) 'Sharp and gradual mountain timberlines as a result of species interactions'. In Hansen, AJ; Castri, FD (eds) *Landscape boundaries. Consequences for biotic diversity and ecological flows*. 92:360–378. Springer, Berlin

Badola, R; Hussain, SA; Mishra, BK; Konthoujam, B; Thapliyal, S; Dhakate, PM (2010) 'An assessment of ecosystem services of Corbett Tiger Reserve, India.' *The Environmentalists* 30: 320–329

Baral, N; Gautam, R; Timilsina, N; Bhat, MG (2007) 'Conservation implications of contingent valuation of critically endangered white- rumped vulture *Gyps bengalensis* in South Asia'. *The International Journal of Biodiversity Science and Management* 3: 145–156

Baral, N; Stern, MJ; Bhattarai, R (2008) 'Contingent valuation of ecotourism in Annapurna conservation area, Nepal: Implications for sustainable park finance and local development'. *Ecological Economics* 66: 218–227

Cadenasso, ML; Pickett, STA; Weathers, KC; Jones, CG (2003) 'A framework for a theory of ecological boundaries'. *BioScience* 53:750–758

CBD (2010) Tenth meeting of the Conference of the Parties to the Convention on Biological Diversity, 18–29 October 2010, Nagoya, Aichi Prefecture, Japan. www.cbd.int/decision/cop/?id=12296

Chen, WY; Jim, CY (2010) 'Resident motivations and willingness-to-pay for urban biodiversity conservation in Guangzhou (China)'. *Environmental Management* 45: 1052–1064

Chettri, N; Sharma, E; Shakya, B; Bajracharya, B (2007) 'Developing forested conservation corridors in the Kangchenjunga landscape, eastern Himalaya'. *Mt Res Dev* 27:211–214

Chettri, N; Shakya, B; (2008) 'Species to landscape: a paradigm shift in biodiversity conservation through people's participation and policy reform'. In Rasul, G; Karki, M (eds) *Policy priorities for sustainable mountain development: proceedings and selected papers from the Regional Policy Workshop*. Kathmandu: ICIMOD

Clements, FE (1905) *Research Methods in Ecology*. Lincoln, UK: Univ. Publ.

Daubenmire, RF (1968) *Plant communities: a textbook of plant synecology*. Harper and Row. NY. pp300

Di Casstri, F; Hansen, AJ (1992) 'The environment and development crises as determinants of landscape dynamics'. In Hansen, AJ; Castris, FD (eds) *Landscape Boundaries*. New York: Springer-Verlag, 3–18

Dyer, MI; di Castri, F; Hansen, AJ (eds) (1988) 'Geosphere-Biosphere Observatories: Their definition and design for studying global change'. *Biology International,* Special Issue 16

Erdos, L; Galle, R; Batori, Z; Papp, M; Koermoeczi, L (2011) 'Properties of shrub-forest edges: a case study from South Hungary'. *Cent Eur J Biol* 6:639–658

Fagan, WF; Fortin, MJ; Soykan, C (2003) 'Integrating edge detection and dynamic modeling in quantitative analyses of ecological boundaries'. *BioScience*, 53:730–738

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

Guangwei, C (2002) *Biodiversity in the Eastern Himalayas: conservation through dialogue. Summary reports of the workshops on biodiversity conservation in the Hindu Kush-Himalayan Ecoregion*. Kathmandu: ICIMOD

Hardt, RA (1989) 'Boundary from effects on woody colonization of reclaimed surface mine'. *Ecology* 70: 1252–1260

Holland, MM (1988) 'SCOPE/MAB Technical consultations on landscape boundaries'. In di Castri, F; Hansen, AJ; Holland, MM (Eds) A new look at ecotones: emerging international projects on landscape boundaries. *Biology International*, special issue 17: 47–106

Joosten, H; Tapio-Bistrom, ML; Tol, S (eds) (2012) *Peatlands – guidance for climate change mitigation through conservation, rehabilitation and sustainable use* (second edition). FAO & Wetlands International

Kevin, L; Thomas, V (2006) 'Climatic variability and episodic *Pinus ponderosa* establishment along the forest-grassland ecotones of Colorado'. *Forest Ecology and Management* 228:98–107

Koerner, C (2003) *Alpine Plant Life*. 2nd ed. Springer, Berlin, pp337

Liu, HY; Cui, HT; Huang, YM (2001) 'Detecting Holocene movements of the woodland–steppe ecotone in northern China using discriminant analysis'. *Journal of Quaternary Science* 16:237–244

Maharana, I; Rai, SC; Sharma, E (2000a) 'Environmental economics of the Khangchendzonga National Park in the Sikkim Himalaya, India'. *GeoJournal* 50:329–337

Maharana, I; Rai, SC; Sharma, E (2000b) 'Valuing ecotourism in a sacred lake of the Sikkim Himalaya, India'. *Environmental Conservation* 27:269–277

Mittermeier, RA; Gils, PR; Hoffman, M; Pilgrim, J; Brooks, T; Mittermeier, CG; Lamoreaux, J; da Fonseca, GAB (eds) (2004) *Hotspots revisited. Earth's biologically richest and most endangered terrestrial ecoregions*. CEMEX/Agrupación Sierra Madre, Mexico City

Neilson, RP (1993) 'Transient ecotone response to climate change: some conceptual and modeling approaches'. *Ecological Applications* 3:385–395

Noble, IR (1993) 'A model of the responses of ecotones to climate change'. *Ecological Applications* 3: 396–403

Noss, RF (1983) 'A regional landscape approach to maintain diversity'. *BioScience* 33: 700–706

Noss, R (1993) *Wildlife corridors.* In Smith, DS; Hellmund, PC (eds) *Ecology of Greenways: Design and Function of Linear Conservation Areas*. pp43–68. University of Minnesota Press, Minneapolis, Minnesota

Odum, EP (1983) *Basic Ecology*. Philadelphia: Saunders College Publishing

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

Peterson, GD (2000) 'Scaling ecological dynamics: self-organization, hierarchical structure and ecological resilience'. *Climatic Change* 44: 291–309

Risser, PG (1995) 'The status of the science examining ecotones'. *BioScience* 45: 318–325

Salthe, SN (1985) *Evolving Hierarchical Systems: Their Structure and Representation*. Columbia University Press, New York, pp343

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

Sharma, E; Chettri, N; Oli, K (2010) 'Mountain biodiversity conservation and management: A paradigm shift in policies and practices in the Hindu Kush-Himalayas'. *Ecological Research* 25: 909–923

Sharma, UR; Yonzon, PB (2005) *People and Protected Areas in South Asia*. Kathmandu: Resources Himalaya and IUCN.

Sherpa, LN; Peniston, B; Lama, W; Richard, C (2003) *Hands around Everest: transboundary cooperation for conservation and sustainable livelihoods*. Kathmandu: ICIMOD

Smith, RL (1974) *Ecology and Field Biology* (2nd ed.). Harper & Row. pp251

Solomon, AM (1986) 'Transient response of forest to CO_2 induced climate change: simulation modeling experiments in eastern North America'. *Oecologia* 68: 567–579

Tansley, AG; Chipp, TF (1926) *Aims and methods in the study of vegetation*. London: British Empire Vegetation Committee

Temuulen, TS (2005) *20th Century forest-grassland shift and effects of livestock herbivory*. Montana: Montana State University Dissertation, USA

Tse-ring, K; Sharma, E; Chettri, N; Shrestha, A (eds) (2010) *Climate change vulnerability of mountain ecosystems in the eastern Himalayas – Synthesis report*. Kathmandu: ICIMOD

Walker, H (1979) (2nd ed) *Vegetation of the earth and ecological systems of the geo-biosphere*. New York: Springer-Verlag

Walker, H (1985) (2nd ed) *Community and ecosystems*. New York: Macmillan Publishing Co.Inc., 167

Wang, QS; Feng, ZW; Luo, JH (2000) 'Study on biodiversity of forest-grassland ecotones in the north of Hei Bei and the east of Inner Mongolia'. *Plant Ecology* 24:141–146

Wiens, JA; Crawford, CS; Gosz, JR (1985) 'Boundary Dynamics: A Conceptual Framework for Studying Landscape Ecosystems.' *Oikos* 45: 421–27

Wu, N; Liu, ZG (1998) 'Probing into the causes of geographical pattern of subalpine vegetation on the eastern Qinghai-Tibetan Plateau'. *Chinese Journal of Application and Environment Biology* 4(3): 290-297. (in Chinese with English abstract)

Yarrow, MM; Salthe, SN (2008) 'Ecological boundaries in the context of hierarchy theory'. *BioSystems* 92: 233–244