

Special Publication

On the occasion of ICIMOD's 30th anniversary

High-Altitude Rangelands and their Interfaces in the Hindu Kush Himalayas

ICIMOD
30

THREE DECADES
FOR MOUNTAINS AND PEOPLE



About ICIMOD

The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalization and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.



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Commemorating 30 years of commitment
for mountains and people

High-Altitude Rangelands and their Interfaces in the Hindu Kush Himalayas

Special Publication

On the occasion of ICIMOD's 30th anniversary

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About this Volume

The high-altitude rangelands in the Hindu Kush Himalayan (HKH) region share boundaries with several other ecosystems such as forests, wetlands, and agricultural land. At present, most of the high-altitude rangelands and their interfaces are suffering from degradation, desertification, and soil erosion, which are further aggravated by climatic and anthropogenic factors. However, there is a lack of knowledge and information on the ecological role of high-altitude rangelands and especially their interfaces; more information is needed as a basis for developing and implementing plans for conservation and sustainable management of these fragile ecosystems at a regional, and even global scale.

This volume has been compiled as a first step in addressing this knowledge gap. It contains a collection of papers and scholarly articles by ecologists, natural resource managers, and other professionals working on the high-altitude rangelands of the HKH region. It is divided into four sections. The first section focuses on a review of high-altitude rangelands and their interfaces. It discusses the definition of ecosystem interface at a landscape scale and provides detailed information on alpine ecosystem interfaces considering the current state of knowledge on the biophysical features and major conservation issues and management strategies in the transboundary landscapes of the HKH region. The second section highlights the distribution patterns and climatic parameters of one of most important alpine ecotones, the timberline, which is considered as an interface between grasslands and forests in high-altitude regions, the carbon and nutrient supply mechanism for timberline formation, and climate change and human disturbance leading to shifting of timberline ecotone. The third section focuses on wetlands in the region, in particular the causes of peatland degradation under overgrazing and emission dynamics of greenhouse gases from peatlands impacted by climate change. The final section provides an overview of the ecosystem services provided by the high-altitude rangelands.

This edited volume has been prepared as a special contribution to mark ICIMOD's 30th Anniversary. It is hoped that findings and recommendations given in this volume will be of interest to scientists, policymakers, students, and researchers.

Acronyms and Abbreviations

AICC	Agriculture Information Communication Centre
AIMS	Afghanistan Information Management Service
AKHS	Aga Khan Health Services
APP	Agricultural Perspective Plan
BBCH	Biologische Bundesanstalt, Bundessortenamt und Chemische Industrien
BNP	Broghil National Park
BSAs	biologically significant areas
CAS	Chinese Academy of Sciences
CBD	Convention on Biological Diversity
CBOs	community-based organizations
CEMP	Comprehensive Environmental Monitoring Plan
CITES	Convention on International Trade in Endangered Species
CKNP	Central Karakoram National Park
CLDP	Community Livestock Development Project
CLMGC	Committee for Land Management Geodesy and Cartography
CV	coefficients of variation
DLSO	District Livestock Services Office
DOC	dissolved organic carbon
ETH	Swiss Federal Institute of Technology
FAO	Food and Agriculture Organization
GBPIHED	GB Pant Institute of Himalayan Environment and Development
GHG	greenhouse gas
GHNP	Great Himalayan National Park
GIS	geographic information system
GLOF	glacial lake outburst flood
GoI	Government of India
GoN	Government of Nepal
GoP	Government of Pakistan
GPS	global positioning system
GWP	global warming potential
HAR	high-altitude rangeland
HKH	Hindu Kush Himalayan region
ICIMOD	International Centre for Integrated Mountain Development
IGBP	International Geosphere-Biosphere Programme
IGSNRR	Institute of Geographical Sciences and Natural Resources Research
IHR	Indian Himalayan region
IRS	Indian Remote Sensing
IUCN	International Union for Conservation of Nature
KNP	Khunjerab National Park
KPL	Karakoram-Pamir Landscape

KSL	Kailash Sacred Landscape
KSLCDI	Kailash Sacred Landscape Conservation and Development Initiative
KWS	Kedarnath Wildlife Sanctuary
LHI	large herbivore initiative
LISS	Linear Imaging Self Scanning Senors
MoE	Ministry of Environment
MoPE	Ministry of Population and Environment
MPF	mountain perspective framework
MSS	multispectral scanner
NASA	nepal animal science association
NCBB	national centre for biodiversity and bio-safety
NDVI	normalized difference vegetation index
NEE	net ecosystem CO ₂ exchange
NGO	non-governmental organization
NSC	non-structural carbohydrate
NTFPs	non-timber forest products
PCA	principal component analysis
PES	payment for ecosystem services
PKR	Pakistani rupee
PMD	Pakistan Metrological Department
PRA	participatory rural appraisal
PRA/PLA	participatory rural appraisal/participatory learning and action
RCF	regional cooperation framework
RECAST	Research Centre for Applied Science and Technology
RPIP	rangeland policy implementation plan
RRN	relative radiometric normalization
SCOPE	Scientific Committee on Problems on the Environment
SES	social ecological system
TAR	Tibet Autonomous Region
TLDP	third livestock development project
TNR	Taxkorgan Nature Reserve
TU	tribhuvan university
UNEP	United Nations Environment Programme
VDC	Village Development Committee

Foreword

Rangeland ecosystems stretch across about 2 million km² of the Hindu Kush Himalayan (HKH) region, cover nearly 60% of the geographical area, and provide numerous goods and services directly to the local pastoral societies and indirectly to millions of other. The rangelands interface with other ecosystems such as forests and wetlands to form ecosystem interfaces (or ecotones) at high altitudes, which are being affected by climate change and anthropogenic pressures throughout the HKH region. This is leading to a reduction in the provision of ecosystem goods and services, which not only threatens the livelihoods of local people, but also ultimately threatens the sustainability of the whole region. As yet, efforts to enhance scientific understanding of the significance of ecosystem interfaces and their dynamics in the HKH region have been limited.

Protection of rangelands and their interfaces can play a significant role in retaining the most needed services such as carbon sequestration, water storage and provision, and maintenance of biodiversity, and can create an opportunity to obtain international finance on service credit schemes. For example, peatlands represent an important long-term sink for atmospheric carbon dioxide (CO₂) and are one of the largest and growing sources of greenhouse gas (GHG) emissions globally. Therefore, protection and restoration of this ecosystem is being pursued by national and international agencies in order to conserve existing carbon stocks and to help mitigate climate change.

There is an urgent need to promote in-depth research on high-altitude ecosystem interfaces and to develop sound methodologies for monitoring, restoring, and valuing these interfaces. In view of this, an expert consultation on research and management priorities for high-altitude rangelands and their interfaces was organized in Pokhara, Nepal in December 2012. This special volume provides a summary of the presentations made by participants during the consultation, and provides a review and addresses issues related to the high-altitude rangelands and their interfaces. Consideration is given to understanding the ecological role of rangelands and their interfaces for conservation and sustainable management at a regional, and even global scale.

The International Centre for Integrated Mountain Development (ICIMOD) is a regional knowledge-based organization with a long history of working with ecosystem management, especially on the Himalayan rangelands, wetlands, and forests. The Centre has been promoting rangeland improvement and conservation of transboundary landscapes in the HKH region with a view to identifying opportunities for equitable development strategies for the people dependent on high-altitude ecosystems. However, there is a lack of the knowledge and information on the ecological role of high-altitude ecosystem interfaces that is needed for conservation and sustainable management planning. This volume provides insights that will help in developing plans for high-altitude ecosystem monitoring, services evaluation, and management measures to enhance ecosystem resilience and the adaptive capacity of local communities.

David Molden, PhD
Director General, ICIMOD

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1

Review of High Altitude Rangelands and Their Interfaces



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' 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

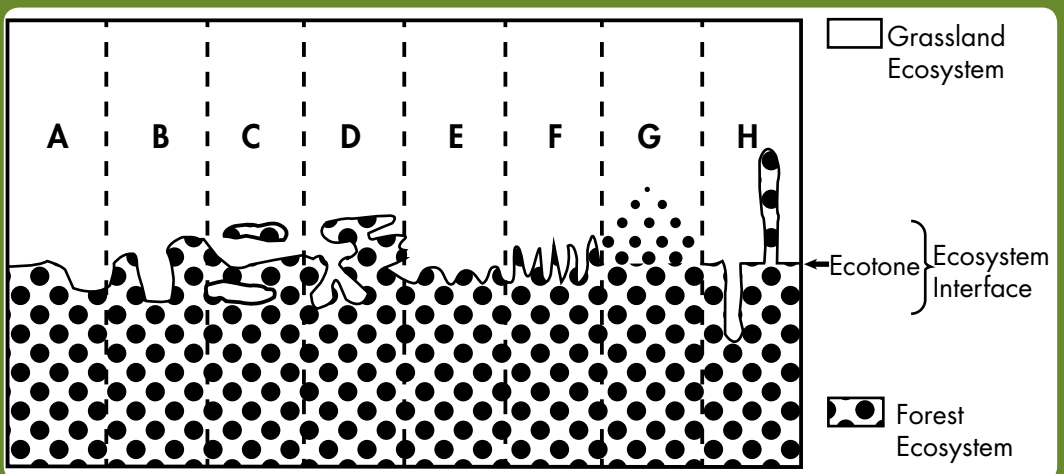
An ecosystem interface is often characterized by a transition from one biome to the other, and is not necessarily marked by changes in the physical or topographic features. It is scale dependent and variable in space and time. When the resolution is finer, every boundary becomes blurred (Erdos et al. 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.

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Highland Rangelands of Afghanistan: Significance, Management Issues, and Strategies

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Approximately 70-85% of Afghanistan's territory is used as rangelands. The rangelands in the Central Highlands of Afghanistan form the major summer pastures for a great number of livestock and are thus crucial for country's farming system, which is based on a combination of sedentary farming and migratory livestock keeping. They are the source areas for some of the major rivers in the region, including the Amu, Kabul, and Helmand rivers. In addition, the highland rangelands are key habitats for Afghanistan's rich biodiversity.

Owing to their crucial importance for the farming system of the country, as well as other historical and contemporary reasons, the rangelands have often been the site of ethnic and communal conflicts. Converting the rangelands into areas for rainfed crop cultivation decreases rangeland availability and reduces pasture connectivity, which creates both ecological and social problems. At the same time, rising temperatures mean that high pastures are now used some 10-20 days per year more than in the past, resulting in greater pressure on the rangeland ecosystem.

Strategies and actions for sustainable management of the highland rangeland resources of Afghanistan should focus on creating an enabling policy environment for community-based management, promoting sustainable rainfed cultivation practices, intensifying fodder production, diversifying rural energy options, enhancing climate change adaptation, assessing and monitoring rangeland resources, and strengthening transboundary conservation initiatives.

Keywords: biodiversity; central highlands; climate change; farming systems; rainfed cultivation; rangelands

Introduction

Regardless of the different and sometimes contradictory definitions of the term 'rangeland', and different assessment of the extent of distribution, rangelands clearly occupy the single largest proportion of Afghanistan's land. Around 45% of Afghanistan's total area of approximately 650,000 km² is classified as rangeland, compared to 12% of arable land and 2% of forest (AIMS and FAO 2003). Moreover, large areas classified as 'barren land' or

'waste land' are also used for opportunistic grazing, particularly in winter or in years with high precipitation. The total area used for extensive grazing is estimated to be between 70% and 85% of the total land area.

The primary and direct use of these rangelands is for livestock grazing. In Afghanistan, livestock are mainly managed through three basic systems: sedentary, settled transhumance, and nomadic pastoral (Fitzherbert 2006). Livestock raising based on the extensive use of the rangeland resources is an essential component of the local farming system and a livelihood strategy for over 80% of Afghanistan's households. It is estimated that there are around 1.5 million Kuchis, or nomadic pastoralists, in Afghanistan, who depend entirely on mobile livestock raising for their livelihood. According to the latest survey conducted in 2002/03 (FAO 2003), the country has 3.72 million cattle, 8.77 million sheep, 7.28 million goats, 1.59 million donkeys, 0.18 million camels, 0.14 million horses, and 12.6 million poultry. However, the livestock numbers are highly variable due to the frequent occurrence of drought, especially in recent years.

Besides providing fodder for livestock, Afghanistan's rangelands are also an important or sole supplier of some critically important ecosystem goods and services. They provide fuelwood and medicinal plants for people; habitat for wildlife and pastoral culture; preserve soil and water; and help regulate the climate. This multiple functionality of rangelands is gaining increasing recognition by the users. Proper management of the rangeland resources in Afghanistan will be critically important for sustainable development, improving the overall quality of life, and ensuring food security.

This paper discusses the highland rangelands of Afghanistan, focusing on their social, economic, and environmental roles, the major issues and challenges for management and sustainable use, and the priority areas for management and future research.

Highland Rangelands of Afghanistan

Afghanistan has a very diverse terrain, which extends from the deserts of the Kandahar region through the western-southwestern lowlands to the Turkestan plains in the north, and through the lower central mountains and high mountains in the northeast. The Hindu Kush and its subsidiary ranges divide Afghanistan into three distinct geographical areas: the Central Highlands, the Northern Plains, and the Southwest Plateau. Approximately 80% of the country is either mountainous or desert. The altitude ranges from about 470 masl along the southwest border with Iran, to over 6,000 masl in the eastern mountains. Most of the country lies between 600 and 3,000 masl.

The Central Highlands of Afghanistan, which include the main Hindu Kush range, is an extension of the Himalayan mountain chain. This area of about 414,000 km² is a region of deep, narrow valleys and lofty mountains, with some peaks above 6,400 masl. The area extends from Uruzgan, Ghazni, and Ghor, through Bamyan and Samangan, to Takhar and

Badakhshan, ending in Little Pamir. It contains most of the highland rangelands, the 225,000 km² of summer pasture. Within the region, the valley bottoms are usually used for cereal and horticultural production and human settlements, and the mountains, as well as high-elevation plateaus, as pasture. These pastures are used by both local communities and nomadic pastoralists (Kuchies) from afar. The major highland pastures include the Nawur pasture in northern Ghazni and the Shiwa pasture and Little Pamir in Badakhshan. Nawur pasture is an area of around 600 km² in northern Ghazni with an elevation up to 3,350 masl. Shewa pasture lies in northeast Badakhshan and is a major destination for summer migration of animals from Kunduz, Takhar, Baghlan, and Badakhshan, herded by Arab, Pashtun, Tajik, and Uzbek shepherds, as well as being used by local communities. Little Pamir pasture lies above 4,000 masl and is used exclusively by Afghan Kirgiz communities who raise fat tailed sheep, goats, and yaks.

The vegetation types depend on the annual precipitation and altitude, which increase from central to northeast Afghanistan. According to Freitag (1971), the potential natural vegetation in the highland rangeland areas comprises the following types: (1) thorny cushions, sub-alpine and alpine semi-deserts, and meadows; (2) steppe and semi-desert vegetation; (3) pistachio woodlands; (4) dwarf *Amygdalus*- semi-desert; (5) sub-nival vegetation; and (6) azonal vegetation (saline flats). Most of these vegetation types have been heavily impacted by human activities such as grazing, agriculture, and irrigation as well as deforestation. It is believed that much of the *Artemisia* steppe of the central highlands was originally a grass steppe which has been converted to *Artemisia* steppe by centuries of heavy grazing. Many original vegetation types are left only in a few spots in remote places and they have been replaced by substitute associations poorer in shape, diversity, and productivity. The soils are often degraded, eroded, or totally exposed.

The floristic composition and the state of the grazing lands of Afghanistan are not well documented and there is little or no up-to-date information. In general, the western part of the Central Highlands is drier and *Artemisia* steppe is by far the predominant grazing vegetation, while grasses and sedges increase in the northeast. For example, the most common rangeland type in the central Bamyán region is *Artemisia-Acantholimon* steppe, with major species including *Artemisia* spp., *Acantholimon* spp., *Astragalus* spp., *Festuca* spp., *Stipa* spp., *Poa*, and many others. In the Wakhan Corridor to the northeast, the most dominant rangeland plant communities are alpine grasslands, sedge meadows, and *Artemisia* steppe, with major species including *Carex* spp., *Bromus* spp., *Kobresia* spp., *Astragalus* spp., *Oxytropis* spp., and *Elymus* spp. The species diversity is much higher in the northeast.

Highland Significance of Highland Rangelands

The high-altitude rangelands of Afghanistan provide a wide range of ecosystem services, the importance of which extends far beyond their geographical boundaries. They are critical resources for the country's socioeconomic development, habitats for biodiversity conservation, sources of water, and corridors for cultural exchange.

Supporting the Afghanistan farming system and rural livelihoods

Afghanistan's farming system is characterized by a mixed farming system with close coupling between crop cultivation on irrigated or rainfed land and a pastoral component, which relies on extensive use of rangeland resources at different elevations. Highland rangelands are the major grazing resources in the summer months, not only for those who live in immediate proximity but also for communities outside the Central Highlands. The fodder resources of the highland rangelands are essential for sustaining livestock management, which is an important undertaking for more than 85% of Afghanistan's nearly 30 million people. Problems with these resources that affect livestock management would affect crop production in the lowland areas and the whole livelihood system, especially the food security of rural communities. Thus the quantity and quality of fodder on the highland pastures, which is often dictated by the precarious rainfall, has a great bearing on the overall socioeconomic situation of the country. Furthermore, around 1.5 million Kuchis (nomadic pastoralists) in Afghanistan depend entirely on the alpine pastures in central and northeast Afghanistan to complete their annual migration cycle and ensure their subsistence (Kreutzmann 2011).

Sources of water for the region

Afghanistan's high-altitude rangelands are mostly found within the Central Highlands, which is the meeting place for all five of the country's major river basins, namely the Amu Darya, Northern, Harirud-Murghab, Helmand, and Kabul-Eastern basins. About 80% of Afghanistan's water resources originate in the Hindu Kush Mountains at altitudes above 2,000 masl. Amu Darya is the largest river in Central Asia region that originates in the highlands of Afghanistan and flow all the way through Afghanistan, Tajikistan, Turkmenistan, Uzbekistan, and Kazakhstan to the Aral Sea. The Kabul river is a major tributary of the Indus. A big natural challenge facing Afghanistan is its uneven distribution of water resources in both temporal and spatial terms. The climate is desert, and Mediterranean types, with a very long dry season from May to October and a cold rainy season from November to April. The rainy season of Afghanistan falls in the winter season and does not coincide with the agriculturally active season. Agriculture is totally dependent on irrigation. The capacity of the highland rangelands to conserve water is thus essential for the continuous water supply to downstream areas during the dry season and the loss of such capacity of the rangelands due to degradation could have grave consequences on the food security of not only Afghanistan but the whole region.

Important habitat for biodiversity

The highland rangelands are the major habitats for Afghanistan's rich biodiversity. Afghanistan is one of the most significant centres of origin of domestic plants and animals, as evidenced by the numerous local landraces of wheat, other crops, nine local breeds of sheep, eight of cattle, and seven of goats. The principal plant species whose wild ancestors are still found in Afghanistan are the pistachio (*Pistacia vera*, *P. khinjuk*), pear (*Pyrus* spp.), apple (*Malus* spp.), plum (*Prunus* spp.), almond (*Prunus dulcis*), and cereals (e.g., *Triticum*) (Saidajan 2012).

Afghanistan has some 3,500 to 4,000 indigenous species of vascular plants of which 20% to 30% are endemic (about 700-1,200 species) (UNEP 2008). In a rapid survey, Bedunah and his team (Wildlife Conservation Society 2010) recorded more than 600 plant species in the alpine rangelands of the Wakhan Corridor. Many of the larger mammals in Afghanistan are categorized by the International Union for Conservation of Nature (IUCN) as globally threatened (UNEP 2003). These include the snow leopard (*Uncia uncia*), wild goat (*Capra aegagrus*), markhor goat (*Capra falconeri*), Marco Polo sheep (*Ovis ammon polii*), urial (*Ovis orientalis*), and Asiatic black bear (*Ursus thibetanus*). Other significant mammals include ibex (*Capra ibex*), wolf (*Canis lupus*), red fox (*Vulpes vulpes*), golden jackal (*Canis aureus*), caracal (*Caracal caracal*), manul or Pallas's cat (*Otocolobus manul*), striped hyena (*Hyaena hyaena*), rhesus macaque (*Macaca mulatta*), and brown bear (*Ursus arctos*). The highland rangelands provide the habitat for all of these species.

Many important landscapes, national parks, protected areas, and wetlands are located in the highland rangeland area, notably the Wakhan Corridor, Bamiyan National Heritage Park, Pamir-i-Buzurg Wildlife Reserve, Band-e-Amir Lake, and Shewa Lake.

Sociocultural Significance

Afghanistan's highland rangelands are the homelands of Kirgyzs, Wakhi, Tajiks, Hazaras, Uzbeks, Pashtuns, and many other ethnic groups. This cultural diversity is clearly reflected in language, religious beliefs, costumes, food customs, and indigenous knowledge about the environment. The highland rangelands are also a venue for cultural exchange between local inhabitants and nomadic pastoralists from the lowland areas. Maintaining the quality of the highland rangeland resources with sustainable utilization is crucial for preserving local cultures. Historically, the highland rangelands have been an important corridor for exchange between eastern and western civilizations. The Ancient Silk Route linking China and Europe passes through all the highland rangeland areas from Pamir and the Wakhan Corridor in the northeast, to the Bamiyan Plateau in the centre of the country. The scale and grandeur of the Buddhist site at Bamiyan and the countless historical sites in the region testify to the glory and prosperity of the civilizations once supported by the highland rangeland ecosystem.

A less discussed but very important dimension of Afghanistan's highland rangelands resources is their role in domestic and regional politics. The highland rangelands are key to supporting the country's overall economic system and rural livelihoods, and they have frequently become a bone of contention between different users, which easily develops into ethnic conflicts. The conversion of highland pastures by local communities into rainfed cropland result in a decrease in available pasture and/or blocking of the migration routes of nomadic pastoralists. Conflict between local sedentary communities and nomadic herders over the use of highland pastures has been common in all the major pastures in the country (Kreutzmann 2011; Wily 2004). The rangelands of the purely pastoral Little Pamir area are the sole resources for Kirgыз communities, and the stability of these communities can have cross-boundary consequences in Tajikistan, Pakistan, and China.

Major Issues and Challenges

Owing to the overwhelmingly important role of rangelands in the socioeconomic development of Afghanistan, issues and challenges related to their status have been discussed intensively in a wide range of documents from very different perspectives and disciplines. This section highlights the major issues specific to the highland rangeland resources.

Conflicts over land tenure

Highland rangelands are the most contested resources in Afghanistan (Patterson 2004; Wily 2004; Kreutzmann 2011). The conflict is multidimensional and often involves people from different ethnic groups. Thus conflicts over rangeland use can develop into ethnic conflicts. In the late 19th century, many highland rangelands were taken forcefully from local inhabitants by the then king of Afghanistan and given to Pashtun pastoralists. This sowed the seed of conflicts between local sedentary communities and nomadic pastoralists which have lasted until today. The lack of any coherent legislation on land rights also generates conflicts between nomads and sedentary farmers, especially related to conflicts of interest between winter grazing and crop cultivation. In some cases, the conflict is between the government, often represented by powerful groups, and local communities, since there is no clear distinction between 'government-land' and 'land owned by the public but under the care of the government'. This facilitates the taking away of common resources from a community by those in power. Conflicts also arise from those who want to convert traditional rangeland into cropland and those who want to keep it as rangeland.

Conversion of rangelands into farmland

Conversion of rangelands into rainfed farmland either for fodder or other production purposes is common across the whole of Afghanistan. This practice has caused a visible decrease in available rangeland area and disturbance to routes of animal migration and is bringing about serious erosion problems. Since rangelands are common resources in Afghanistan, and cultivated land is often privately owned, converting rangelands into farmland is actually converting commons into private land. This land seizure is often done by influential and wealthy families at the cost of the poor.

Overexploitation of rangeland resources

Due to the arid to semi-arid nature of Afghanistan, most of the rangelands have very low and highly variable fodder productivity ranging between 0.4 and 0.8 tonnes/hectare in years with good rainfall (Bedunah 2006). Many studies suggest that in most of Afghanistan, the productivity of the rangelands is so low that an average ewe would need at least 1 ha of all-rangelands and 16.4 ha of one-season rangeland. The number of livestock has fluctuated over the years, but even at its lowest, the number of animals is still very high compared to the total fodder production from the natural rangelands. In 2003, Afghanistan had roughly 44.2 million sheep equivalent livestock units (FAO 2003), well-exceeding the carrying capacity of the rangelands. As a result, most of the rangelands are overused.

Fuel shortage is a critical issue in rural areas of the country. The increasing demand for energy arising from the growing population has created increasing pressure on traditional rural energy sources, particularly on fuelwood and rangeland shrubs. Because of the long winters and cold climate, people need large amounts of fuelwood for survival. The tremendous demand on fuelwood has created serious pressure on the rangelands.

Climate change

Afghanistan is extremely vulnerable to climate change. The temperature in the country has increased by an average of 0.13°C per decade since the 1960s, higher than the world average, and precipitation has decreased by 2% per decade. The number of incidences of rain has decreased by 4-8 times per month during the rainy season. Over the last 10 years, summers in the alpine regions have become longer and winters shorter. Fruit trees now begin flowering 10-12 days earlier on average than in the past, and the fruit ripening time has advanced accordingly. Visible changes have also been seen in the flora and fauna of the high pastures. It is projected that Afghanistan will experience an average temperature increase of 2.0 to 6.2°C by the 2090s (also significantly higher than the global average), and that warming will be most rapid in spring and summer. It is also predicted that in general Afghanistan will become even drier in the 2090s mainly due to a decrease in spring rainfall.

Climate changes, especially rising temperatures and more erratic precipitation, have been felt by the pastoralists and are affecting their livelihood strategies. The increasing frequency of droughts and floods has caused great losses of life and property. Local communities have adapted to these changes, either passively or proactively, by changing the temporal and spatial pattern of seasonal migration, introducing drought-resistant crops or animal varieties, and turning to alternative income-generating activities. However, the adaptive capacity of the pastoral communities to deal with change is severely limited by multiple factors including insufficient information, low economic capacity, lack of modern technologies for farming and livestock management, lack of a risk management system, heavy dependence on rainfed cultivation, and direct use of natural resources.

In general, there is a lack of data on almost every aspect of rangeland management in the area, including climate, soil, vegetation, rangeland resource volume and distribution, and socioeconomics.

Strategies for Management

Creating an enabling policy environment for sustainable use

Many issues related to rangeland management in Afghanistan can be traced to the lack of an enabling policy environment for sustainable rangeland use. Following the disintegration of traditional institutional arrangements due to decades of war, new policies and laws are needed to redefine and clarify the rights of access to the rangeland resources by different users, especially those of the nomadic pastoralists, and to encourage community-based

management. Due to the non-equilibrium nature of the rangeland ecosystem in Afghanistan, it is important that local communities be given the right to own the resources and make decisions on their management so as to cope with uncertainties and increase their incentives for management input and sustainable use.

Promoting sustainable rainfed cultivation practices

If it cannot be stopped, cultivation of rainfed land should be made more sustainable and less damaging to the environment, by introducing non-tillage technologies, perennial crops (e.g., fodder species and cash crops) to replace annual plants, and adopting contour-planting practices. The yield of the current rainfed crops is very low and can be increased by introducing better crop varieties and methods of cultivation. There is also a need to develop locally appropriate models for rangeland rehabilitation. Such models need to take into account both the short-term and long-term interests of the farmers while reconciling ecological and economic efficiencies, for example through the integrated use of fodder plants, short-lived cash crops, and fodder-fuelwood (shrub) and fruit tree models. In terms of revegetation, it is important to remember that tree planting is not always the best choice, especially for highly-degraded south-facing slopes in an arid environment where the temperature is high and soil moisture very low. In such places, it is more realistic to start with grasses or shrubs and; tree planting may be possible after the microenvironment improves.

Intensifying fodder production and developing rural energy

As outlined above, human demand for fodder and fuelwood from the rangelands greatly exceeds the productive capacity. Reducing pressure on the already degraded natural pastures is imperative for the recovery and health of the rangeland ecosystem. Wherever possible, fodder cultivation should be encouraged using drought resistant species (e.g., wild alfalfa). The demand for fuelwood in the target area is huge, and there is considerable potential to meet part of this demand by developing and diversifying rural energy (fuelwood forests and shrubland, smokeless and energy efficient stoves, solar energy) and improving energy efficiency in the local communities. Multipurpose forestry that provides fuelwood, timber, soil and water conservation, bank stabilization, and wind barriers could also have a good potential.

Enhancing climate change adaptation

Afghanistan is very susceptible to climate change. Drought has become much more frequent over the past 20 years and it is believed that drought will become the norm by 2020. Due to the rising temperature, pastoralists are going to the highland pastures much earlier than in the past (Yi et al. 2012), which is likely to have a marked impact on the rangeland ecosystem. Efforts are needed to help local communities develop strategies to cope with the negative impacts of climate change and exploit the opportunities.

Monitoring highland rangeland ecosystems

A nationwide survey of rangeland conditions is needed to establish a baseline condition for the highland rangelands that can be used as a basis for management decisions and to monitor future trends. The study and exploration of the Afghan flora and vegetation started in the middle of the 19th century when some botanists such as Moorcroft and Griffith came to Afghanistan with the British military troops. Since then, a lot of studies have been carried out in Afghanistan till the conflicts started (Breckle 2007). In 1963, Rechinger published the first fascicle of *Flora Iranica* which also covered Afghanistan (Breckle et al. 2010). The most recent systematic study of Afghanistan vegetation was conducted in the 1970s (Freitag 1971) and no longer reflects the reality. The times of war made it impossible for ecological researches and monitoring in Afghanistan. With the downfall of Taliban and unfolding reconstruction of Afghanistan, scholars again turned their interest in Afghanistan flora and fauna. In 2010, a field guide to flora and vegetation of Afghanistan was published by Breckle et al. (2010) that brings together the results of several decades of botanical research in Afghanistan by several renowned international scholars. In the past decade, many isolated studies have been carried out by different organizations for conservation or development purposes. However, the lack of unified sampling methods or spatial and temporal coverage makes it difficult to generate an overall picture. What is more, for a specific network of monitoring is needed to collect timely information on rangelands for proper management.

Strengthening transboundary conservation initiatives

The area from the Wakhan Corridor up to the Little Pamir has a unique biodiversity from species to landscape level. It is the habitat of many endangered wildlife species such as the snow leopard, Marco Polo sheep, urial, and brown bear. The natural habitat of these unique and important wildlife species spreads across the geographical boundaries of four countries, thus protection of the natural habitat to ensure transboundary conservation requires close collaboration and cooperation among Afghanistan, China, Pakistan, and Tajikistan.

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Strategies for the Management of High-altitude rangelands and their Interfaces in the Kailash Sacred Landscape

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The Kailash Sacred Landscape (KSL) extends over an area of approximately 31,000 km² around the trijunction of southwestern China, India's northern state of Uttarakhand, and Far Western Nepal. The most prominent physical feature of this landscape is Mount Kailash or Kang Rinpoche (6,714 masl) in the Gandise mountain range of the Tibetan Plateau in China. The Kailash region is well known for its biological, geo-hydrological, and cultural significance. It is also the source of four of Asia's major rivers – the Indus, the Brahmaputra, the Karnali, and the Sutlej – which irrigate much of the Indian sub-continent, providing essential transboundary ecosystem goods and services. High-altitude rangelands (HARs) constitute nearly 27% of the geographical area within the KSL. These rangelands intergrade into sub-alpine forests towards lower elevations (<3,300 masl); agricultural fields along flat river valleys; wetlands and peatlands in the lake basins; and the sub-nival zone (pioneer habitats) above 5,500 m. A large number of agropastoral and migratory pastoral communities within the KSL depend heavily on the bioresources of HARs for livestock grazing, high-value medicinal plants, agriculture, and religious and other traditional rites. Recent changes in land use practices, including sedentarization of pastoralists, overharvesting of high-value medicinal plants, uncontrolled livestock grazing in sub-alpine forests, and rapid increases in the number of tourists in alpine areas, and the resultant pressure on water and other biomass resources, have led to degradation of HARs. Effective management of HAR ecosystems and their interfaces requires scientific understanding of the way in which they function and their transboundary linkages. This paper discusses the current state of knowledge about the biophysical features of HARs and their interfaces within the KSL, major conservation issues, and management strategies. Under a regional transboundary landscape initiative, ICIMOD has launched a collaborative conservation and development programme in the KSL involving several partner institutions in all three countries.

Keywords: adaptive management; alpine arid pastures; alpine meadows; community-based organizations; comprehensive environmental monitoring; human-wildlife conflict; participatory natural resource management; timberline ecotone; transboundary cooperation

Introduction

The Kailash Sacred Landscape (KSL) is a culturally rich, ecologically diverse, and geologically fragile transboundary region encompassing an area of more than 31,000 km² in the remote southwestern portion of Tibet Autonomous Region (TAR) of China, adjacent areas of Uttarakhand State in north India, and Far Western Nepal. Marked by the presence of holy Mount Kailash and several other natural and culturally significant sites, KSL has come to the fore during recent years. Mount Kailash and Lake Manasarovar are revered by millions of people from at least five different religions – Buddhists, Hindus, Jains, Bon, and Ayyazhavi – and attract thousands of tourists and pilgrims each year (Bernbaum and Gunnarson 1997). The region is also the source of four of Asia's major rivers – the Indus, the Brahmaputra, the Karnali, and the Sutlej – which provide water and ecosystem goods and services that are vital for the lives and livelihoods of millions of people in the Hindu Kush Himalayan (HKH) region. Recognizing the global and regional significance of the KSL, the governments of China, India, and Nepal have come together through their nodal ministries and key scientific institutions to collaborate and enhance scientific cooperation for the cause of conservation and development of this transboundary landscape and its communities. This programme is coordinated by the International Centre for Integrated Mountain Development (ICIMOD) as the Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI), which promotes collaboration among partner institutions in each country for the sustainable development of the KSL through the ecosystem management approach, as recommended by several international conventions including the Convention on Biological Diversity (CBD). Together, the participating countries have developed a regional cooperation framework (RCF) setting out the objectives and mechanisms of transboundary cooperation for the conservation and sustainable use of biological and cultural resources and associated indigenous knowledge, as well as for increasing the adaptive capacity and resilience of communities within the KSL. This approach builds on the principles of the landscape approach to biodiversity conservation (Sharma et al. 2007), regional cooperation (Messerli 2009), and sacred cultural and historical linkages of the region, while considering both the risks and opportunities created by various drivers of change.

One of the key features of KSL is its wide eco-climatic variation along an altitudinal gradient of 369 to 7,678 masl, with diverse ecosystems manifested in as many as 22 forest types and many more land use/land cover types, in addition to several scrub and herbaceous formations. The basic biophysical attributes of the KSL are summarized in Table 1. High-altitude rangelands (HARs) form a distinct and significantly large proportion of the various ecosystems, covering about 27% of the KSL. In addition, nearly 15% of the landscape above 3,500 masl is under perpetual snow and glaciers. The HARs intergrade into the timberline ecotone in the sub-alpine area and multiple use zones, such as agroecosystems, towards lower altitudes. The rangelands and their interfaces comprise more than 50% of the geographical area of the KSL, forming a contiguous ecosystem spread across three countries that provides numerous ecosystem goods and services. The most important ecosystem service from the HARs is the regulatory service in the form of watershed functions; they also support

Table 1: Biophysical attributes of the Kailash Sacred Landscape

Attributes	Overall	China	India	Nepal
Total area (km ²)	31, 252	10,843	7,120	13,289
Elevation (masl)	369–7678	3,641–7,678	428–6,895	369–7,132
No. of watersheds	12	2	4	8
Key watersheds and area (km ²)		Peacock River basin or upper Karnali (3,062) Manasarovar (7,781)	Saryu (350) Ramganga (1,500) Kali, including subbasins of Gori, Dhaul, and Kali (5,400)	Humla Karnali (600) Seti (1250) Chamelia (700) Tinkar (450) Nampa (350) Tampa (200)
Protected areas in or adjacent to the KSL	6	Manasarovar Wetland Complex	Nanda Devi Biosphere Reserve (part) Askot Wildlife Sanctuary	Khaptad National Park Rara National Park Api-Nampa Conservation Area
Ecologically and/or culturally significant lakes	8	Lake Manasarovar Lake Rakshastal	Parvati Tal Anchari Tal Chhipla Kund	Chhungsa Daha Chhyungar Daha Rara Khaptad
Forest area (km ²)	8,489	The whole area is above the forested zone	4,965	3,524
Rangelands (%)	27%	49%	13%	18%
Human population	1.1 million	8,800	460,000	630,189

Source: Zomer and Oli 2011

globally significant species of flora and fauna, including plants that provide life-saving medicines, and provide fodder and other biomass resources.

The rangelands of the KSL, besides supporting the livelihoods of local communities, serve as an important habitat for several endangered species, including snow leopard (*Panthera uncia*), blue sheep (*Pseudois nayaur*), Himalayan musk deer (*Moschus chrysogaster*), Himalayan tahr (*Hemitragus jemlahicus*), Tibetan wild ass (*Equus hemionus kiang*), and a variety of resident and migratory birds including the endangered black-necked crane (*Grus nigricollis*). The local agropastoral communities, especially those residing in the alpine valleys of India, Nepal, and TAR, China, have had intimate historical and cultural linkages with each other. Over the millennia, these highlanders have developed and inherited a rich traditional knowledge related to the use of rangelands and their bioresources, and such knowledge has been shared across the region over generations. With the rapid changes in socioeconomic conditions of the local communities, the change in the practice of cross-border winter grazing following new political arrangements between China and Nepal, and the new demands of 'development', it is feared that much of the traditional knowledge on the HARs may be lost and critical elements of this landscape, including important interface areas may further degrade unless the local institutions concerned with natural resource management are revived with technical inputs from the concerned line agencies and scientific organizations (Farooque et al. 2011).

This paper provides an overview of the biophysical features of the HARs in the KSL and flags some conservation issues and potential management strategies.

Key Features of High-altitude rangelands in KSL

The high-altitude rangelands discussed here refer to all the natural and semi-natural pastures located in the transboundary landscape of the greater Kailash region above an elevation of 3,000 masl. These rangelands are used by both local and migratory pastoral communities for livestock grazing in different seasons. It is estimated that nearly 27% of the geographical area within the KSL comprises high-altitude rangelands. The proportion of rangelands is highest in TAR, China (49%), followed by Nepal (18%), and India (13%). The following categories of rangelands are discernible within the KSL; they are determined by altitude, topography, and precipitation: (i) cool temperate grassy slopes, (ii) sub-alpine pastures, (iii) alpine moist pastures, and (iv) alpine arid pastures and steppe. The characteristic features of the different types of rangeland and their interfaces are described briefly below.

Cool temperate grassy slopes

These rangelands, dominated by grasses, lie on the steeper south-facing slopes in the cool temperate and sub-alpine zones of the greater Himalayas. The sloping grassland has evolved as a result of frequent fires set by pastoral communities during the winter season to increase grass growth. Common grasses on such slopes include *Chrysopogon gryllus*, *Themeda anathera*, *Themeda tremula*, *Adropogon munroi*, and *Cymbopogon distans*. The slopes harbour a rich array of flora and fauna including wild ungulates such as Himalayan tahr and goral (*Nemorhaedus goral*), and a variety of birds, including partridges, pipits, vultures, and a number of raptors. The grasslands intergrade into temperate and sub-alpine forests or into gentler village grazing lands or cultivation.

Sub-alpine pastures

The sub-alpine pastures represent open areas in forested land at elevations of 3,000–3,500 masl resulting from the clearing of forests, especially on the gentler slopes, largely due to anthropogenic pressures (e.g., camping, timber, and cutting of fuelwood). Depending on the exposition, topography, and degree of anthropogenic pressure, these pastures may take the shape of secondary scrub or herbaceous meadows. These areas are usually seral in nature and subject to conversion into woodland and eventually forests, provided anthropogenic pressures are removed. Typical species of plants include *Rhododendron barbatum*, *Piptanthus nepalensis*, *Angelica glauca*, *Triosteum himalayanum*, *Syringa emodi*, and *Calanthe tricarinata*. Typical faunal species found in these pastures (in the absence of heavy anthropogenic use) include Himalayan musk deer, serow (*Nemorhaedus sumatraensis*), Himalayan monal (*Lophophorus impejanus*) and other pheasants.

Alpine moist pastures

The area between the natural timberline (3,500+200 masl) and the perpetual snowline (5,500+200 masl) in the lower part of the KSL (the greater Himalayas) is characterized by treeless vegetation. Typical vegetation types in these pastures include alpine scrub, tall and short herbaceous formations, *Danthonia* grasslands, sedge meadows, and high alpine cushionoid vegetation (Rawat 1998; 2005). The most charismatic species of wildlife representing this habitat is the endangered snow leopard (*Panthera uncia*), which is at the apex of the food chain and regarded as a flagship species for conservation in this zone. Common herbivores sharing the alpine habitat include Himalayan tahr and blue sheep. The moist alpine pastures form an interface with the alpine scrub and timberline ecotone towards lower elevations, and with the sub-nival zone towards higher elevations. Several alpine valleys in the Indian and Nepalese parts of the KSL have been used traditionally for agropastoral purposes by the indigenous ethnic communities.

Alpine arid pastures and steppe formations

The alpine arid pastures of the trans-Himalaya are found mostly towards the inner dry ranges of Humla and Bajhang districts in Nepal and Burang County in TAR, China. Most of the area is characterized by treeless vegetation, except in parts of the upper Karnali. These rangelands include sedge meadows (along the banks of lakes), scrub steppe, desert steppe, and sub-nival cushion plant communities. The scrub steppes are dominated by *Artemisia*–*Caragana*–*Lonicera* communities in drier and elevated zones, while the riverine scrub is represented by *Hippophae*–*Myricaria* associations. The wet sedge meadows along the banks of the Manasarovar merge with the semi-arid steppes and cold deserts of the western part of the landscape. The alpine arid pastures are home to a number of globally threatened faunal species such as the snow leopard, Tibetan wild ass or kiang, Tibetan wolf (*Canis lupus*), Himalayan marmots (*Marmota himalayana*), and Tibetan snow cock (*Tetraogallus tibetanus*). Of these, the snow leopard and wolf are typical transboundary species ranging across all the alpine rangelands. The alpine arid pastures form interfaces with high-altitude wetlands such as the Manasarovar, Rakshash Tal or Langha Tso, and Parvati lakes, the sub-nival zone of the Gandise ranges, and human habitation in the various river basins.

Land Use Practices and Conservation Issues

The high-altitude rangelands in the KSL have traditionally been used for livestock grazing by both local and migratory pastoral communities. Three distinct forms of pastoral practices are prevalent within the upper parts of KSL-India and KSL-Nepal: nuclear transhumance, trans-migratory, and sedentary. The agropastoral communities in several valleys practice nuclear transhumance, in which only a part of the family moves to the summer settlements (alpine villages) together with surplus cattle. Where there is drastic decline in the number of livestock in such valleys, there has been a sign of recovery in the rangelands as well as in biodiversity (Garbyal et al. 2005). In other pocket areas, local agropastoralists, especially from the

middle elevation villages, drive their surplus cattle to sub-alpine and alpine areas for free grazing during the summer monsoon (Chaudhary 2000). This is a rather recent phenomenon and leads to faster degradation of sub-alpine and alpine pastures, including soil erosion, profusion of unpalatable and invasive species, and loss of vegetation cover. Similarly, there are reports of rangeland degradation and desertification, and subsequent reduction of rangeland capacity, in KSL-China, especially in the Manasarovar catchment. Manasarovar is a Ramsar site and degradation of the catchment rangelands has implications for siltation and degradation of the wetlands, leading to loss of biodiversity as well as a reduction in productivity (Harris 2009; Lu et al. 2009).

The influx of large herds of livestock and summer season congregation of scrub cattle around timberline and sub-alpine forests are causes for concern that need to be addressed urgently. Deforestation and degradation of the timberline ecotone is reported in all the KSL-Nepal districts and parts of KSL-India. Overharvesting of timber, especially high-altitude fir (*Abies spectabilis*), blue pine (*Pinus wallichiana*), and Himalayan yew (*Taxus wallichiana*), for illegal trade across the borders has been reported from many pockets of KSL-Nepal. Recent reports from neighbouring sub-alpine areas of KSL-India have provided evidence of a significant impact of intense anthropogenic disturbance on the structural and functional features of forest communities, which is influencing their integrity (Gairola et al. 2009; Rawal et al. 2012). The process of degradation of these important interface areas is further accelerated due to other drivers of change such as extreme weather events, drought, and forest fires (Xu et al. 2009; Singh et al. 2011).

The alpine rangelands are home to a large number of high-value medicinal and aromatic plants (Hamilton and Radford 2007). In recent years, there has been a sudden influx of herb collectors in moist alpine areas of both the Nepalese and Indian parts of KSL. One of the high-value products collected from this landscapes is yarshagumba or caterpillar mushroom (*Ophiocordyceps sinensis*), which fetches as much as USD 16,000 per kg in the local market (Winkler 2008) and has a global market of USD 5–11 billion per year (Qiu 2013). Yarshagumba has provided an opportunity for rather easy earning of huge amounts of cash for the under-employed rural communities in the region. As a result, every year, thousands of herb collectors throng around the timberline ecotone and moist alpine meadows during May and June. Herb collectors also harvest several other high-value species such as *Dactylorhiza hatagirea*, *Picrorhiza kurrooa*, *P. scrophulariifolia*, *Nardostachys grandiflora*, *Jurinea dolomaea*, *Trillidium govianum*, *Pleurospermum angelicoides*, *Rheum australe*, and *Fritillaria roylei*. Camping and extensive use of fuelwood along the timberline ecotone has its own negative impacts on the wildlife habitat. The possible devastating consequences for the ecosystems and local economy if harvesting regulations are not put in place have recently been highlighted (Shrestha and Bawa 2013; Qiu 2013).

Most of the high-altitude lakes, alpine sites, and meadows are becoming increasingly important as tourist destinations. Unorganized tourism often contributes to degradation of the

fragile landscape due to solid waste pollution, trampling of soil and vegetation, and extraction of fuelwood and other biomass for camping that may negatively affect aesthetic and cultural values (Siwakoti and Basnet 2007). The impact of unregulated tourism on the mountain ecosystems of the Indian Himalayas and their bioresources has been identified as a major concern, particularly in view of the uniqueness of the biodiversity and the environmental sensitivity of the region (Gol 2009). Many tourists, particularly pilgrims, harvest juniper and other woody shrubs at high altitudes to cook food. In particular, the Mount Kailash and Manasarovar areas show significant impacts from the 70,000 or more visitors per year. There are issues of waste disposal, sanitation, and water pollution, and adverse impacts on the wetlands, as well as inappropriate and unaesthetic infrastructural development. KSL-China is mainly inhabited by agropastoral communities. This area has about 6.83 km² of cropland as well as 4,500 km² of pasture. The main crops are spring barley, spring wheat, rape, peas, and vegetables. The main livestock are yak, cattle, a hybrid of yak and scalper, sheep, goats, horses, and donkeys. Sedentarization of pastoralists and overstocking of pastures have led to pasture degradation in several places. As in many parts of the Tibetan Plateau, the agricultural practices are reported to be disintegrating (see, for example, Yi et al. 2008).

The local communities within the KSL depend largely on the high-altitude rangelands for their livelihoods and for cash income from collection and sale of non-wood forest products. So far, there has been very little effort to manage the ecosystems to sustain the services. Government inputs are limited due to poor infrastructure, lack of adequately trained people, and lack of coordination among line agencies. The ever increasing demand for certain wildlife products in the illegal markets makes this landscape all the more vulnerable to poaching and other illegal activities (Yi-Ming et al. 2000). During recent decades, several consignments of bear galls, musk pods, shahtoosh, and bones and skins of tiger and leopard have been seized within this landscape. Poaching is reported to be particularly high for Himalayan musk deer, Asiatic black bear, snow leopard, and high-value medicinal plants. As there are very few alternate livelihood opportunities for the poor, they resort to the wildlife trade and play into the hands of moneylenders and rich traders who can pay a huge amount of cash in advance for valuable wildlife products.

There are several protected areas of different categories within the KSL, including the newly gazetted Api Nampa Conservation Area in far western Nepal (GoN 2008), the Askot Wildlife Sanctuary in India, and the Lake Manasarovar Ramsar Wetland Complex in China. Most of these areas face challenges due to their remote location, lack of people's participation (Samant et al. 1998; Rawal and Dhar 2001), and human-wildlife conflicts.

The HARs have also emerged as critical areas under the climate change scenario, although the interaction of climate change and land use change in these areas is so intense that it is difficult to identify the main driver of change in ecosystem structure and function. Recently Brandt et al. (2013), while describing regime shifts of alpine meadows (i.e., conversion into shrublands) in northwest Yunnan, China, suggested that such shifts should act as a warning

signal for the greater Himalayan region, where vegetation change could greatly affect livelihoods, hydrology, and climate. Shrub encroachment has major implications for ecosystem structure and function, including reduced herbaceous plant biomass and species richness (Ratajczak et al. 2012), alterations in soil conditions (D' Odrico et al. 2012), and changed net primary productivity and nutrient balances in the ecosystem (Barger et al. 2011). In turn, all of these affect pastoral communities who rely more than others on forest resources (Yi et al. 2007).

Management Strategies

Management of high-altitude rangelands and their interfaces within the KSL requires a strong participatory and adaptive approach. This means that the local agropastoral and pastoral communities need to develop mechanisms to equitably share the rangeland resources in a sustainable manner, and the national and provincial governments need to provide policy back up for use of the rangeland resources. Participatory natural resource management planning for each watershed or sub-watershed would require convergence of government line agencies and community institutions, so that critical landscape elements such as high-altitude wetlands, important biological corridors, biodiversity hotspots, and important watersheds are spared from rapid changes in land use and excessive exploitative pressures. Most of the interface areas serve as important biological corridors for the seasonal movement of high-altitude fauna and also serve as important habitat for a large number of species. Management of the high-altitude rangelands would be incomplete without management of these functional elements of the landscape. We suggest the following strategies for management of the high-altitude rangelands and their interfaces within the KSL:

Institutional arrangements for management of the rangelands

Customary laws and policies related to the use of rangeland resources vary considerably across the three countries within the KSL, but the socioeconomic conditions of the local agropastoral and pastoral communities in the high-altitude regions are similar. In each country, there are a number of stakeholders who are responsible for implementation of government programmes and schemes in the HARs, e.g., Departments of Animal Husbandry and Livestock Production, Departments of Forests and Wildlife Protection, Departments of Rural Development, and district or county administration. However, in the absence of a participatory approach and convergence among these departments and local communities, the rangelands remain neglected and unattended. There is an urgent need to organize and strengthen the local (community-based) institutions, which could then develop comprehensive management plans for these rangelands to sustain the ecosystem services. This would require setting up local rangeland management committees comprising representatives from civil society and community-based organizations, livestock husbandry departments, the district administration, and a rangeland ecologist. Recently, the Ministry of Livestock and Cooperatives, Government of Nepal, has brought out a National Rangeland Policy (GoN 2012). This policy needs to be piloted in some districts so as to learn lessons before

implementing it nationwide. KSL-Nepal has a significantly large proportion of rangelands and thus provides an ideal site for piloting such a policy. Piloting would involve enabling community-based organizations to (i) identify social, economic, and ecological problems related to the rangelands, (ii) prepare management plans to deal with the problems, and (iii) implement the management plans. This would be an important step towards institutionalizing a rangeland management programme in the region and scaling up the good practices across the transboundary landscape.

The traditional knowledge and practices of rangeland management that were prevalent in the KSL are in progressive decline (Sundriyal 2011). It would be worthwhile to document, validate, refine, and replicate these practices at representative pilot sites in the KSL. Further, in view of the changing gender roles in traditional pastoral societies, bringing a gender perspective into rangeland management and its linkages with livelihoods will make a further important contribution to sustainable pastoralism in the Himalayas (Hoon 2011).

Capacity building of community-based organizations

The community-based organizations (CBOs) at high altitudes, especially within KSL-India and KSL-Nepal, need to be oriented in terms of current policy instruments, and their roles and responsibilities both in planning and in implementing the plans. The CBOs will have to be trained in participatory comanagement approaches, social mobilization, user group formation including women's self help groups, conflict resolution, implementation of natural resource management plans, and local governance, monitoring, and support to poorer sections of the society in livelihood improvement. In some parts of KSL-India, the community-based organizations have demonstrated that with a little empowerment and capacity building, participatory management of natural resources and monitoring of endangered species is possible (Viridi et al. 2009). With adequate training, empowerment, and assurance of equitable benefit-sharing mechanisms, particularly by way of exposure to emerging access and benefit sharing (ABS) mechanisms, the local communities would be able to play an active role in the conservation and management of the HARs in the landscape.

Restoration and monitoring of ecologically sensitive sites

Restoration of degraded rangelands and their interfaces, such as wetlands and timberline ecotones, should form part of the comprehensive management plan. However, certain areas within the rangelands such as Ramsar sites, ecologically sensitive sites, biological corridors, and biodiversity hotspots will require special efforts in terms of eco-restoration and scientific monitoring. Riverine and wetland habitats in the KSL are particularly vulnerable and threatened by the increased anthropogenic pressures. These areas need to be designated as biologically significant areas (BSAs) as they serve as important habitat for a large number of local and migratory species and provide watershed functions. It is expected that partner institutions would initiate regular monitoring within HARs of endangered or indicator species and taxa and their habitats, interface areas, BSAs, and other ecologically sensitive sites, as

part of the KSLCDI Comprehensive Environmental Monitoring Plan (CEMP). These activities, especially where they involve local stakeholders, may prove to be effective in identifying human-wildlife conflict areas, evolving mitigation measures, and minimizing conflicts.

Valuation of rangeland ecosystem services

As several partner institutions are involved in the implementation of KSLCDI, it is pertinent to initiate policy dialogues and institutional mechanisms at both national and regional levels to handle access and benefits to and from the rangeland ecosystem services using documented evidence. The rangeland ecosystem services from these areas have not yet been properly inventoried and monitored. These steps would be necessary for valuation and assessment of the impact of various drivers of change. There is a need to generate baseline data on the state and health of the rangeland ecosystems from all classes of HARs to feed into rangeland ecosystem services accounting and to develop suitable policies including gender mainstreaming, value chain development, especially from high-value medicinal plants, and institutional innovation.

High-altitude rangeland management in the KSL also needs to be viewed in the light of historical changes with respect to sociopolitical interventions, which have contributed significantly to the rapid process of socioeconomic transformation in pastoral communities in the KSL areas within Nepal and India. In these areas, social organizations and pastoral practices were transformed in a very short span of time, resulting in loss of trade and pasture dependent traditional livelihoods, and leading to extensive migration from the high-altitude areas. The results of such social change and transformation on the rangelands have not been investigated or understood. Therefore, it is imperative to consider both social and climate change dimensions in rangeland management in the KSL. As for other parts of high Asia, using a holistic approach which includes both dimensions and operates from the perspective of pastoralists might help avoid the fallacies of confusing causes and effects (Kreutzmann 2012). The huge potential for improved livestock rearing and linking with the emerging sector of ecotourism in the rangelands and neighbouring sites needs to be taken up as a priority in the KSL.

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High-altitude rangelands and Land Use Practices in the Karakoram-Pamir Landscape

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The Karakoram-Pamir Landscape (KPL) lies in the transboundary area northwest of the Qinghai-Tibetan Plateau in the border area of Xinjiang Province in China and Gilgit-Baltistan Province of Pakistan. The landscape is known for its snowy peaks, glaciated valleys, high-altitude wetlands, alpine pastures, and globally significant biodiversity. High-altitude rangelands cover 24% of this landscape and form the main base of livelihoods for the pastoral and agropastoral communities. These rangelands are currently fragmented as a result of, infrastructure construction, and unsustainable development, which has resulted in the weakening of traditional land use practices and increased the socioeconomic vulnerability of the local herders. The degradation of the landscape has been accelerated by climate change and increased populations of both humans and their livestock. ICIMOD has launched a transboundary landscape management initiative involving key partners in Pakistan and China to enhance cooperation among the countries for biodiversity management and sustainable development and to achieve long-term conservation and development goals in the KPL. This paper provides an overview of the high-altitude rangelands in KPL and the related grazing systems.

Keywords: biodiversity conservation; high-altitude rangelands; Khunjerab National Park; migratory pastoralism; Taxkorgan Nature Reserve

Introduction

The landscape of the Karakoram and Pamir Mountains lies to the northwest of the Qinghai-Tibetan Plateau in the border area of Xinjiang Province in China and Gilgit-Baltistan Province in Pakistan in the western part of the extended Hindu Kush Himalayas (HKH). Almost a quarter of the landscape area comprises high-altitude rangeland, which forms the main base of livelihoods for the pastoralists and agropastoralists in the region. Topographically, this landscape includes some of the most rugged and imposing mountains in the world, with peaks mostly above 6,000 masl and rising to 8,600 masl, i.e., the peak of K2 or Mount Godwin-Austin. Recently, the International Centre for Integrated Mountain Development (ICIMOD) launched a Karakoram-Pamir Landscape (KPL) initiative to enhance transboundary

cooperation for biodiversity management and sustainable development in the China-Pakistan border region. The initiative began with an agreement signed in Beijing for bilateral collaboration between the governments of China and Pakistan to ensure the protection of Marco Polo sheep (*Ovis ammon polii*) and other endangered species in the two adjacent transboundary protected areas – Khunjerab National Park in Pakistan and Taxkorgan Nature Reserve in China, which represent unique cold desert ecosystems.

The outstanding features of the KPL include alpine lakes, mud volcanoes and other geological processes, highly fragile alpine ecosystems such as rangelands, small areas of forest, and wetlands (Khan 2011). The high-altitude rangelands in KPL are rich repositories of biodiversity and water, and providers of various ecosystem goods and services on which both upstream and downstream communities depend. The KPL provides habitats for wildlife such as ibex (*Capra sibirica*), blue sheep (*Pseudois nayaur*), and Marco Polo sheep (*Ovis ammon polii*). Carnivore species like Himalayan brown bear (*Ursus arctos isabellinus*), Himalayan lynx (*Lynx lynx*), snow leopard (*Uncia uncia*), and Tibetan wolf (*Canis lupus chanco*) are found in different parts of the landscape (Schaller et al. 1987; Khan 1996). The area is also rich in freshwater and tourism resources, which if managed carefully can bring about socio-ecological change in both countries, and especially for the pastoral communities residing in the border region. The KPL initiative is being implemented through the involvement and with ownership of the respective governments and allied departments on both sides of the international boundary. This paper provides an overview of the current understanding of the high-altitude rangelands and their related grazing systems and land use practices in the KPL region, which can be used as a benchmark for future planning of transboundary conservation.

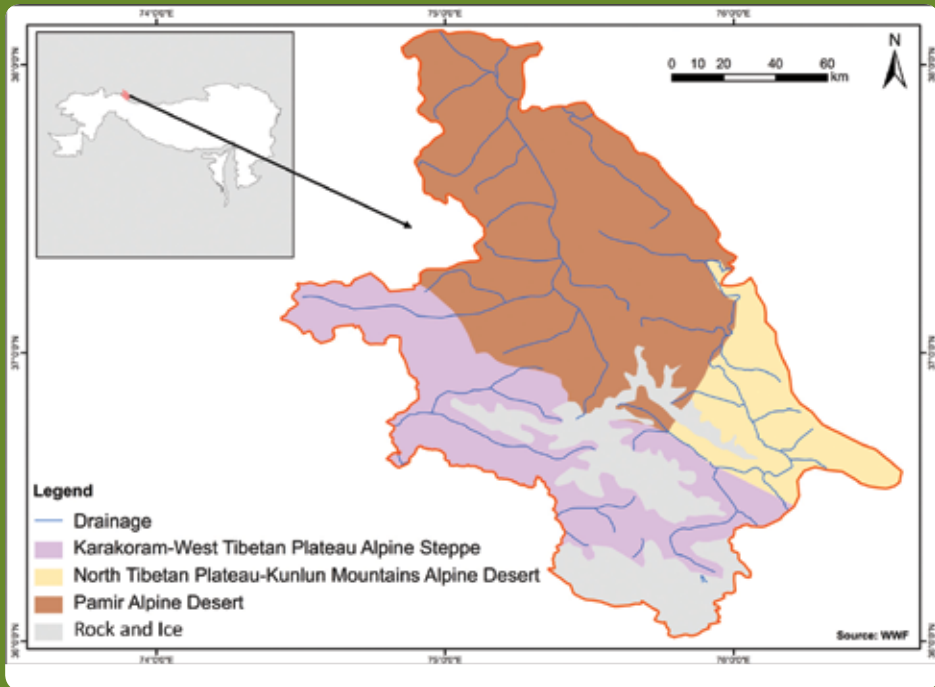
Ecoregions and Life Zones in the KPL

The KPL is a complex mountain region with diverse vegetation types especially adapted to an arid and/or high-altitude environment. The eastern boundary of the landscape merges into the Pamir Plateau and is dominated by semi-desert and desert, whereas the western boundary connects with the high peaks of the Karakoram range and contains alpine vegetation appropriate to the cold sub-humid conditions (Figure 2). The largest ecoregion in the KPL (60% of the area) is alpine desert, formed as a result of the continental and high-altitude conditions (Table 2). Alpine steppe, including alpine meadows, accounts for one quarter of the total and is the most important vegetation supporting local livelihoods in the form of migratory pastoralism.

Table 2: Ecoregions in the KPL

Ecoregion	Area (ha)	Area (%)
Karakoram-West Tibetan Plateau Alpine Steppe	473,070	25.2
North Tibetan Plateau-Kunlun Mountains Alpine Desert	227,696	12.1
Pamir Alpine Desert	890,755	47.4
Rock and Glacier	286,472	15.3
Total	1,877,993	100

Figure 2: Distribution of ecoregions in the KPL



The major life zones are described in two parts: the Taxkorgan Nature Reserve (TNR) in China and the Khunjerab National Park (KNP) in Pakistan.

Taxkorgan Nature Reserve

Taxkorgan Nature Reserve is located in the eastern part of KPL in western Xinjiang in China, on the western fringe of the Pamir Plateau. Much of the terrain is too high and arid to support much vegetation.

Sub-alpine steppe: 3,300–3,900 masl

In the sub-alpine belt, the landscape is dominated by steppe-like vegetation with sparse herbaceous plants and dotted shrubs. The vegetation cover rarely exceeds 15% and the average concentration of species is only around 4–6/100 m². The sparse vegetation is dominated by prickly cushion plants such as *Acantholimon*, *Lycopodioides* and *Thylacospermum caespitosum*. Other typical species include *Krascheninnikovia ceratoides*, *Ajanía fruticulosa*, *Stipa caucásica*, *S. glareosa*, and *Oxytropis microphylla*. The few shrubs such as *Ephedra intermedia*, *Berberis ulicina*, *Rhamnus prostrata*, *Myricaria elegans*, and *Potentilla salesoviana* are usually confined to special situations such as walls of bedrock, boulder-rich slopes, gullies, and scree fans.

Alpine meadows: 3,900–4,700 masl

The deeper river valleys in the central north-facing slope of the Karakoram are more arid than the higher slopes above around 4,200 masl (Dickore 1991). The alpine belt, which is extensive throughout the TNR, consists of alpine sedge-meadows (*Kobresia* spp. and *Carex* spp.) with many forb species and is similar to the vegetation over much of the Tibetan Plateau and the Tien Shan. From 4,200 to 4,500 masl, chamaephyte-communities (*Astragalus webbianus*, *Oxytropis chiliophylla*, *Ephedra monosperma*, *Pleurospermum govanianum*, *Ajania tibetica*, *Rhodiola fastigiata*, *Poa poophagorum*, and *Elymus schrenkianus*) grow on the boulder-strewn slopes. Tall *Carex nivalis* meadows (with *Delphinium brunonianum* and various other species) cover relatively large areas.

Sub-nivale vegetation: 4,700–5,200 masl

Delimitation of the sub-nivale vegetation belt is difficult, although the species composition is very characteristic. *Sibbaldia tetrandra* and *Saussurea gnaphalodes* are frequent cushion-like species on superficially thawing permafrost slopes. About 37 species of phanerogams have been found here, including nine species not found elsewhere (*Oxytropis* spp., *Carex haematostoma*, *Draba winterbottomii*, *Lagotis globosa*, *Potentilla gelida*, *Saxifraga oppositifolia*, *Sibbaldia olgae*, *Stellaria decumbens* and *Waldheimia tridactylites*). High-alpine or sub-nivale turf spots with a vegetation cover up to 90% are confined to the gentler slopes and shallow depressions.

Khunjerab National Park

Khunjerab National Park is located on the western side of the KPL in Gojal tehsil in Hunza-Nagar District in the extreme north of Pakistan. Major vegetation types in KNP include:

Sub-alpine steppe: below 3,700 masl

Sub-alpine dry steppe with 15-20% of total cover is found at medium and low elevations on south-facing dry slopes not covered by sub-alpine scrub and forest. It is sparsely vegetated with *Juniperus* spp. and *Artemisia* spp. A few woody species are found, including *Lonicera quinquelocularis* and *Artemisia mexicana*. *Primula* is the most prominent plant. Grassy species are found in relatively moister places and include *Setaria* spp., *Festuca* spp., *Poa bulbosa*, *Poa sinaica*, *Phleum* spp., and *Carex* spp.

Alpine meadows: 3,500–4,400 masl

Alpine meadows (20% of total cover) are confined to north-facing slopes, level ground, and depressions above 3,500 masl and along glaciers. They are generally rich in plant biomass due to an adequate moisture regime and are therefore important habitats for both domestic and wild herbivores. Sedges and grasses dominate, but forbs such as *Primula macrophylla*, *Potentilla desertorum*, *Gentiana* spp., *Anemone* spp., *Polygonum* spp., *Sedum* spp., *Plantago* spp., and *Saxifraga sibirica* are also common. *Poa bulbosa* and *Poa sinaica* are prominent among the grasses.

Sub-nivale vegetation: above 4,200 masl

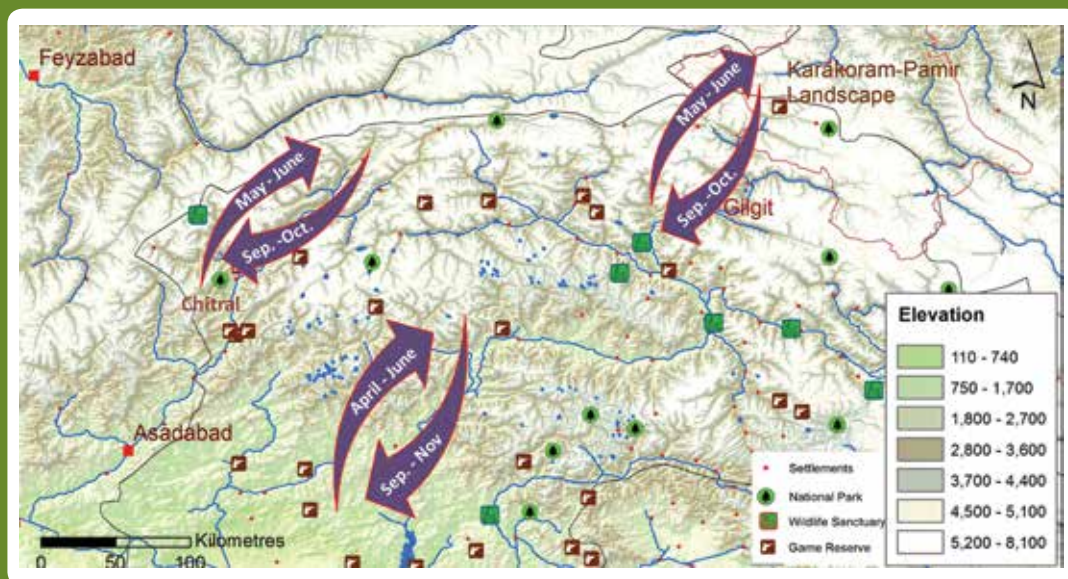
Permanent snow field and cold desert cover an estimated 25-30% of the park area, lying mainly above 4,200 masl. Vegetation is sparse and most species adopt ecological modifications in order to cope with extensive sun radiation and chilling temperatures. The characteristic species in the community are *Saussurea simpsoniana*, *Allardia glabra*, *Christolea crassifolia*, *Primula macrophylla* subsp. *moorcroftiana*, *Oxytropis microphylla*, *Oxytropis chiliophylla*, *Potentilla desertorum*, *Mertensia tibetica*, and *Potentilla pamirica* subsp. *pamiroalorica*.

Grazing System and Land Use Practices in KPL

Pastoralism is the predominant land use in the Karakoram-Pamir border region and is only occasionally mixed with crop farming in low lying flat areas and valley bottoms. Livestock grazing on rangelands is a prominent way of life for the mountain communities and a major source of livelihood (Khan 2012). The grazing lands are characterized by steep, dissected slopes and narrow valleys, and terrain that is subject to active erosion and naturally unstable. Livestock herding accounts for 20–35% of total household income, contributing around 5.3% and 11% to the total GDP of China and Pakistan, respectively (Zhou et al. 2010; Beg 2010). Two different types of pastoral practices are common: transhumance and sedentary. In the transhumant system, animals are moved across a vast mountain terrain, utilizing sub-alpine and alpine pastures in a complex pastoral herding system according to season. Pastoralists maintain their principal settlements at lower altitudes, where they live for approximately seven months of the year. The system is characterized by a continuous search for pasture and the year round movement of cattle, sheep, and goats. In the sedentary system, the animals are kept on the farm all year round. Cattle (mainly yaks), sheep, and goats are allowed to graze on gentle slopes on community land and fallow fields and in fields after harvesting. Only 5% of the total population of ruminants in KPL are thought to be stall fed. Maize stover, hay, and grasses are the principal sources of fodder for stall feeding. Maize stover, green grass, and wheat straw are sold or exchanged among farmers in some villages.

The border area of Khunjerab National Park and Taxkorgan Nature Reserve is inhabited by Wakhi-Tajik, Kyrgyz, and Burusho people and their livestock (Schaller and Kang 2008). In the traditional form of migratory pastoralism, the movement up and down the mountains takes place in stages (Suleri et al. 2002). In late April or early May a part of the family takes the livestock to the edge of the coniferous forest where a second house is located. They stay there for three to four weeks before moving to a third house located within the forest itself. After a further stay of three to four weeks, both livestock and people move to the high alpine pasture, where they remain for up to two months. The return journey begins with the first snowfall in late September or early October (Figure 3). For the Wakhi people who reside in or near the Khunjerab National Park, women take care of yaks, sheep, and goats on the alpine pastures above 4,000 masl during the summer. In late autumn, herders move the yaks to lower elevations where they look after them through the winter (Knudsen 1999).

Figure 3: Pastoral migration in the KPL and surroundings



In Taxkorgan, the traditional migratory management system has been gradually transformed to a more sedentary style since the 1990s. With the support of the local government, many settlements were constructed with improved infrastructure. Even so, the seasonal pastures have been kept for rotational grazing of livestock. Of about 4,634,000 ha of summer pasture in the county, which are usually grazed for 120 days, 5,924,000 ha are winter pasture, used for 140 days and 211,000 ha of pastures are used during the transitional period in spring and/or autumn (Editorial Board 2009).

The local communities in KPL depend solely on the natural resources of the reserves for their livelihood. They collect fuelwood, timber, fodder, and non-timber forest products (NTFPs) from the area for subsistence and sale. Because of the limited livelihood opportunities, and to meet the energy needs, there is heavy pressure on bushes and scrub in the form of overgrazing and uprooting. The extensive collection of fuelwood to meet the demand of an increasing population has been reported as threat to habitat in Taxkorgan, with desertification accelerated by human activities (Animal Husbandry Bureau of Xinjiang 1993).

The high-altitude rangeland in KPL has become a tourist destination for mountaineering, culture (e.g., the ancient Silk Road), and archaeological sites. Tourism has provided economic and livelihood benefits to the local communities, but unregulated tourism is having a negative effect on the KPL due to the large amounts of solid and human waste left by expeditions and exploitation of fuelwood and other resources along trekking routes.

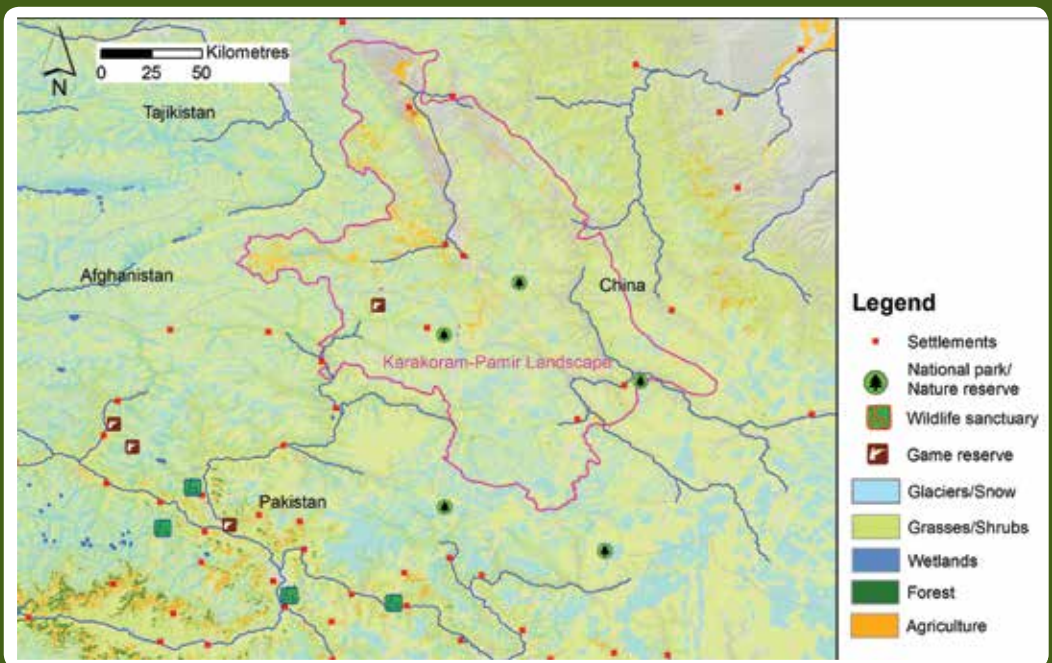
Challenges to Rangelands and Land Use Practices

The high-altitude rangelands in the landscape share boundaries with several other ecosystems such as forests, wetlands, and agricultural lands (Figure 4). Any shift in these boundaries can be an indicator of ecosystem dynamics and external disturbances. Recently, the intensification of land use in the high-altitude rangelands has resulted in some man-made interfaces being formed, e.g., the boundary of the protected area, which occasionally becomes a secondary transitional belt between conserved and degraded vegetation. Looking at the boundary shift can be a feasible way of studying the status and challenges faced by the rangeland ecosystem.

Degradation of rangelands

Although the rangelands in the KPL span a relatively large geographical area, they are an under acknowledged and rarely described resource. The KPL rangeland is under threat as a result of removal of shrubs and trees for fuelwood, overgrazing by livestock, and other land use changes. During the last few decades, the productivity of the rangelands has been adversely affected due to the growing human and livestock population, centuries of overgrazing, and changes in land use practices (Ahmad 2000). Overgrazing has also resulted in a move in species composition towards less palatable forage species, including weeds and poisonous plants, in a number of range and pasture ecosystems. In addition, extraction of the

Figure 4: Rangeland resources and interfaces in the KPL



roots of species of medicinal plants is not only damaging the vegetation but also upsetting the surrounding soil. Collection of *Saussurea simpsoniana* (boshi phonar) by Pakistani locals and Chinese traders is an emerging threat to the landscape. In the part of the landscape in China, extraction of medicinal plants by local traders is now occurring on a large scale; several valuable medicinal plant species are at risk, and there has even been destruction of vegetation. The main products collected by local people include Radix Glycyrrhizae (*Glycyrrhiza korshinskyi*, *G. inflata*), Herba Ephedrae (*Ephedra sinica*, *E. equisetina*, and *E. intermedia*), and *Apocynum venetum*. Furthermore, expansion of settlements, construction of roads recreational facilities, and other infrastructure, and other economic activities have also contributed to vegetation destruction and fragmentation.

Impacts of climate change

Climate change and its impact on ecosystems, especially high-altitude ecosystems, is an important current and emerging issue. The change in climate is posing a serious threat to the fragile ecosystems and poor communities of the mountainous areas of KPL. Almost all the natural ecosystems in the KPL are vulnerable to climate change, with effects including, but not limited to, loss of habitat, species extinction, growth of less palatable grasses in pastures, diseases in wild animals, pest attacks on crops, increased intensity of melting of glaciers, high turbidity in water bodies, heat waves, cold spells, droughts, landslides, water-borne epidemics, avalanches, heavy rainfall, heavy snowfall, glacial lake outburst floods, and soil erosion.

Furthermore, due to both climate change and population increase, the availability of water resources has become a major issue in Taxkorgan in terms of both quantity and quality. The water resources are used by both nomadic herders and livestock. There are few protective measures and water quality is frequently affected by livestock. More frequent droughts in recent decades have led to occasional shortages of drinking water; at the same time floods in the summer also affect the quality of drinking water and the health of local people. It is believed that global warming is contributing to the modification and breakdown of the traditional migratory system and sometimes disturbing the natural upstream-downstream interactive system. With earlier warming in spring, and a longer summer in the high mountains, herders in the Pakistan part of KPL can move earlier to higher summer pastures, and the traditional migration route has been modified accordingly (Joshi et al. 2013). The longer stay in summer pasture might help herders cope with the shortage of winter feedstuff, traditionally a critical issue, but may also increase pressure on this fragile ecosystem, allowing less time for recovery. A warmer winter might also lead to some negative effects, such as an increase in livestock disease. The nature of climate change has not yet been fully understood by scientists and is thought to vary greatly at the local level (Hewitt 2005).

Fragmentation of landscape

Historically KPL provided contiguous habitat for the local movement of threatened fauna. Recently, the international boundary between China and Pakistan has been fenced with

barbed wire leading to fragmentation of habitat. This has affected migration of wildlife especially the endangered Marco Polo sheep, which could lead to more intensive inbreeding and further degradation of the population. Flagship species such as Marco Polo sheep and snow leopard, share common wildlife habitats. Due to unsustainable hunting, habitat destruction, and restricted movement of these species across the border, the growth of the species is very limited. Land ownership conflicts have also contributed to natural resource exploitation on the Pakistan side (Sheikh et al. 2002). On the Chinese side, settlement of herders and fencing of pastures has introduced new issues in rangeland management. Enclosure of winter pasture on a large scale impacts the migration routes of both livestock and wildlife. A more sedentary grazing system can lead to intensive overgrazing around herders' winter settlements. A long-term monitoring system on land use change should be established to improve understanding of the changing trends and impacts.

In some parts of the KPL, especially in sub-alpine and alpine meadows with peat accumulation have been drained to enable cutting of peat for fuel (Ullah and Khan 2010). The collection of peat from wetlands not only destroys the vegetation cover, it also changes the hydrological cycle of the alpine ecosystems, which further impacts downstream areas. Fragmentation can also be seen in the timberline, the ecosystem interface between grasslands and forests in the alpine belt. The *Betula utilis* belt, which forms the upper treeline, has been largely destroyed due to depression of the treeline as a result of overgrazing (Schickhoff 1995). Since fuel is very scarce above the timberline, considerable areas of sub-alpine forest and scrub have been cleared in order to meet fuel needs.

Human wildlife conflict

Human-wildlife conflict is another major problem in the high-altitude rangelands of the KPL. Local communities have a close interaction with wildlife and high probability of sharing habitat for livestock grazing. Khan (1996) reported that about 70% of the pastures in the KNP area were degraded due to excessive use by domestic livestock, reducing the availability of forage for wild herbivores. Wildlife such as snow leopard and wolf, which prey upon domestic livestock, often cause economic loss. A decline in the availability of wild ungulates, a key component of the snow leopard diet, due to extensive hunting practices and habitat loss has caused a significant shift in predation pressure toward domestic stock in some areas of KPL (Khan 2012). Depredation by carnivores has become a major livelihood concern and an emerging challenge for conservation managers and park authorities in the protected areas of KPL region. According to Wegge (1989), livestock depredation rates in KNP were 10%, mainly due to snow leopard and wolf. In Taxkorgan Nature Reserve it was 7.6%, mainly by snow leopard (Schaller et al. 1987).

Conclusion

The high-altitude rangelands in the KPL region provide seasonal grazing grounds for native wildlife and livelihood options for the pastoral communities. Unfortunately, these rangelands

are becoming increasingly fragmented as a result of unsustainable development, resulting in the weakening of traditional land use practices and increased socioeconomic vulnerability of local herders. Lack of good understanding and description of rangeland ecosystems further aggravates the degradation process in KPL under the challenges of climate change. Local livelihoods, social needs, wildlife, and their complex interactions call for scientific innovation and handling of this landscape to facilitate sustainable adaptation by local communities harmonized with the natural requirements of the KPL. Close transboundary cooperation is needed between the stakeholders in Pakistan and China to conserve the biodiversity and sustain the livelihoods of local herders in this unique landscape.

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Changes in Pastoral Production Systems in High-Altitude Village-Rangeland Interfaces in Nepal

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Livestock farming is an important part of livelihoods in rural Nepal. Transhumant ruminant production is practised in the higher altitude areas, whereas extensive ruminant production prevails in the lower altitudes of the mid-hills. The low productivity of livestock in the high hills is mainly due to the low availability of feed. Rangeland is an important source of forage, but as a result of poor management only 37% of forage is accessible to livestock. A study conducted in the rangeland area of Kalinchowk village development committee (VDC) of Dolakha District indicated that climate change had resulted in a negative impact on traditional livestock farming practices. However, local people are exploring coping strategies for improving and securing their livelihoods. Information obtained from focus group discussions and a district level consultation meeting indicated an urgent need to prepare a rangeland policy implementation plan, to carry out rangeland action research, and to implement climate change adaptation and risk management programmes in consultation with and through mobilization of local communities to ensure sustainable utilization of the rangelands in Nepal.

Keywords: climate change; livelihood; livestock; Nepal, rangelands

Introduction

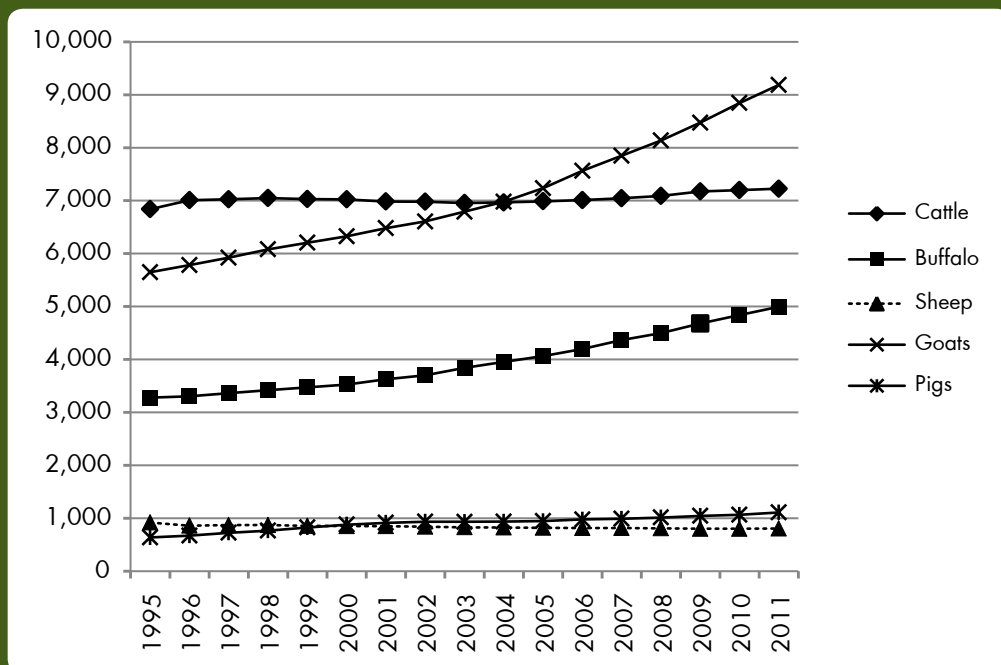
Nepal is an agricultural country. About 66% of the population depends on agropastoral practices. Livestock forms an integral part of the overall farming system; it is not only an important source of protein in the form of milk, milk products, eggs, and meat, but is also a source of draft power for cultivation and of organic manure to increase soil fertility (Sherchand 2001). In the Terai, bullocks and buffalo bulls are used to pull carts and plough the fields, but in the hills, mules, donkeys, yaks, and even sheep and goats are used to transport goods (Subedi and Jaisy 2000). A large population is involved in the production, processing, and trade of livestock and livestock products for their livelihoods. The agricultural sector provides about 26% of the national GDP, with the share of the livestock sector about 12%. Dairy, meat, and eggs contribute 63%, 32%, and 5% to livestock GDP, respectively. The Agricultural Perspective Plan (APP) has identified livestock as an important sector with a potential increase

in growth rate from 2.1% in the base year (1995/96) to 6.1% at the end of the plan period (2014/2015) (APP 1995).

Nepal's livestock statistics show that over 80% of the country's rural households own livestock and about 20% of household income comes from livestock (CLDP 2009). Livestock is an important sub-sector that ensures the supply of cash from urban to rural areas. Figure 5 shows the change in livestock numbers from 1995 to 2011. According to the most recent livestock census, Nepal has 7.2 million cattle, 4.8 million buffaloes, 0.8 million sheep, 9.2 million goats, 1.0 million pigs, 25.7 million chickens, and 0.4 million ducks (AICC 2012). The country produces about 1.6 million tonnes of milk, 0.277 million tonnes of meat, 0.586 tonnes of wool, and 700 million eggs annually. More than half of the cattle, buffaloes, goats, and sheep are reared in the hills, and one-third in the Terai. Transhumant pastoral production is practised in the temperate, sub-alpine, and alpine regions, whereas much of the livestock production in the Terai and lower-middle hills (<1,000 m) is sedentary, utilizing available forage in and around the villages.

The per unit productivity of livestock in Nepal is very low in comparison with that in other South Asian countries (Gurung et al. 2011a). This is the result of poor genetic make-up, poor health care, poor feeding, and inefficient livestock management. Nepal's livestock suffer from a 34% feed deficit calculated on a dry matter basis (Pariyar 1994), which clearly indicates the

Figure 5: Livestock statistics for Nepal from 1995 to 2011



Source: AICC 1996–2012

limitation for higher production (NASA 2004). Thus the state of the rangelands and their scientific management is a pertinent issue in Nepal.

Rangeland comprises grasslands, pastures, shrubland, and forests (MoPE 1998) and occupies 22.6% of the total area of the country. About 70% of Nepal's rangelands lie in the Western and Mid-Western Development Regions, with the major part in the mountain region. (50.5%, 29.0%, 16.7%, 1.2%, and 2.8% in the high mountains, high hills, middle hills, Siwaliks, and Terai, respectively). Forest, agricultural land, grassland, shrubland, water, uncultivated land, and others occupy 29.0%, 21.0%, 12.0%, 10.6%, 2.6%, 7.0%, and 17.8% of the rangeland area, respectively (TLDP 2002).

Notwithstanding the importance for people's livelihoods, only limited interventions have been made towards sustainable management and judicious and environmentally friendly utilization of Nepal's rangelands. A case study was carried out on the rangelands in Dolakha District in the Central Development Region of Nepal with the following objectives:

- to assess the impacts of climate change on major aspects of animal husbandry practices;
- to explore adapting/coping mechanisms practised by local communities to improve and secure their livelihoods; and
- to suggest recommendations for adaptation and coping strategies in similar agro-climatic situations.

Study Area and Methodology

Dolakha District in the Central Development Region was selected because of its high vulnerability index (MoE 2010), vulnerability to glacial lake outburst floods (GLOFs), and the high level of drought prevailing in the district. The district has a wide altitudinal range from 732 to 7,148 masl and contains a famous glacial lake, Chho Rolpa. The greater part of the area (59.3%) is forested, which includes pasture land (DLSO 2011). Only 27.4% of the area is agricultural land, and 11.4% is snow covered. More than 90% of the population depends on agriculture, and livestock is a mainstay of farming.

The Kuri area of Kalinchowk Village Development Committee (VDC), Ward Number 9, in Dolakha was selected for a field survey and focus group discussion. A district level consultation meeting was carried out with key resource persons at the district headquarters to verify the information obtained from the focus group discussion. Kalinchowk VDC lies between 27.76 and 27.82°N latitude and 86.10 and 86.02°E longitude, and has an altitudinal range of 1,700 to 3,810 masl with three distinct climatic zones: subtropical in the lower belts; temperate in the middle regions; and sub-alpine to alpine around Kalinchowk peak. The study was carried out from February to April 2011. The information collected was tabulated and interpreted using validation from the focus group discussion and district level consultation meeting.

Results and Discussion

The case study provided some valuable information on rangeland management and pastoral production systems in high-altitude village-rangeland interfaces. The results are summarized below.

Herders' perception

The yak herders have witnessed several man-made and climatic changes in their surroundings during recent years. They reported rapid deforestation around their villages coupled with frequent forest fires after 1992. Villagers recall that 1992 was a particularly severe year in which they witnessed a severe forest fire, followed by a prolonged drought and terror of common leopards around the villages. The villagers felt that there had been a reduction in snowfall over the previous 7-8 years accompanied by rapid melting of snow, so that the total duration of snow cover was less. According to the villagers, the intensity of rainfall has increased and unseasonal rainfall is common. Both the quantity and duration of snowfall affected water resources and biomass production of the rangeland. The changes led to reduced availability of drinking water for herders and their chauri (hybrid bern yak and cattle), and faster drying of the land with reduced forage production resulting in a fodder deficit for the livestock. Thorny and invasive plants had also increased. Farmers in these areas graze their livestock on government-owned rangeland during summer, which is limited in extent, and in community forests during winter. Stall feeding is only practised for lactating animals. Recently, farmers started to grow white clover on private land as improved forage. Farmers do not give priority to raising male calves. It is important to note that a mountain perspective framework (MPF) is needed to explore information from the hill and mountain regions of Nepal. The MPF defines the uniqueness of mountain situations as a basis for designing and implementing integrated rangeland management for sustainable livelihoods and the environment (ICIMOD 2006). Focus group discussion was chosen as an effective tool for obtaining information about the unique characteristics in remote areas. In this study, the participants in the focus group discussion were mainly chosen from the yak and chauri keeping farmers' groups. Lohani (2007) noted that climate change is responsible for erratic weather patterns that may destroy crops and livestock in Nepal.

General trends at district level

The consultation meeting with key informants held at the Dolakha District headquarters revealed that there were fewer large ruminants in the farming system than ten years before and the breeding season of animals had changed. Bacterial diseases had been frequent and the efficiency of veterinary drugs had gone down. Gynaecological problems such as abortion and repeat breeding were thought to have increased. Pine forest and bush canopy, which have a negative impact on pasture species and water resources, had increased and farmers were therefore giving priority to timber production. The district has experienced the start of the semi-commercialization of livestock farming. The sheep population had declined drastically

Table 3: Rangeland carrying capacity and stocking density in Nepal

Rangeland type	Carrying capacity (LU/ha)	Stocking density (LU/ha)	Stocking density divided by carrying capacity
Mid-hills	0.31	4.08	13.2
Steppe grassland	0.01	0.19	19.0
Open grassland	0.54	7.07	13.1
Alpine meadow	1.42	0.64	(0.5)

Source: Pariyar (1994)

and there was less interest in yak and chauri farming, while broiler chicken farming was increasing as a new opportunity. All these changes were reported and attributed by the informants.

Rangelands have a tremendous potential in terms of natural vegetation, forage supply, non-timber forest products (NTFPs), niche products like *Ophiocordyceps sinensis* (yarshagumba), the rich floral and faunal biodiversity, the rich indigenous culture (Sherpas, Limbus, and others), the unique lifestyle of pastoralists, as destinations for tourists, as water reservoirs, and as a basis for mountain farming. However, this potential has been shrinking in recent years. The carrying capacity of the rangelands is decreasing and the high stocking density has led to degradation. Pariyar (1994) noted that the stocking density was much higher than the actual carrying capacity in all range types except alpine meadows (Table 3).

Management issues

According to the Livestock Master Plan (1993) and Pariyar (1998) only 37% of the rangeland forage is accessible to livestock in Nepal. The production and productivity of forage are also very low and fodder is scarce, especially in winter. Under these circumstances, the often-quoted 'livestock revolution' might remain a dream in Nepal if proper strategies are not adopted in time (Paudel 2006).

Uncontrolled grazing due to overstocking, unsustainable harvesting of rangeland resources, and loss of indigenous vegetation including legumes, is leading to degradation of the rangelands. Rangeland management is perceived by most of the stakeholders as 'Everybody's land while using and no man's land when it comes to the issue of management.' Deforestation, soil erosion, forest fires, and other issues are becoming common. As a result, the sustainability of the livestock production system is severely threatened, and conflicts between different groups of herders about the use of rangeland even affect social relations (ETH 2009). Despite the clear objectives and strategies for rangeland management contained in the Rangeland Policy, 2012, management is still a low priority for the government. It is further hindered by the weak intersectoral coordination among the stakeholders and public service networks, the limited research interventions, and poor adaptation to climate change.

Noticeable achievements in rangeland management

The national Rangeland Policy, 2012, which was approved by the government after a series of regional and national level consultations, workshops, and discussions with experts and stakeholders, is a remarkable achievement for rangeland management in Nepal. The Rangeland Policy clearly recognizes the Department of Livestock Services as the lead agency for rangeland management. The policy highlights the importance of rangelands and the major issues; analyses the holistic management of rangelands from the viewpoint of different stakeholders; and considers rangelands as under constant and serious threats, which require urgent attention. A draft for the rangeland policy implementation framework has also been prepared recently by the Directorate of Livestock Production, Department of Livestock Services.

Conclusion and Recommendations

Poorer people are the most dependent on agriculture and adjacent rangelands in the dryland areas of Nepal. Therefore, they are hit hardest by climate change, desertification, and drought (Winslow et al. 2004). However, most of the rangelands are rapidly degrading because of the limited attention paid to sustainable management and issues related to climate change. Although the Rangeland Policy, 2012, is in the process of implementation, there is an urgent need for a rangeland policy implementation plan (RPIP) which pays due attention to programmes and budget as well as the formation of implementing bodies at all levels. In addition, effective programmes are needed on climate change adaptation and risk management as well as participatory action research on rangeland management for the promotion of high-value mountain commodities for supporting pastoral livelihoods. Cross-border coordination, cooperation, and collaboration with neighbouring countries would go a long way in effective and scientific management of high-altitude rangelands. Mobilization of communities at the local level, and regular expert consultation workshops at national and international levels, are needed to support the sustainable management and utilization of the rangelands in Nepal.

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An Ecological Assessment of Grasslands and their Interfaces in Kumaon Himalaya, India

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Rangelands form one of the major components of the natural landscape in the Himalayas. However, they are changing rapidly due to increasing population pressure, rapid urbanization, the growth of tourism, and economic globalization and the consequent land use intensification. These changes are disrupting the hydrological system of rangelands through reduced groundwater recharge, drying of natural springs, and decreased stream flow, which is increasing the vulnerability to water, food, livelihood, and health insecurity of a large population in the mountains and downstream that depends on subsistence agriculture. It is imperative to monitor land use change, understand the drivers of land use intensification, and evolve an integrated and community-based rangeland management framework. A study was carried out in Dabka Watershed, Kumaon Lesser Himalaya, India, to support this.

The results indicate that nearly 58% of the total geographical area of the watershed is composed of forest, wetlands, and grassland, of which 69% is forest, 20% grassland, and 11% wetlands. Land use changed in approximately 16% of the watershed between 1982 and 2012; the land use intensification decreased the proportion of forests, grassland, and wetlands by 3.0%, 3.3%, and 1.7%, respectively. In total, 37% of the springs and a 7 km length of stream dried up completely, and water discharge from the streams originating from the rangeland headwaters decreased by 15%. As a result, 74% of the villages are facing marked scarcity of drinking water and the watershed has lost 16% of its irrigation potential. Agricultural and food productivity declined by 15% over the 30-year period. A community-oriented, participatory integrated rangeland management framework based on comprehensive rangeland mapping and land use planning was developed in agreement with local communities and government line departments and is expected to affect policy and decision making in the Himalayas in the long term.

Keywords: food security; grassland; ground water recharge; headwaters; land use changes; integrated natural resource management; rural livelihood improvement; wetland

Introduction

Rangelands, comprising grasslands and wetlands, are an important component of the natural landscape in the Himalayas and represent the headwaters of freshwater ecosystems. The

temperate and subtropical grasslands in the lower-middle Himalayan ranges have mostly evolved on steeper and more exposed slopes with thin to very thin soil and are somewhat comparable to 'hill-savannah' or 'hay slopes' in western and central Europe. These small grasslands are considered to be secondary anthropogenic grasslands (Knapp 1979), developed and modified by human use associated mostly with forest clearing, grazing by domestic livestock, and in some cases fire (Coupland 1979). They are highly fragmented and interspersed with temperate and sub-tropical forests and are characterized by a high floristic diversity (Pott 1995). The contiguity of these grasslands with alpine meadows, and their proximity with the tropical monsoon grasslands at lower elevation makes them interesting.

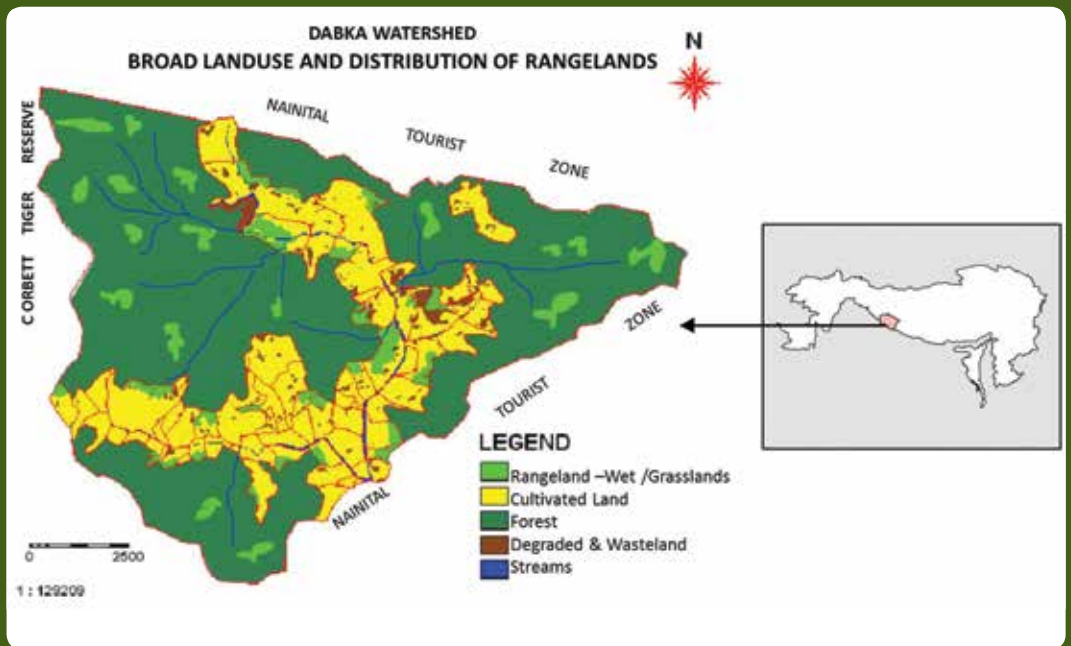
Gentler slopes in outer Himalayan ranges in India are used for livestock grazing by the local rural communities. Water flowing down from the upper catchments in the form of springs and streams not only contributes to the discharge of the rivers which form a lifeline for the local communities, it also supports the food and agricultural systems downstream (Tiwari and Joshi 2012a). However, there has been a rapid change in land use practices throughout the Himalayan range primarily due to increasing population pressure, rapid urbanization, and infrastructure development for economic gains (Wasson et al. 2008; Tiwari 2000). These changes have led to the disruption of the hydrological system, reduced groundwater recharge, drying of natural springs, and decreased stream flow (Rawat 2009; Tiwari and Joshi 2012a). As a result, the regime of the rangeland water resources is likely to change with respect to discharge, volume, and availability, thereby increasing the vulnerability to water, food, livelihood, and health insecurity of the large population dependent on subsistence agriculture, both in the mountains and in the densely populated adjoining lowlands (Tiwari and Joshi 2013). Furthermore, climate change has already stressed the Himalayan rangelands through changes in temperature and precipitation and an increase in extreme weather events (ICIMOD 2009). It is therefore imperative to monitor land use change, understand the socioeconomic drivers of the change, assess the impact on rangeland ecosystems, and evolve an integrated and community-based rangeland management framework.

This paper deals with the status of anthropogenic grasslands and their interfaces in the Dabka watershed in the outer Himalayan range of Uttarakhand (India). The study aimed to monitor land use dynamics and the socioeconomic drivers. The key findings of the study are presented together with the implications for conservation and management of the forest-grassland interface.

Study Area

Dabka watershed lies in the catchment of the Koshi River, which originates in the Lesser Himalayan ranges, in Almora District in the Indian state of Uttarakhand. The Dabka drainage basin extends from the low lying narrow foothill zone comprising the Bhabar and Siwalik Hills to the Lesser Himalayan ranges to the north of Nainital District in Uttarakhand. The watershed lies in close proximity to the world famous Corbett National Park. It encompasses a geographical area of approximately 69 km² at an elevation of 700 to 2,623 masl (Figure 6).

Figure 6: Detailed map of Dabko watershed study area



Average annual rainfall is about 190 cm. The catchment is intersected by the Main Boundary Fault; the area is tectonically active and prone to landslips, landslides, and soil erosion, and, therefore, considered to be ecologically sensitive. The principal geomorphic features of the region are dissected hills, active landslides, colluvial fans, old talus, cones, fluvial terraces, hogbacks, and saddles. The altitudinal and topographic variation result in a rapid transition of ecoclimatic zones. Approximately 40 km² (57.6%) of the watershed consists of natural vegetation including different types of forest, interspersed with grasslands.

The watershed has a total population of 5,250 persons living in 43 villages, with a population density ranging from approximately six to 322 persons per square kilometres. The foothill belt along the southern fringe of the catchment is formed by alluvial soils deposited by streams and rivers flowing down from the Lesser Himalayan ranges and Siwaliks Hills, and constitutes one of the most productive and densely populated tracts of the Kumaon Himalaya. The high population pressure in the foothill zone is affecting resource use practices such as grazing and collection of fodder and fuelwood and moving them to higher elevations, which is leading to degradation and depletion of the grasslands as well as forests.

As in other parts of the Kumaon Himalaya, animal husbandry is an integral part of the subsistence agricultural economy in the catchment. Primary data collected from all 43 villages in the catchment indicate that livestock and crop production constitute the main source of

food and livelihoods for about 51% of households, while 35% depend primarily on animal husbandry. The environmental impacts of the resource development processes associated with traditional biomass-based subsistence agriculture and animal husbandry are of special significance in this region. The practices of cultivation, grazing, and construction now extend over large areas, and land use on the fragile slopes is intensifying, leading to degradation and depletion of critical natural resources including the rangeland ecosystem. The region, therefore, deserves special attention and priority measures to ensure conservation and sustainable development of the rangeland resources.

Methodology and Data Source

The methodological approach included (i) geospatial analysis of land use and land cover using high resolution satellite data supported by intensive ground validation; (ii) hydrological monitoring of springs and streams and assessment of the impacts of hydrological disruptions on water resources and agricultural productivity; (iii) appraisal and analysis of natural resources using participatory resource appraisal (PRA) methods and a comprehensive socioeconomic survey; (iv) comprehensive discussion and consultation with local government agencies and rangeland user communities for developing a rangeland conservation framework; and (v) integration of various parameters to develop a watershed management action plan using GIS. Analysis of land use and rangelands was carried out for the years 1982 and 2012. Survey of India Topographical Maps at a scale of 1:50,000 were used for the land use survey and mapping for 1982. Linear Imaging Self Scanning Scanner-III (LISS-III) and Panchromatic (PAN) merged data from the Indian Remote Sensing Satellite-1C (IRS-1C) were used for the survey and interpretation of land use for the year 2012.

Digital interpretation techniques supported by intensive ground validation were used for the analysis. Image enhancement techniques such as principal component analysis (PCA) and normalized deviation vegetation index (NDVI) were used to enhance the interpretability of the remote sensing data for digital analysis. In the Himalayan region, the interpretability of the remote sensing data is affected to a large extent by the complexity of the terrain and the effects of elevation and slope and aspect, which can lead to the same object having a different spectral signature and vice versa. In order to overcome these constraints and attain the best possible level of accuracy, intensive ground truth surveys were carried out in the study region and a visual interpretation key was developed for primary land cover/land use classification. This was followed by digital classification of land cover land use through on screen visual recording and rectification (Joshi et al. 2003).

The land use map of 1982 was digitized and a thematic layer created. The land use map generated for the year 2012 was used as the base map for further characterization of different types of rangeland through intensive field surveys and mapping in the watershed. The land use maps of 1982 and 2012 were used for detecting land use changes during the period using a geographic information system (GIS). Information related to important drivers of land

use change, water availability and utilization patterns, and food production was generated through intensive socioeconomic surveys using specifically designed questionnaires and schedules. The status of water resources was monitored through long-term hydrological monitoring of streams and springs. In addition, quantitative and qualitative information was collected and generated from forest and cadastral maps of the areas, through field surveys, ground observations, socioeconomic surveys, and interviews with local people.

Results and Discussion

Land use/land cover dynamics

Land use in the watershed in 1982 and 2012 was classified in terms of the seven categories of forest, grassland, wetlands, cultivated land, settlements (mainly houses, hotels, resorts and roads), degraded and wasteland, and other (Figure 6) using the land use maps prepared using information from multiple sources as outlined in the methods section. The results are shown in Table 4.

Overall, approximately 11 km², or 16% of the total watershed area, showed a change in land use between 1982 and 2012. The area of all the components of rangeland decreased: the proportion of forest area in the watershed decreased from 43 to 40%; grassland from 15 to 12%; and wetland from 8 to 6%. The total rangeland area decreased by 12%, and that of grasslands and wetlands by 20%. At the same time, the area under cultivation increased from 15 to 17%, settlements from 1 to 2%, and degraded and wasteland from 17 to 21%.

Characteristics of the forest-grassland wetland interface

The forest-grassland-wetland interface in the Dabka watershed comprises sub-tropical forest, Himalayan temperate forest, grasslands, and wetlands. The main characteristics are summarized below.

Table 4: Land use change in Dabka Watershed, Uttarakhand between 1982 and 2012

Land use category	1982		2012		% change
	Area (km ²)	% of total area	Area (km ²)	% of total area	
Forest	29.4	42.5	27.3	39.5	(-) 3.0
Grassland	10.4	15.1	8.1	11.7	(-) 3.3
Wetlands	5.5	8.0	4.4	6.3	(-) 1.7
Cultivated land	10.5	15.1	11.8	17.2	(+) 2.0
Settlements	0.7	1.1	1.5	2.2	(+) 1.2
Degraded and wasteland	11.8	17.1	14.6	21.2	(+) 4.0
Other	0.7	1.1	1.3	1.9	(+) 0.9
Total	69.1	100.00	69.1	100.00	16.1

Sub-tropical forests consist of (a) sub-tropical deciduous forests found up to an elevation of 1,000 masl along the foothills zone and (b) chir pine forests upto 1,600 masl.

Himalayan temperate forest includes (a) forests banj oak (*Quercus leucotrichophora*); (b) temperate moist deciduous forest at 1,800–2,623 masl, which includes many broad-leaved species, principally tilonj oak (*Quercus dilatata*), between 2,000 and 2,100 masl, replaced by other species of oak at higher elevations.

Grasslands are interspersed with natural forest. The individual grasslands are very small, ranging in size from 0.05 to 0.88 km², with an average of 0.32 km². A total of 25 grassland patches were mapped in the watershed.

Wetlands are also interspersed with natural forest. The wetland areas are also small, ranging in size from 0.01 km² to 0.53 km² with an average of 0.27 km². A total of 16 wetland areas were mapped in the watershed.

Distribution of grasslands and wetlands

The extent and distribution of grasslands and wetlands were assessed in terms of altitudinal range, slope, and aspect. The results are shown in Tables 5–7. The grassland area increased with altitude up to 2,500 masl; whereas the greatest area of wetland (43%) lay between 1,500 and 2,000 masl (Table 5). Approximately 78% of grassland and 71% of wetlands were found between 1,500 and 2,500 masl. Grasslands were most common on the steeper slopes (>35°) and wetlands on slopes of 10–25°, with 81% on slopes between 10 and 35° (Table 6). Close to 50% of the grasslands are located on slopes with a south, southeast, or southwest aspect; whereas the single most common aspect for wetlands was west (Table 7).

Status of forests and grasslands

Dabka watershed has only around 2.8 ha forest for each hectare of cultivated land, and more than 60% of this forest is in a highly degraded condition, mainly due to increased encroachment and resultant degradation and depletion of forest resources. The area under cultivation increased from 15.1% in 1982 to 17.2% in 2012, an increase of 14% (Table 4),

Table 5: Distribution of grassland and wetlands with altitude in Dabka watershed

Altitude (masl)	Grassland		Wetlands	
	Area (km ²)	% of total grassland	Area (km ²)	% of total wetland
<1,000	0.25	3.15	0.55	12.66
1,000–1,500	0.72	8.91	0.46	10.54
1,500–2,000	2.35	29.05	1.89	43.25
2,000–2,500	3.99	49.34	1.20	27.43
>2,500	0.78	9.55	0.27	6.12
Total	8.09	100.00	4.37	100.00

Table 6: Distribution of grassland and wetlands with slope in Dabka watershed

Slope	Grassland		Wetlands	
	Area (in km ²)	% of total grassland	Area (km ²)	% of total wetland
<10°	0.03	0.34	0.24	5.51
10–25°	0.52	6.45	2.16	49.45
15–35°	2.23	27.55	1.39	31.75
>35°	5.31	65.66	0.58	13.29
Total	8.09	100.00	4.37	100.00

Table 7: Distribution of grassland and wetlands with slope aspect in Dabka watershed

Slope aspect	Grassland		Wetland	
	Area (km ²)	% of total grassland	Area (km ²)	% of total wetland
South	3.00	37.13	0.22	5.11
Southeast	0.90	11.07	0.69	15.75
Southwest	0.10	1.21	0.52	11.97
North	1.70	21.07	0.42	9.55
Northeast	0.77	9.47	0.32	7.28
Northwest	0.12	1.49	0.15	3.35
East	0.59	7.31	0.48	11.02
West	0.91	11.25	1.57	35.97
Total	8.09	100.00	4.37	100.00

with a similar increase in the livestock population. The availability of grazing land is 0.21 ha per head of cattle, compared with an ecologically recommended standard minimum of 3.5 ha per head of cattle (Ashish 1983). The grazing pressure is very high, and the pastures are coming under increased biotic stress. As a result, the forest and rangelands around rural settlements are in a highly degraded condition to a distance of 7 km on average.

Daily subsistence and resource use patterns in the Himalayan region centre around agriculture and animal husbandry, which is strongly influenced by the agriculture-forest interface and other landscape elements (Aase et al. 2013; Moench 1989; Maithani, 1996). Singh et al. (1984) estimated that 5–10 ha of well-stocked forest is required to meet the energy requirement of one hectare of agricultural land in the Himalayas in terms of manure and draught power. One of the important reasons for the rapid land use change in Dabka watershed is the town of Nainital, which is located on the southeastern boundary of the watershed and is one of the most popular and heavily visited tourist centres in the Himalayas. Furthermore, the densely populated foothill belt of Bhabar is situated to the south, and the geographic advantages of the region have led to several other locations developing into large centres of tourism. The processes of urban development and tourism growth are very fast

across the entire region, and are to a great extent responsible for the intensification of land use in the area. Moreover, the main national highway of Kumaon and its several branches pass through the western, eastern, and southern margins of Dabka watershed and have opened access to remote areas, thus facilitating the exploitation and depletion of forest and other natural resources in the entire region.

Status of watersheds

The rapidly changing land use pattern and the resultant decrease in forest area and degradation of grasslands have severely affected catchment capability in the watershed. In the mid-Himalayas, the amount of surface runoff from cultivated and barren land is much higher than the amount of runoff from other categories of land, particularly forests and rangelands (Tiwari 2000). The continued depletion of wetlands during the last 30 years has also affected groundwater recharge and availability of water in the watershed. Of the 195 natural springs identified in 1982, 73 (37%) had dried up by 2012 and 28 (14%) had become seasonal (Table 8). The number of dry and seasonal springs was higher at low elevation (below 1,000 masl) and mid elevation areas (1,500–2,500 m) than at high altitudes (above 2,500 m). Satellite data indicated that 7.4 km of a total stream length of 105.8 km had also dried, and that this particularly affected the first order perennial streams which have their source in headwater areas situated in wetlands, grassland, and forests. Observations during the hydrological monitoring indicated that 75% of the dried and seasonal springs and dried up streambeds were located in aquifers situated in the recharge zone composed of forest, grassland, and wetlands.

The changing climatic conditions are likely to intensify these impacts across the Himalayas as well as downstream since the contribution of rainfed discharge is much higher than the contribution of snowmelt to the Himalayan river basins (ICIMOD 2009). The rangeland and forest ecosystems have been important components of rural resource utilization in the Himalayas for several thousand years, and have been integral to the development of the economy, culture, traditions, and history. Thus these resources need to be looked at as part of

Table 8: Changes in water resources in Dabka Watershed

Altitude (masl)	Changes in water resources between 1982 and 2012							
	No. of springs in 1982	Springs that dried between 1982 and 2012	% springs dried	Springs that became seasonal between 1982 and 2012	% springs seasonal	Stream length 1982 (km)	Stream length dried between 1982 and 2012 (km)	% length dried
<1,000	71	29	41	12	17	15.00	0.84	5.60
1,500–2,000	58	21	36	6	11	25.17	1.14	4.53
2,000–2,500	45	21	47	9	21	26.00	2.27	8.73
>2,500	21	2	10	1	5	39.58	3.11	7.85
Total	195	73	37	28	14	105.75	7.36	6.96

the economic and sociocultural system as well as the local natural system. It is not possible to manage forests, protected areas, or rangeland ecosystems sustainably without considering the needs and problems of the rural communities that live within them, particularly when traditional activities have been limited or prohibited in many parts of the region following the creation of national parks, sanctuaries, and biosphere reserves, and the rangeland resources cannot be conserved and protected in isolation following a sectoral approach. It is imperative to analyse both the natural and the socioeconomic issues related to the conservation and protection of the rangeland resources in a holistic and integrated manner, and to consider rangeland management as one essential component in the overall land use policy and a part of any sustainable development strategy. This approach is a necessary basis for developing a realistic and integrated framework for the conservation of the rangeland ecosystems while ensuring the wellbeing of the rural communities that traditionally depend on the rangeland resources.

The hydrological disruptions can be attributed to large scale deforestation and degradation of wetland and grassland ecosystems and the resultant loss of water generating capacity of the land in the area (Rawat 2009). On average, the water discharge in the streams originating from wetlands, grassland, and forests has decreased by about 15% over the last 30 years, and these changes are affecting the availability of water for both domestic and agricultural use. The number of villages facing water scarcity, loss of irrigated land, and decline in agricultural productivity in the Dabka watershed between 1982 and 2012 is shown in Table 9. In total, 32 of 43 villages were identified as water scarce in terms of water availability for domestic use based on the water requirement norms set by the Government of India (Gol 2005). The irrigated area fell by 78 ha or 16% between 1982 and 2012, and agricultural production fell by 15%. This increases the vulnerability of the rural communities to food and health insecurity, particularly the poor and marginalized households that constitute nearly 75% of the total population of the region (Tiwari and Joshi 2012b). The problem of water availability is likely to have long-term implications for water, food, livelihoods, and health security in the watershed if the expected changes in precipitation and temperature resulting from climate change take effect (Tiwari and Joshi 2013).

Table 9: Water availability, irrigated land, and agricultural productivity in Dabka watershed (1982–2012)

Altitude (masl)	Number of villages	Villages currently facing water scarcity	Irrigated agricultural land (ha)		Loss of irrigated agricultural land (1982–2012)		Decline in agricultural productivity (1982–2012)
			1982	2012	ha	%	%
<1,500	19	13	285	245	40	14	11
1,500–1,800	15	14	107	89	18	17	15
1,800–2,200	5	3	81	64	17	21	15
>2,200	4	2	15	12	3	20	17
Total	43	32	488	410	78	16	15

Conclusion

The grassland–forest interfaces of Kumaon region in the lower and mid-Himalayan ranges are changing rapidly, mainly due to increasing population pressure, rapid urbanization, growth of tourism, and resultant land use changes. More than 15% of the total area of Dabka watershed changed its land use between 1982 and 2012, mainly as a result of increased human encroachment on forests, and there was a reduction in the proportion of forests, grassland, and wetlands in the watershed. These changes have disrupted the hydrological regime of the watershed through reduced groundwater recharge, drying of natural springs, and decreased stream flow. Villages in both the mountains and the adjoining foothill zone are facing scarcity of water for domestic and irrigation purposes, and agricultural productivity has declined. Degradation of natural forest and grassland ecosystems and resultant loss of ecosystem services, particularly freshwater, is likely to increase the vulnerability of rural communities both upstream and downstream. It is imperative to monitor the land use dynamics, understand the social and economic drivers of land use change, and develop a comprehensive land use policy for the lower to mid-Himalayan ranges. Rangeland conservation should constitute an integral component of an overall land use and sustainable resource development action plan for the region.

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High-altitude rangelands and their Interfaces in Gilgit-Baltistan, Pakistan: Current Status and Management Strategies

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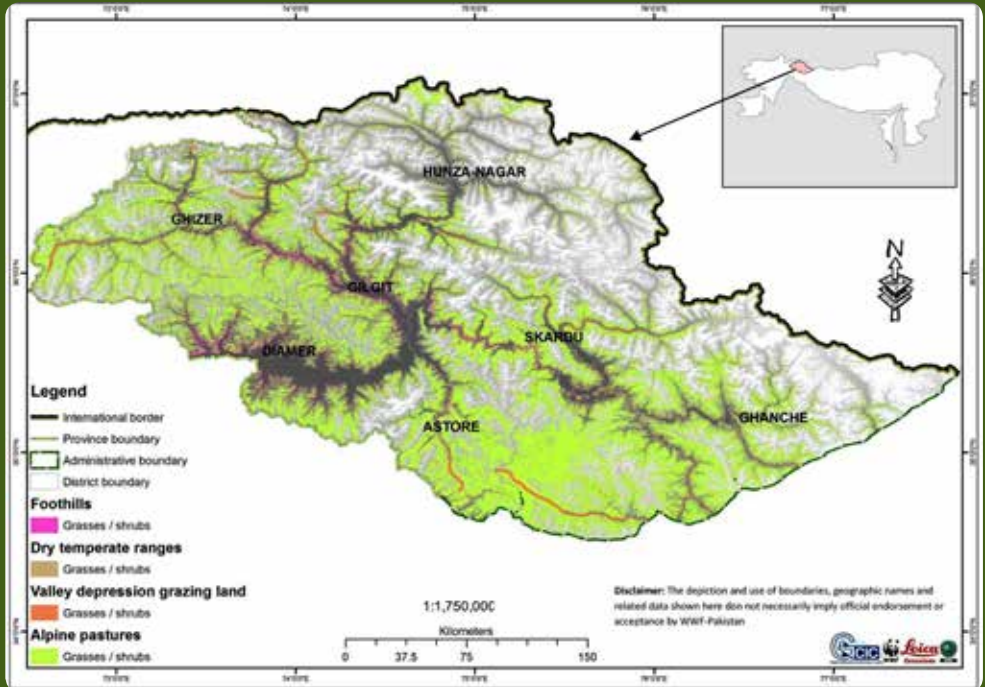
The rangelands and their interface areas in Gilgit-Baltistan of Pakistan span over 2.34 million hectares and constitute the second largest land cover after snow-capped mountains. Subsistence agriculture, including livestock herding, is the major source of livelihood for mountain dwellers, accounting for about 35–40% of their household income and 11% of GDP. Apart from conventional uses, the rangelands provide a substantial amount of fuelwood to meet domestic energy needs, fodder for livestock, and high-value aromatic and medicinal herbs for traditional uses and sale. As an ecosystem, rangelands have been vital for sustained economic growth, regulation of air and water, and ecosystem flows. However, the ever-increasing human population and increased livelihood needs have led to a rapid increase in livestock numbers over the past four decades. This increase, coupled with other factors such as removal of natural vegetation for fuelwood, fodder, food, and medicine, has resulted in degradation of the rangelands. The reasons for the fast depletion of rangelands in the region include lack of adequate regulations and appropriate policies regulating rangeland resource use, and sheer lack of capacity, both human and material, in the custodian departments to enforce and monitor even the available laws. A multi-pronged integrated conservation and development strategy comprising short, medium, and long-term interventions is required to protect, restore, and eventually improve the degraded rangelands in Gilgit-Baltistan.

Keywords: alpine; Baltistan; Gilgit; Himalayas; Indus; livestock; peatland; rangelands

Introduction

The region of Gilgit-Baltistan, formerly known as the 'Northern Areas', forms part of northern Pakistan amidst the Karakoram, Greater Himalayas, Pamir, and Hindu Kush mountain ranges. It shares international borders with Afghanistan to the northwest, China to the northeast, and India in the east. Gilgit-Baltistan encompasses an area of 72,496 km² and is home to a human population of approximately 1.2 million. Administratively, the region is divided into seven districts – Astore, Diamer, Ghanche, Ghizer, Gilgit, Hunza-Nagar, and Skardu – with the administrative capital in Gilgit city.

Figure 7: Location of Gilgit-Baltistan and distribution of rangeland resources



Source: GIS Lab, WWF-Pakistan, Gilgit

Table 10: Extent of rangelands in Gilgit-Baltistan, Pakistan

Rangeland category	Area (million ha)	Mountain range
Foothill grasslands	0.02	Karakoram-Hindu Kush
Dry temperate grazing lands	0.28	Himalaya-Karakoram-Hindu Kush
Valley grazing areas	0.21	Himalaya-Karakoram-Hindu Kush
Alpine pastures	1.83	Himalaya-Karakoram-Hindu Kush

Source: GIS Lab, WWF-Pakistan, Gilgit

One of the most prominent land use and land cover categories in Gilgit-Baltistan is that of high-altitude rangelands. According to a new land cover map prepared by WWF-Pakistan in 2012 using satellite images and GIS techniques, the area under rangelands is 2.34 million hectares, i.e., about one-third of the total land area of Gilgit-Baltistan. Earlier estimates of the extent of the rangelands in the province differed considerably, e.g., 22% (GoP and IUCN 2003) and 52% (FAO 1992). Table 10 and Figure 7 show the present extent and distribution.

Types of Rangeland

According to the classification of Khan (2003), there are two main types of rangeland in Gilgit-Baltistan: alpine pasture and trans-Himalayan rangelands.

Alpine pastures

Alpine pastures mostly comprise meadows, which remain under snow cover for almost six months and are accessible during summer. The meadows are situated above the alpine tree line which is located between 3,300 and 4,000 masl. At higher elevations, such as the Khunjerab and Deosai plateau, the growing season is very short and lasts only three to four months (June to September). Below this zone lies the sub-alpine scrub. Forage production varies from place to place depending on altitude, slope aspect, and moisture availability. Above ground biomass production varies from place to place, e.g., Khunjerab National Park (370–580 kg ha⁻¹) and Chaprote near Gilgit (500–750 kg ha⁻¹); with an overall average of 700 kg ha⁻¹ (Khan 2003). If properly managed, alpine meadows contain luxuriant ground flora that offer the highest value grazing lands with an average stocking capacity of five animal unit per hectare (Khan 2003). Vegetation in the alpine meadows is dominated by grasses, perennial herbs, and shrubs. The most common floral species are listed in Table 11.

With the melting of snow during summer, vegetation in the meadows flourishes giving rise to an astonishing array of flowering plants. In addition to functioning as a food source for wild and domestic herbivores, these flowers attract a mass of insect biodiversity resulting in the appearance of a variety of birds in the zone for breeding. This region is home to 41 endemic butterfly species with a notable variety of Apollo butterfly of the genus *Parnassius* (IUCN 1997).

The major mammalian fauna inhabiting the alpine zone include brown bear (*Ursus arctos*), Himalayan ibex (*Capra ibex sibirica*), snow leopard (*Uncia unica*), markhor (*Capra falconeri*), musk deer (*Moschus chrysogaster*), long-tailed marmot (*Marmota caudata*), Royle's high mountain vole (*Alticola roylei*), True's vole (*Hyperacrius fertilis*), ermine (*Mustela ermine*),

Table 11: Common floral species in alpine pastures

Type	Species
Trees and shrubs	<i>Juniperus communis</i> , <i>Rosa webbiana</i> , <i>Berberis</i> spp., <i>Cotoneaster</i> spp.
Grasses	<i>Phleum alpinum</i> , <i>Agrostis gigantea</i> , <i>Trisetum</i> spp., <i>Poa</i> spp., <i>Elymus dentatus</i> , <i>E. caninus</i> , <i>Festuca ovina</i> , <i>Alopecurus gigantea</i> , <i>Dactylis glomerata</i> , <i>Pennisetum lanatum</i> , <i>P. filaccidum</i> , <i>Clamagrostis pseudophragmites</i> , <i>Oryzopsis</i> spp., <i>Carex</i> spp.
Forbs	<i>Plantago ovata</i> , <i>P. major</i> , <i>P. lanceolata</i> , <i>Trifolium pratense</i> , <i>T. repens</i> , <i>Fragaria nubicola</i> , <i>Medicago lupulina</i> , <i>Potentilla</i> spp., <i>Rumex nepalensis</i> , <i>Polygonum alpinum</i> , <i>Anaphalis contorta</i> , <i>Thymus linearis</i> , <i>Astragalus</i> spp., <i>Taraxicum officinalis</i> , <i>Iris hookeriana</i> , <i>Nepeta spicata</i> , <i>Saxifraga</i> spp.
Medicinal flora	<i>Aconitum heterophyllum</i> , <i>A. chasmanthum</i> , <i>A. laeve</i> , <i>Saussurea lappa</i> , <i>Rheum emodi</i> , <i>Podophyllum hexandrum</i>

Source: Rasool 1998a; Karki and William 1999; Khan et al. 2011

Chinese birch mouse (*Sicista concolor*), and migratory hamster (*Cricetulus migratorius*). Major bird species include snow partridge (*Lerwa lerwa*), golden eagle (*Aquila chrysaetos*), snow pigeon (*Columba leucozona*), Turkistan hill pigeon (*Columba rupestris*), Eurasian blackbird (*Turdus merulus*), yellow-billed chough (*Pyrrhocorax graculus*), and red-billed chough (*Pyrrhocorax pyrrhocorax*). Skinks (*Liolopisma ladacensis*, *Agama himalayana*) and gecko (*Tenuidactylus baturensis*) are also found in this zone, as is the Baltistan toad (*Bufo siachensis*), which is found in water bodies (Roberts 1997; Mirza 1998; Rasool 1998b; Anwar 2011).

Trans-Himalayan rangelands

The Trans-Himalayan rangelands extend over the northern mountains in the Astore, Darel, Tangir, Haramosh, Jaglote, Kargah, and Naltar valleys. The climate has typically cold desert characteristics, with severe winters (usually with moderate to heavy snowfall) and dry summers. Altitudinal differences influence the climatic variation. At lower altitudes (below 2,300 masl), there are both diurnal and seasonal temperature variations and scanty precipitation. Areas between 2,300 and 3,300 masl receive sufficient snow and have a temperate climate. Areas above 3,300 masl are very cold with a limited growing season. Most of the areas lie in the rain shadow zone out of reach of the summer monsoon. Average annual precipitation in the valleys is 100-300 mm, mostly occurring during winter and early spring in the form of snow (Khan 2012). The main occupation of local communities is farming, which includes animal husbandry, limited agroforestry, and horticulture. Maize, wheat, buckwheat, and barley are the principal crops grown at lower elevations, with seed potato an important cash crop throughout. The grazing lands are deteriorating as a result of overgrazing of livestock and illicit removal of natural vegetation for firewood. Forage production varies from 500 to 1,500 kg ha⁻¹. Indigenous vegetation includes trees, shrubs, herbs, and forbs. Some of the common floral species found in the rangelands are listed in Table 12.

Table 12: Common floral species found in the trans-Himalayan rangelands

Type	Species
Trees and shrubs	<i>Juniperus macropoda</i> , <i>Quercus ilex</i> , <i>Pinus gerardiana</i> , <i>Cedrus deodara</i> , <i>Pinus wallichiana</i> , <i>Fraxinus xanthoxyloides</i> , <i>Artemisia maritima</i> , <i>A. sacrorum</i> , <i>Indigofera</i> spp., <i>Ephedra</i> spp., <i>Daphne oleoides</i> , <i>Sophora</i> spp., <i>Cotoneaster</i> spp., <i>Parrotia jacquemontiana</i> , <i>Salix</i> spp., <i>Jasminum</i> spp., <i>Sorbaria tomentosa</i> , <i>Caragana</i> spp.
Grasses	<i>Chrysopogon</i> spp., <i>Cymbopogon</i> spp., <i>Dichanthium annulatum</i> , <i>Pennisetum orientale</i> , <i>Aristida</i> spp., <i>Oryzopsis</i> spp., <i>Dactylis glomerata</i> , <i>Poa</i> spp., <i>Bromus inermis</i> , <i>Agrostis</i> spp., <i>Rottboellia exaltata</i> , <i>Phacelurus speciosus</i> , <i>Eragrostis</i> spp.
Forbs	<i>Iris</i> spp., <i>Tulipa stellata</i> , <i>Polygonum</i> spp., <i>Sambucus</i> sp., <i>Lotus comiculatus</i> , <i>Medicago lupulina</i> , <i>Plantago lanceolata</i> , <i>Lathyrus</i> spp., <i>Thymus linearis</i> , <i>Nepata spicata</i> , <i>Viola</i> spp., <i>Taraxicum officinalis</i>
Medicinal flora	<i>Ephedra nebrodensis</i> , <i>Artemisia maritima</i> , <i>Carum bulbocastanum</i> , <i>Thymus</i> and <i>Ferula</i> , <i>Juglans regia</i> , <i>Pinus gerardiana</i> , <i>Zizyphus sativa</i>

Source: Ahmed and Qadir 1976; Alam 2010; Qureshi et al. 2011

High-altitude rangeland Interfaces

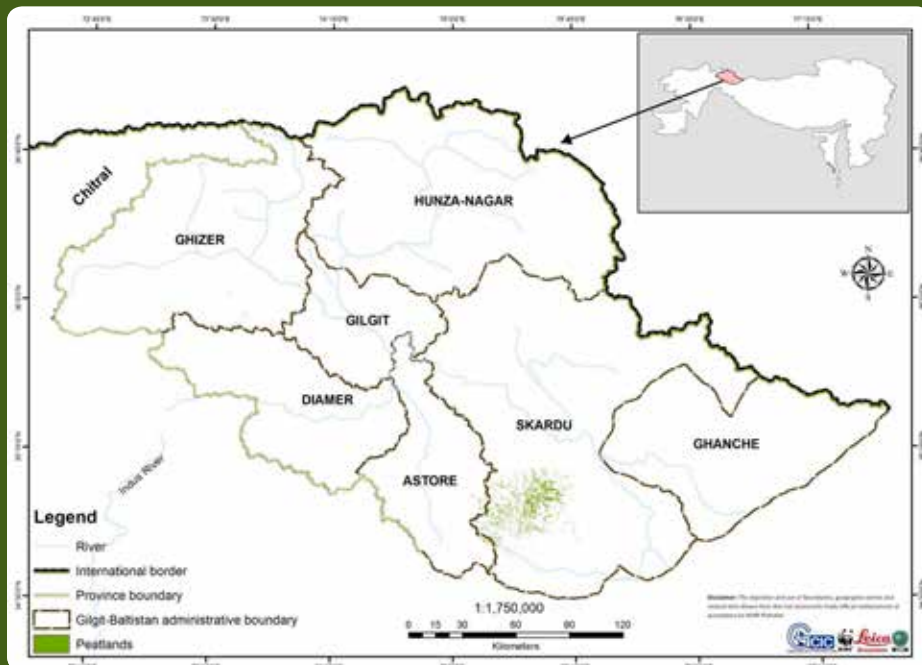
The unique confluence in Gilgit-Baltistan of three great mountain ranges – the Himalayas, Karakoram, and Hindu Kush – and the resultant altitudinal variation coupled with diverse topographic and climatic conditions, give rise to multiple interfaces over a short distance. Anthropogenic factors also produce different interfaces in the form of newly-formed boundaries. Some of the distinct interfaces found in the high-altitude rangelands of Gilgit-Baltistan are described briefly below.

Natural interfaces

Peatlands are interfaces between wetlands and rangelands. Globally, peatlands comprise an area of 150 x 10⁶ km², about 3% of the total terrestrial surface. They contain a total of 550 Gt carbon stock, equivalent to 75% of all atmospheric carbon, equal to all terrestrial biomass, and twice the carbon stock in the forest biomass of the world (Wetlands International 2009). Peatlands' highly regarded carbon sequestration value equals around 13% of the global carbon stock.

In northern Pakistan, peatlands are found in the Deosai plateau, Langar-Shandoor wetlands (Phunder valley), Fairy Meadows, and Shimshal and Broghil valleys (Figure 8). An estimated 25,000 ha of Gilgit-Baltistan is covered by peatlands. Peatlands are valuable ecosystems that

Figure 8: Distribution of peatlands in Gilgit-Baltistan



Source: GIS Lab, WWF-Pakistan, Gilgit

provide services such as biodiversity conservation, carbon stock, water storage and regulation, grazing grounds, and domestic fuel. In Phunder and Broghil valleys, the peatlands are a major source of domestic fuel as these areas lack natural vegetation that can be used for fuelwood. Degradation and shrinkage caused by anthropogenic activities and climate change are major threats to peatlands. Anthropogenic pressures result from accessibility to nearby populations and result from extensive grazing, over-dependency for domestic fuel, and drainage and diversion of water sources.

The alpine timberline represents another predominant interface between forests and alpine meadows. It marks the junction between mountain forests and alpine meadows at elevations of 3,300 to 4,000 masl in Diamer, Astore, Naltar, Haramosh, Bagrote, Roundu Nagar, and Puniyal valleys. The specific geographical and ecological features of the timberline vary with ecological zone. Himalayan dry coniferous forest species like *Abies pindrow*, *Picea smithiana* and *Pinus wallichiana* are found at lower elevations, while higher elevations are dominated by species of *Betula*, *Salix*, *Juniperus*, *Rhododendron*, and large number of herbaceous species.

Anthropogenic pressures such as excessive grazing, cutting of fuelwood during seasonal stays in the high pastures, trampling effects, and soil erosion, combined with climatic factors, have caused a downward shift of the alpine timberline on south-facing slopes.

Forest–agriculture interfaces

The lower timberline generally encompasses the areas between mountain forests and farming land. The major vegetation at lower altitudes (1,400-2,000 masl) consists of Himalayan dry coniferous forest species such as *Quercus ilex*, *Artemisia maritima*, *Ephedra intermedia*, *Monothea buxifolia*, *Corylus coluna*, *Cotoneaster nummularia*, and *Sophora mollis*.

The lower timberline ecotone is undergoing excessive degradation and severe erosion due to intensive farming, deforestation, infrastructure development, and frequent hazards like flash floods, mud slides, and land slips. It is further threatened by expansion of farming activities, road networks, resorts, and others infrastructure.

Protected areas

Buffer zones of protected areas represent yet another type of interface. A number of protected areas fall within the geographical boundaries of Gilgit-Baltistan, in addition to an extension of the Pamir range in its territory. The Pamir range, predominantly situated at 3,500-5,000 masl in Tajikistan and Afghanistan and extending into Kyrgyzstan, China, and northern Pakistan, has a scattered network of protected areas (Schaller 2007). The entire range has man-made interfaces, along with human activities such as border fencing, road transportation, excessive hunting, and armed conflict pressurize the high-altitude ecosystems and their components. Schaller (2007) has shown that Marco Polo sheep (*Ovis ammon polii*) roam across the frontiers of Afghanistan, China, Pakistan, and Tajikistan in the Pamir Mountains. However,

fenced borders increasingly hamper their movement. According to Mr Aziz Ali (personal communication), fifteen carcasses of Marco Polo sheep were found over a distance of only six kilometres along the fenced Afghan-Tajik border, testifying to the grave danger posed to this species. He suspects these deaths to have been caused by speeding animals colliding with the fence when they are chased by predators such as wolves or snow leopards. Recent fencing along the Sino-Pak border area is feared to cause similar perils for Marco Polo sheep and other wildlife species around Pakistan and China's mountainous landscapes (see also Joshi et al., this volume).

Current State of High-altitude rangelands

Gilgit-Baltistan has an arid climate, characterized by low precipitation (<200 mm annual rainfall), extreme temperatures, and low humidity, owing to the limited influence of the monsoon. Despite the general arid and dry conditions, the rangelands contribute a major part of the feed requirements for 2.0–2.5 million heads of livestock (Beg 2010). Rangeland productivity is believed to have decreased significantly due to excessive livestock grazing, increasing human and livestock population, and the expansion of dryland farming to marginal land to satisfy the increasing demand for food, and the cutting of shrubs and trees for domestic fuel (FAO 1987). Unpalatable low quality vegetation has replaced the more palatable grasses, shrubs, and trees that once covered the rangelands. Every year, insufficient forage during the dry period leads to heavy losses of livestock (Alvi and Sharif 1995; PARC 1998).

The alpine pastures are situated on gentle slopes of Greater Himalayas, where the habitat is under heavy grazing pressure and faces a decline in productivity and biodiversity (MACP/IUCN 2001). Accelerated erosion and land degradation illustrates the negative impact of mismanagement. Most of these lands are communal and management is a communal responsibility. However, the land tenure system directs the community's focus to immediate returns rather than long-term benefits. Table 13 shows the potential and actual productivity in selected pastures in three districts (Skardu, Astore, and Hunza-Nagar).

Table 13: Pasture potential and actual productivity in Gilgit-Baltistan area of Pakistan

Region/ District	Species composition	Cover (%)			Productivity (kg/ha)		Remarks	
	No. of species recorded	Foliar cover	Bare ground	Weeds	Estimated potential productivity	Productivity at the time of survey	Pasture condition	Pasture trend
Gojal (Hunza- Nagar)	27	73	27	2	1,400	407	Poor	Down
Astore	26	72	28	27	1,600	428	Poor	Down
Skardu	30	54	46	7	1,200	241	Poor	Down

Source: MACP/IUCN 2001

The number of livestock in Gilgit-Baltistan, especially cattle, sheep, and goats, increased from 0.88 million in 1976 to 2.45 million in 2006, an increase of 1.67% per annum. Almost 80% of the livestock are grazed in pastures and rangelands during summer. The substantial increase in domestic herbivores and their large dependence on rangelands has resulted in a tremendous grazing pressure on the rangelands. Generally, the animal production systems in the rangelands operate on a low input basis, but the pressure on grazing land is further increased by animals brought for grazing by herders from down country, particularly to pastures in Deosai. Currently, an estimated 0.86 million animal units are being grazed on 2.34 million ha of rangelands in Gilgit-Baltistan, which is a stocking rate of 2.73 ha per animal unit (Afzal et al. 2008), substantially higher than in 1996 (2.89 ha/animal unit, according to GoP/IUCN 2003), and about six times higher than the critical stocking rate of 16 ha/animal unit suggested by FAO (1987) for low potential rangelands. Thus the already burdened and overgrazed rangelands are likely to face further degradation. Such overstocking of animals and the resultant decline in vegetation cover will accelerate soil erosion and may cause desertification.

Significance of the High-altitude rangelands

One of the major functions of the rangelands in Gilgit-Baltistan is the provision of agropastoral livelihoods and contribution to food security and household income. With close to 2.5 million heads of livestock, 80-90% of the local people practice transhumant animal husbandry, which accounts for 20-35% of total income. In addition, nomadic and transhumant pastoralists also grow potatoes, peas, barley, and buckwheat in cultivable areas near high pastures if irrigation water is available from springs and seasonal streams, and also collect medicinal and aromatic plants in those areas. Rangelands also provide plant biomass for domestic energy requirements as the whole area lacks alternative sources of energy. People collect fuelwood from trees, shrubs, and bushes for both cooking and heating during the long winters.

Ecotourism and mining are also valuable rangeland attributes providing economic opportunities. The beautiful landscape and unique cultural heritage catch the eye of tourists from all over the world. The area possesses numerous mining sites, some currently under exploration such as Haramosh, Dassu, Bubin, and Nagar, and other valleys such as Chipurson, Yasin, and Gupis that are yet to be investigated for their potential.

Water regulation is another important function of the rangeland areas. There are a number of high-altitude wetlands most of which are fed by snowmelt or runoff from adjacent glaciers, which often have outflows in the form of small streams or rivers. These water bodies play an essential role in the hydrological regime of the Indus, which is the lifeline of the agrobased economy of the country, besides being a source of water for drinking, industry, agriculture, and hydropower generation. The Gilgit, Hunza, Ghizer, Astore, Shigar, and Shyoke rivers provide almost 72% of the total annual influx into the Indus. Freshwater lakes, rivers, and streams also provide habitat for indigenous and exotic species of freshwater fish. Rainbow and brown trout are abundant in the rivers and lakes of Gilgit, Ghizer, and Skardu valleys (Khan 2011).

Gilgit-Baltistan has a marked geographical, geological, and topographical heterogeneity. The myriad natural features together constitute an astonishing but fragile mountain ecosystem sheltering a rich diversity of flora and fauna, including 230 species of birds, 54 species of mammals, 23 species of reptiles, 20 species of fish, and six species of amphibians; many of them rare, endangered, and/or endemic to the Karakoram-Himalaya-Hindu Kush highlands (GoP/IUCN 2003).

Keeping in view the extraordinary natural wealth of these areas, the Government of Gilgit-Baltistan has brought certain key areas under the protected areas network by notifying five national parks, three wildlife sanctuaries, seven game reserves, and 24 community-managed conservation areas, covering some 30,000 km² almost half of the total land area.

Threats to the High-altitude rangelands

The rangelands in Gilgit-Baltistan are diminishing fast due to over grazing, encroachment and conversion into other land uses, drought and climate change, and trampling effects. The major threats and their causes are described briefly in the following.

Overgrazing

The majority of the rangelands in Gilgit-Baltistan are regularly grazed beyond their carrying capacity (FAO 1987; Alvi and Sharif 1995; Beg 2010). The overgrazing can be attributed to two main factors: lack of a grazing management system, and lack of a proper land tenure system, in which the protection of grazing lands seems to be no one's responsibility as they are a common asset. Shimshal Pamir pasture is a good example. In 2010 it was being used for grazing for 5,000 yaks, 2,000 goats, 1,900 sheep, and 500 cows, along with a few hundred wild herbivores such as Himalayan ibex and blue sheep, whereas the 10,429 ha area is only just enough to feed to 715 yaks for a maximum of six months (Khan 2012). Similarly, more than 420,000 animals are being grazed around Central Karakoram National Park (Baig 2011) with extensive grazing in some lower pastures year round. At higher altitudes, where foliage growth is limited by the harsh climate, grazing beyond the carrying capacity not only deteriorates the ecological health of the pastures, but also leaves less or no food for wild herbivores and accelerates soil erosion.

Encroachment

The lack of a proper management system is coupled with various exploitative uses of rangelands such as agriculture, extraction of plant biomass for fuelwood, and rapid infrastructure. The use of pasture and rangeland for crop cultivation is increasing at an alarming pace. The agricultural statistics for Gilgit-Baltistan show that nearly 83% (8,422 ha) of the total area is under vegetable crops (10,080 ha), mainly because potato has emerged as the only cash crop in the area. Removal of the sparse and scattered natural vegetation for fuelwood has also markedly increased the pace of rangeland desertification. Heavy vehicular movements and due to off-road driving has been a big threat to grasslands in the Deosai and

CKNP. However, prolonged grazing periods of big herds in alpine oases also result in overgrazing and trampling of pastures. Lack of grazing and pasture management regulations in the region are probably a contributing factors.

Climate change

The rangelands of Gilgit-Baltistan receive little precipitation, particularly at lower elevations where it rarely exceeds 200 mm per annum. The higher elevations (>3,500 masl) receive more snow during winter (Awan 2002). Mean temperatures range from -10°C in winter to +35°C in summer. Unlike the general global pattern, significant increases have been observed in the region in winter mean and maximum temperatures, and consistent decreases in summer maximum temperatures (Fowler and Archer 2006). Zeidler and Steinbauer (2008) reported an increase in annual mean temperatures from 1980–2006. Such climatic variations, coupled with other biotic and anthropogenic factors, have contributed to an alarming increase in the rate of desertification of the rangelands, especially in the arid and semi-arid zones (GoP 2010). Temporal data analysis by the Pakistan Metrological Department (PMD) also showed a decrease in vegetation cover over the northern half of the country compared to 1998, thought to be due to failure of the winter rains (Chaudhry et al. 2010). Similar evidence has been recorded from Afghanistan, China, Nepal, and other areas in Pakistan, where a decrease in rainfall has accelerated rangeland desertification, and in some places prolonged droughts have forced people to change their migration routes or abandon pastoralism completely. Pastures in Misgar, Chipurson, and parts of the Central Karakoram National Park (CKNP) such as the Bagrote valleys have been severely affected by droughts over the past decade or so (Beg 2010).

Recommendations for Improvement of the Rangelands

A multi-pronged integrated conservation and development strategy comprising short, medium, and long-term interventions is required to protect, restore, and eventually improve the degraded rangelands. Some suggestions are outlined below:

- Comprehensive assessment and valuation of rangeland and associated resources should be carried out and a rangelands monitoring framework needs to be developed.
- The existing policies and legislation that include land use practices should be revised and enforced according to the changing circumstances.
- At present, range management in Gilgit-Baltistan is looked after by the Forests and Wildlife Department, however, rangelands don't seem to be a priority area for the Department. There should be a separate department for rangeland management with appropriate technical competencies.
- Restore degraded rangelands through appropriate measures.
- Develop and implement research-based rangeland and livestock management plans.
- Engage local communities in the implementation of the management plans.
- Instill rangeland conservation values among local communities through awareness and education programmes.

Conclusion

Rangelands and their interfaces are the dominant land-use type in Gilgit-Baltistan and encompass unique ecosystems like alpine meadows and forests, peatlands, swampy areas, high-altitude lakes, and agroecosystems adjacent to high pastures and on alluvial fans. These ecosystems provide critical services to about 1.5 million vulnerable mountain people who often depend upon natural resources for their livelihoods. In addition to sustaining local livelihoods, the high-altitude rangelands and their interfaces amass major freshwater reserves and are the source of rivers that flow into the Indus and fuel the agrobased economy of Pakistan. In the absence of a proper management system, the rangelands and their components are facing serious threats from overgrazing, erosion, and encroachment. A rangelands monitoring and management framework is highly desirable to conserve the rangeland and associated resources in the area.

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High-altitude ecosystems and Biodiversity of Tajikistan: Conservation and Management

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Tajikistan is uniquely placed in Central Asia due to its biogeographic location and rich assemblage of flora and fauna. It is located at the confluence of northeastern Europe, Central Asia, Middle East, and North Africa exhibiting affinities with these regions. At the same time the country has many relic and endemic species of its own, especially the cultivars, and several highly threatened species wildlife which are facing threats due to anthropogenic pressures such as poaching, overfishing, illegal logging, and overgrazing by domestic livestock. These factors stem from socioeconomic conditions of local communities, lack of environmental awareness, poor management capabilities of concerned departments, and lack of transboundary cooperation. Conversion of mixed-farming into mono-crop agriculture has also reduced biodiversity. This paper deals with the present status of conservation in Tajikistan, constraints, and the way forward.

Keywords: biodiversity; habitat fragmentation; hot spot; land degradation; mono crop agriculture; poverty; transboundary issues

Introduction

Tajikistan, the smallest of the Central Asian countries, is landlocked yet uniquely placed in the region at the confluence of several biogeographic regions. At the same time it represents an important centre of origin of cultivated plants. Tajikistan shares its boundaries with Uzbekistan and Kyrgyzstan to the west and north, Afghanistan to the south, and China to the east and is characterized by the prominence of mountains and rivers. Mountains include the towering ranges of the Pamir and Tien Shan containing peaks ranging from 1,300 to 7,495 masl. The Pamirs are the source of several torrential rivers that have carved out gorges and canyons. There are 947 rivers longer than 10 km. The longest among these are the Amu Darya, the Syr Darya, the Zeravshan, the Vakhsh, and the Panj. Tajikistan also contains numerous lakes, among which the biggest is the saline Lake Karakul (in the eastern Pamirs) with a total area of 380 km². The freshwater Lake Sarez (in the western pamir) is the deepest (490 metres) and has an area of 86.5 km². The Hissar-Alay (Southern Tien Shan) ridges are central to Tajikistan

geography, with numerous mountains exceeding 5,000 masl in altitude. Dushanbe, the capital city, is situated in the Hissar Valley at the foothills of the Hissar Mountains. The Tajikistan mountains are noted for their glaciers, probably the largest in Asia. The Fedchenko Glacier is the largest in the Pamir (77 km long and 1,700–3,100 m wide); the Zeravshan Glacier is also noteworthy. The topography is heavily dissected, which makes it difficult to accurately map the fragmented vegetation types. There are no extensive unfragmented areas of rangeland, unlike the extensive steppes in China, Kazakhstan, and the Russian Federation.

The high levels of landscape diversity in the uplands are largely the result of the temporal-spatial variability in the region. The unique geology and terrain, consisting of three major mountain chains separated by valleys and plains, permit a variety of different microclimate, soil, and vegetative conditions, resulting in a broad range of landscapes and unusually high levels of species diversity for the Temperate Zone. Climatic conditions are very diverse, with precipitation ranging from more than 1,200 mm per annum in the wettest areas, to less than 200 mm per annum in the Zeravshan and Pyanj deserts. The Fergana Valley and other lowlands are shielded by mountains from Arctic air masses, but temperature in that region still drops below zero degrees for more than 100 days a year. In the subtropical southwestern lowlands, which have the highest average temperatures, the climate is more arid, although some sections are now irrigated for farming. At Tajikistan's lower elevations, the average temperature range is 23 to 30°C in July and -1 to 3°C in January. In the eastern Pamirs, the average July temperature is 5 to 10°C, and the average January temperature is -15 to -20°C. The average annual precipitation ranges between 700 and 1,600 mm for most of the country. The heaviest precipitation is at the Fedchenko Glacier, which averages 2,236 mm per annum, and the lightest in the eastern Pamirs, which averages less than 100 mm per annum. Most precipitation occurs in winter and spring. Summers are hot and dry in many places, which limits water supply in some upland regions that might otherwise be used for transhumance.

This paper gives an overview of major ecosystems in Tajikistan, including the status of rangelands and their interfaces, major elements of biodiversity, the protected area network and their conservation status. Major threats to conservation and future management strategies are discussed.

Major ecosystems

The major ecosystems in Tajikistan include forests, woodlands, rangelands (steppe and grasslands), deserts and wetlands. The vegetation changes from steppe communities in the west to semi-desert and desert-like formations in the south. Towards the east, the land rises above the plains with several peaks above 5,000 masl and is enveloped by broadleaf and coniferous forests, sub-alpine and alpine meadows, glaciers and snowfields. The eastern and southern districts are characterized by open, rocky slopes having extensive woodlands dominated by juniper (*Juniperus*) and pistachio (*Pistacia*) species. Lowland forests are found on the floodplains and low river terraces, generally growing on alluvial, swampy, or moist soils. Very few lowland forests have been preserved, although some stands remain. High

mountain meadows are dominated by herbaceous species. About 1,000 vascular plant species are reported from the high mountains with high levels of endemism. Alpine habitats are dominated by dense low-lying perennial plants. Unique communities of cliff and rock vegetation are distributed throughout the high mountains. Approximately 80% of the plant species found in rock and scree communities on limestone ridges are endemic. Wetland ecosystems are found throughout and include river deltas, marshes, swamps, lakes, and streams in alpine regions. A variety of lakes are scattered throughout Tajikistan, from small alpine lakes to significant bodies of water with highly specific fish fauna which attract a variety of waterfowl.

A considerable area in Tajikistan falls under high-altitude rangelands which include alpine meadows and grasslands, largely used for livestock grazing. Other areas such as woodlands and wetlands are also used extensively for seasonal grazing (Strong and Squires 2012). The total area of rangelands and pasturelands in the country is 3.9 million hectares. The largest area under rangelands (60% of the total rangelands in the country) falls in Khatlon and Dushanbe. Most of the rangelands are in hilly and mountainous areas above 2,000 masl. Traditionally, these rangelands have formed the basis of Tajikistan's livestock sub-sector and have been used for centuries in ways that utilize the various altitudinal belts via the system of transhumance grazing (Table 14). In recent times, much of the rangelands at lower elevations (<1,500 masl) have been used for year-round grazing by local communities whose access to more distant pasturelands has been restricted due to changes in tenure arrangements as a result of population increase in most places. There have also been changes in livestock holding patterns and most families own only two to five livestock. Because the majority of the rangelands in the country are located in remote areas, there is most hope for conserving these ecosystems.

Table 14: Areal extent of rangelands, altitudinal distribution, and season of use in Tajikistan

Attribute	Season of use			
	Winter	Spring-autumn	Summer	All year
Altitude (masl)	500–1,200	900–1,500	2,200–3,400	500–1,200
Use months	Nov–Mar	Mar–May, Sept–Nov	June–Aug	Jan–Dec
Use days	120–150	90–110	80–90	300–330
Total area (ha)	699,000	675,000	2,081,000	400,000+
Percentage of total rangeland area	18	18	54	10
Distance from villages (km)	0.8–1.4, 4–5	1.2–1.8, to 30	200–600*	<1

* 6–8 weeks per year are spent travelling between winter and summer pastures

Biodiversity

The flora and fauna of Tajikistan contain more than 23,000 species of which approximately 1,900 are endemic. Rare and endangered mammals include various gazelles (*Procapra* spp.), the argali (*Ovis ammon*), snow leopard (*Panthera unica*), peregrine falcon (*Falco peregrinus*), paradise flycatcher (*Terpsiphone paradise*), mountain goose (*Anser indicus*), Menzbier's marmot (*Marmota menzbieri*), Siberian ibex (*Capra siberica*), and others. The Bukhara red deer (*Cervus elaphus*), the Persian gazelle (*Gazella subgutturosa*), and the markhor (*Capra falconeri*) are also listed in the Tajikistan Red Data Book as vulnerable species. A number of birds are equally endangered, including several species of waders, birds of prey, pheasants, cranes, plovers, pigeons, and swifts. Nearly half of the flora and fauna species of the mid-mountain ecosystems are considered endangered. A brief biodiversity profile of Tajikistan is given in Table 15.

Table 15: Main components of biodiversity in Tajikistan

Components/attributes	Number
Ecosystem types	12
Vegetation types	20
Flora	9,771 species
Wild relatives of cultivated plants	1,000 species
Endemic plants	1,132 species
Plants listed in the Red Data Book of Tajikistan	226 species
Fauna	1,353 species
Endemic animals	800 species
Animals listed in the Red Data Book of Tajikistan	162 species
Agricultural crops	500 varieties
Domestic animals	30 breeds

One of the reasons for species richness in the country is diversity of habitats ranging from foothill semi-deserts to alpine meadows combined with characteristic mountain forests. Foothills (below 1,800–2,000 masl) are occupied by ephemeroid sagebrush communities (*Artemisia diffusa*, *A. sogdiana*, *Poa bulbosa*, *Carex pachystilis*), which are replaced at higher levels by herbaceous low herb ephemeroid communities (*Poa bulbosa*, *Carex pachystilis*, *Phlomis thapsoides*, *P. bucharica*). Spectacular red tulips (*Tulipa micheliana*) form the characteristic aspect of ephemeroid spring vegetation. In the middle mountain belts, characteristic grasslands are dominated by *Prangos pabularia*, *Ferula* spp., *Inula macrophylla*, *Crambe kotschyana*, and *Paraligusticum discolor*. Grass meadows are widespread at higher elevations of the Zaravshan and Gissar ranges, and fescue (*Festuca alaica*) is a dominant bunchgrass species. Sub-alpine meadows begin at 3,100–3,400 masl, with fescue, *Poa relaxa*, *Puccinella subspicata*, *Nepeta podostachys* and *N. cocanica*.

The woodlands in the country have a variety of wild fruit and nut trees including walnut (*Juglans regia*), maple (*Acer semenovii*, *A. turkestanicum*), pistachio (*Pistacia vera*), hawthorn (*Crataegus turkestanica*, *C. pontica*), mountain ash (*Sorbus tianschanica*), pear (*Pyrus korshinskyi*, *P. regelii*), almond (*Amygdalus communis*, *A. buharensis*), apricot (*Prunus ferganica*, *P. sogdiana*), cherry (*Cerasus mahaleb*), and apple (*Malus sieversii*). Common shrubs include various species of *Rosa*, *Cotoneaster*, *Lonicera*, *Caragana*, *Colutea*, and

Rhamnus. Juniper forests grow at the higher altitudes of the mountain ranges dominated by three species of juniper (*Juniperus turkestanica*, *J. seravschanica*, *J. semiglobosa*). The valleys of mountain rivers house riparian forests with dominant trees such as poplars (*Populus* spp.), ash (*Fraxinus sogdiana*), willow (*Salix*), birch (*Betula*), jidda (*Elaeagnus* spp.), and *Tamarix* spp.; and shrubs such as *Hippophae rhamnoides*, *Berberis sphaerocarpa*, and *B. interregima*.

Tajikistan is also home to more than 1,350 species of animals, including 385 species of bird, about 800 of which are endemic to the region, including four bird species. Twenty-two of the 46 reptiles in Tajikistan are endemic to the region. Fourteen amphibian species including two endemic ones, are found in the region. More than 52 species of fish are found in the rivers and lakes, more than a third of which are found nowhere else. The most common mammals in the forested habitats of Tajikistan are wild pig (*Sus scrofa*), various species of rodents, and shrews. Indian porcupine (*Hystrix leucura*) is found at lower altitudes. Predators include wolves (*Canis lupus*), red fox (*Vulpes vulpes*), weasel (*Mustela nivalis*), ermine (*M. erminea*), marten (*Martes foina*), badger (*Meles meles*), otter (*Lutra lutra*), Turkestan lynx (*Lynx lynx*), and Tien Shan bear (*Ursus arctos*). Species more common to the juniper forests and higher altitudes include marmots (*Marmota*), tolai hares (*Lepus tolai*), Turkestan red pikas (*Ochotona rufescens*), juniper voles (*Microtus juldaschi*), and Siberian roe deer (*Capreolus capreolus*).

Protected areas

Almost 3 million hectares of the country's territory have been designated as natural reserves, national parks, site management areas, tourist and recreation zones, botanical gardens, or stations. The nature reserve Tigrovaya Balka lies along the Vakhsh River delta in southern Tajikistan and is characterized by tugai forests along the Vakhsh and Panj rivers; populations of markhor and Bukhara red deer are conserved in Dashtijum Reserve; and the argali is found and the bar-headed goose nests in Zorkul in southeastern Tajikistan, which includes the protected areas of Zorkul lake islands. The Romit Nature Reserve has practically lost its status as a valuable biodiversity refuge (Box 1).

Around 10% of the unique ecosystems of Tajikistan are situated outside the protected areas. Poor ecological education contributes to irregular use of biological resources. For example, more than 60 species of wild medicinal herbs are used by the population who have no idea that some of them are about to become extinct. New protected areas need to be created in regions where there are none, and corridors need to be created between existing protected areas. The protected status of sanctuaries, which have low levels of protection, needs to be increased in areas that are important for the conservation of biodiversity and which have endangered species and ecosystems. Management and planning in nature reserves needs to be improved by increasing the qualifications of nature reserve staff and elaborating and implementing management plans.

Protecting sites alone will not be sufficient to conserve biodiversity in the long term; conservation of landscapes large enough to allow the persistence of biodiversity must be

Box 1: Romit: A protected area in Varzob Raion

Romit Reserve is a mountain-landscape nature conservation area of 16,000 ha in the highest protection category. Romit was recognized by the IUCN as a major biodiversity site and is a declared zone of international tourism. The main purpose of the reserve is to study and preserve mesophyllic forest, mountain-steppe, meadow ecosystems, and rare endemic species, including fauna and flora listed in the Red Data Book of Tajikistan. Despite the limited territory of the reserve, it is rich in diversity of species of flora and fauna. The Reserve has about 1,500 higher flowering plants. The vegetation cover is quite diverse and consists mainly of shiblyak, deciduous forest, tall-grass (shroud) semi-savanna, mountain steppe, and alpine and sub-alpine meadows at some places along the upper boundary. Maple and juniper are the main forest-forming species. In addition, there are walnut (*Juglans regia*), Bokhara almonds (*Amygdalus bucharica*), Turkestan birch (*Betula turkestanica*), and many species of plants such as *Allium rosenbachianum*, *Petilium Eduardii*, and *Allium suworowii*. The highlands of the Varzob River basin are mainly savanna type steppe, with small areas of meadow pasture, and the alpine pastures of the Romit River basin are mainly sub-alpine meadows with steppe type tall-grass. Only 500 plant species, including 130 forage plants, have been recorded in the mountainous territory of the Varzob valley (Romit river basin or Kofarnihan) and in Varzob gorge, where there is regular intensive summer grazing. Unfortunately, due to intensive and unregulated grazing, the pastures are heavily contaminated with buzulnik, Rumehs, kotovnik tarragon, and wormwood (*Artemisia* spp.). This type of biodiversity is typical for the river basin of Varzob, the only difference is that in the river basin in the middle of Varzob, the large areas of floodplain are occupied by chinar (*Pinus* spp.) plantations, and willows (*Salix* spp) grow in large areas of the floodplains. Romit home to partridge (*Alectorica kakelik*), quail (*Coturnix sotiirnih*), a large dove (*Streptopelia orientalis*), ringdove (*Solimba palumbus*), kestrel (*Falco tinnunculus*), golden eagle (*Aquila chrysaetus*), owl (*Bubo vibo*), splyushka (*Otus ssors*), ordinary starling (*Sturnus vulgaris*), Himalayan snow cock (*Tetraogallus himalayensis*), Himalayan merganser (*Mergus merganser*), and other birds. The mammals include a stone marten (*Martes foina*), ermine (*Mustel erminea*), weasel (*Mustela nivallis*), badger (*Meles meles*), wolf (*Canis lupus*), fox (*Vulpes vulpes*), lynx (*Felix lynx isabellina*), wild boar (*Sus scrofa*), Siberian ibex (*Sarra sibirica*), tolai rabbit (*Lepus tolai*), and long-tailed marmot (*Marmota caudata*). Reptiles include the viper (*Vipera lebetina*), copperhead (*Ancistrodon halys caraganus*), non-venomous spotted whip snake (*Hemorrhhois ravergieri*), patterned snake (*Elaphe dione*), and sand boa (*Ehuh* sp.). The rivers are home to fish such as the marinka (*Schizothorax intermedius*), trout (*Salmo trutta oxianus*), and Turkestan catfish (*Glyptosternon reticulatum*). Sadly, the value of the Reserve has been compromised by unregulated grazing, wood gathering, and illegal hunting.

anchored on core areas, embedded in a matrix of other natural habitat and anthropogenic land uses. A preliminary assessment of such landscapes within Tajikistan should be carried out to identify and delineate suitable sites based on the following criteria: coverage of representative sites, existence of large-scale intact biotic assemblages (all the living things within an environment: plants, animals, invertebrates, birds, and micro-flora and fauna), needs of wide-ranging (landscape) species, connectivity of habitats, and opportunities for maintaining ecological and evolutionary processes. Areas that should be considered include intact rivers and landscapes, natural mountain passes, known migratory corridors, and areas

with spatial heterogeneity that could serve as stepping stones for many species. Other factors to be considered are the range of habitats represented, resilience to anthropogenic development scenarios, and the need to safeguard as yet unstudied areas that might harbour high levels of biodiversity or endemism. Remote sensing and GIS are important tools and the results of the initial studies in Tajikistan (and elsewhere) illustrate the value of such an approach (Akhmodov 2008).

Most species are best conserved through the protection of the sites in which they occur. Sites are physically and/or socioeconomically discrete areas of land that need to be protected to conserve the target species. Sites are scale-independent, which means they can be very small or very large. The defining characteristic of a site is that it is an area that can be managed as a single unit. Sites can be any category of protected area, government land, or private farm. The main objective of defining important sites for conservation of threatened species is to identify areas where investments can be made to create protected areas or special conservation regimes, expand existing protected areas, and/or improve protected area management, all of which will help to prevent species extinctions and biodiversity loss.

International hunting is organized for argali (*Ovis ammon*), Siberian ibex (*Capra sibirica*), urial (*Ovis vignei*), and Tajik markhur (*Capra falconeri*). Overhunting of legal game species and poaching of rare species is widespread, especially in the mountain regions. Government agencies set quotas for game species without carrying out appropriate research on game numbers or population dynamics. Thus quotas are often too high to ensure that viable populations of game animals (mostly ungulates like argali and Siberian ibex) are maintained. In the last ten years, poaching alone caused a drop in numbers of argali and Siberian ibex by 50%.

Nature reserves are neither equipped nor authorized to control poaching outside of protected areas. The limitations of enforcement capabilities also lead to uncontrolled hunting, for example of snow leopards (*Uncia uncia*), within so-called protected areas (Jackson 2012). Measures to reduce poaching include building capacity (training, equipment, transportation) of existing services, inspection agencies, and NGO groups to patrol areas where poaching is prevalent. Harvesting of animal parts, such as horns and antlers for oriental medicines and snow leopard (*Uncia uncia*) skins for decoration, threatens several endangered species. Poaching and unsustainable hunting are rampant in nearly all areas. Vipers (*Vipera lebetina*) have long been exploited for their venom, but have been hunted almost to extinction in the first decade of the twenty-first century. The mountain forests of Gissaro-Alai play a crucial role in preventing wind and water erosion. During the past two centuries, much of the natural woodland in this ecoregion has been cleared for fuelwood and overgrazed by an increasing number of domestic cattle, causing soil erosion (Akhmadov 2008). Agriculture, grazing, forestry, extractive industries, building construction, and recreation have caused the greatest impact on these mountain ecosystems. Many foothill ecosystems have shown a marked decline in biodiversity.

The ungulates, wild sheep and goats, are the most affected by human influence in this ecoregion. Wild goats are threatened primarily from traditional hunting by the local population, but they are also prized trophies for foreign hunters. In addition, the urial faces threats from loss of habitat and grazing land due to competition from flocks of domestic livestock, as the majority of land in the ecoregion is used for sheep pasture, in some areas year round.

Threats to biodiversity

The biodiversity of Tajikistan is being lost at an alarming rate. On average, nearly half of the lands in the major biodiversity sites have been transformed by human activities. The plains, foothills, and sub-alpine belts have been the most heavily impacted. Native floodplain vegetation remains on only half of its original area, and only 2-3% of original riparian forests remain. Most natural old growth forests have been fragmented into small sections, divided by areas of commercial forests or plantations as well as agricultural and developed lands. For Tajikistan as a whole, less than a quarter of the region remains in reasonable condition, while less than 10% of the original vegetation, including forests, can be considered pristine. Numbers of large native herbivores such as wild sheep, camels, and asses have dropped dramatically over the past century as have carnivores such as red marmot (*Marmota caudata*), muskrat (*Ondatra zibethica*), fox (*Vulpes vulpes*), badger (*Meles meles*), snow leopard (*Uncia uncia*), and wolf (*Canis lupus*), which is being over hunted and placed at risk. Data on reptiles, birds, and fish are not easy to obtain, but doubtless many species have been lost or are in danger of extinction (at least locally).

Illegal logging, harvesting of fuelwood, and the timber trade threaten biodiversity in the region's forests and lead to habitat degradation. While officially-sanctioned logging has actually decreased in some areas over the past few years, illegal logging persists. Illegal logging leads to a decline in species composition, forest degradation, and overall habitat loss, impacting a number of plant and animal species. Rural populations are largely dependent on fuelwood for heating and cooking. Harvesting of fuelwood has increased nearly three times in some areas compared to even a decade ago as a result of energy shortages and the economic crisis, which leads to forest degradation and the disappearance of certain species.

Overgrazing is causing environmental damage over much of the Tajikstan rangelands. The number of sheep grazing on the winter ranges and steppes and semi-deserts has nearly tripled over the past two decades. Intensive grazing has resulted in reduced species diversity and habitat degradation. A large portion of the pasturelands in Tajikstan are subject to erosion. Secondary plant communities now occupy 80% of the rangelands in the sub-alpine belt. Grazing of cattle in forested areas disturbs the undergrowth and creates competition for wild ungulates.

Strategies for management

Developing new models for sustainable resource uses: Measures to prevent overgrazing include developing sustainable rangeland management plans, enforcing restrictions on grazing in protected areas, and prohibiting grazing in damaged fields near rivers and on steep slopes. Developing opportunities for alternative sources of income would reduce the need to keep large numbers of livestock in some rural communities (Strong and Squires 2012; Lerman 2012). Examples of alternative income generation include ecotourism, sustainable collection and sale of medicinal plants and other non-timber forest products, and sustainable hunting and fishing.

Building the capacities and awareness of local communities for the sustainable use of resources: NGOs and other civil institutions can work with local communities to develop the capacity for alternative livelihoods. Sustainable resource use also entails reducing the impacts of development on the environment and biodiversity. Civil society can play an important role in monitoring these impacts and providing objective information on pressing conservation issues. Finding ways for rural communities to benefit from nature conservation through sustainable resource use will boost local economies, helping reduce pressures on biodiversity. Involving NGOs in planning and monitoring development projects will ensure that long-term economic endeavours take into account the consequences to biodiversity. Rural populations – those with a direct link to natural resource use – are generally the least informed on conservation issues. By focusing awareness strategies in target corridors, these rural communities will gain knowledge that will last a lifetime, empowering them to make informed decisions about their environment.

Demonstrating sustainable resource use: Investments to demonstrate sustainable resource use might involve evaluation and implementation of models for sustainable forestry, water use, and rangeland management. It could start by identifying communities within the selected corridors that have the desire to participate in model projects. The steps are (1) build capacity in these model communities through training and technical support; and (2) elaborate guidelines for sustainable resource use and implement in model areas. International donors have provided considerable support to help resolve some of these issues. Funding opportunities exist, particularly in promoting transboundary cooperation, training conservation professionals, building environmental awareness, and demonstrating the benefits of sustainable resource use.

After the breakup of the Soviet Union in 1990, Tajikistan faced the challenge of building new governmental structures. New state institutions dealing with natural resources were created, while others were dismantled or reorganized. Various line ministries, forestry, water resources, agriculture, and other agencies also have jurisdiction over various aspects of natural resources. Ministries generally have regional divisions in each of the provinces within the country. State conservation agencies, however, often lack the funding and capacity to implement their mandates or to enforce legislation and international obligations. Conflicting

policies in legislation and overlapping jurisdictions, in addition to a general lack of communication among governing bodies, hinder effective management of environmental resources and create significant contradictions in regulation. Transboundary cooperation on environmental issues is limited. Tajikistan has signed the majority of international conventions, including the Convention on Biological Diversity, Convention on Desertification and Drought, Wetlands of International Importance, Convention on International Trade in Endangered Species (CITES), and World Cultural and Natural Heritage, but does not have the capacity and finances to fulfil its international obligations. Following accession to the UN Convention on Biological Diversity and the approval of the National Strategy and Action Plan on Conservation and Sustainable Use of Biodiversity (Government Resolution No. 392 of RT of 01.09.2003), the National Centre for Biodiversity and Bio-safety (NCBB) was established. This is the interagency coordination unit for assessing and protecting pasture biodiversity, but interagency coordination is not easy. There are severe budget constraints and a lack of properly trained staff.

Planning issues pertinent to rangeland biodiversity use, conservation, and functional activity, should be the responsibility of 'hukumats' (local government at the district level), with interagency coordination by the Ministry of Agriculture (MoA). There are units within the MoA related to grazing and biodiversity who are also assigned biotechnical activities as diverse as seed production and measures to ensure the long-term sustainable use of forest biodiversity. The Ministry of Agriculture, together with the Pasture Trust, should join the NCBB to unite efforts to improve pasture biodiversity. The Committee for Land Management Geodesy and Cartography (CLMGC) handles land transfers and should do so according to the season of use and with proper cadastral registration. Such actions by existing state institutions could do much to improve the situation in Tajikistan's rangelands and pasturelands.

Further, there is no single coordination system between departments, and no common strategy to engage with pasture users in a meaningful way. Plant biodiversity, even as it relates to valuable forage species and weedy and poisonous plants, is neglected. Training systems and university level instruction are also quite divorced from practical pasture studies, especially in the species composition aspects of rangeland biodiversity. The important issue of preserving biodiversity as a part of grazing management and assessment of the adverse effects of overgrazing on the biodiversity of rangelands, especially the impact of use on forest biodiversity, are often overlooked when short-term gains are uppermost in people's minds. Neither the forest authority who benefits from leasing out the land, nor the livestock owner who needs access to better pasture, is sufficiently concerned to monitor the situation and regulate grazing pressure or entry and exit dates if overuse is detected.

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2

Timberline Ecotones in the Hindu Kush Himalayas



Structure and Functioning of Timberline Vegetation in the Western Himalaya: A Case Study

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An ecological assessment of timberline vegetation was carried out during 2008–2011 at selected locations in the Indian Himalayan states of Uttarakhand and Himachal Pradesh. The objectives were (i) to establish baseline data on the vegetation structure and composition along the timberline ecotone, (ii) to assess the functioning of major communities (net primary productivity, litter decomposition, and nutrient dynamics), and (iii) to study the effects of interannual climatic variation on the phenological responses of the tree species forming the alpine timberline in the study area. Geospatial analysis of the timberline ecotone (3,000–4,000 masl) showed that fir (*Abies spectabilis*) occupied the greatest area within the timberline (1,886 km²) followed by oak (*Quercus semecarpifolia*, 1,142 km²), birch (*Betula utilis*, 433 km²), and krummholz (412 km²). An area of approximately 81 km² had undergone major change during the last three decades, with a proportionally greater change in the last ten years (44 km²) than in the previous decades. Fir forest had increased by 33 km² since 1980. The phenological study showed that the broadleaf deciduous species *Betula utilis* was more sensitive to interannual climatic variation and early snow melt. This Paper discusses the broad findings of the study, especially the extent and changes in the forests along the timberline ecotone, the pattern of tree species regeneration, the population structure, and phenological responses under different conditions.

Keywords: change detection; phenology; remote sensing; timberline; Western Himalaya

Introduction

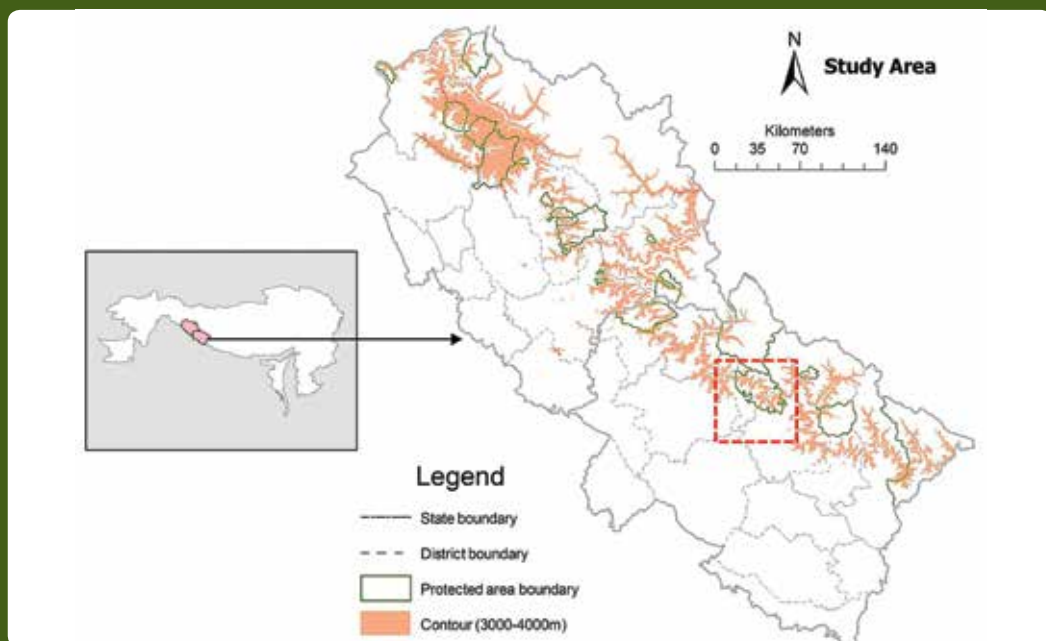
The timberline ecotone, marked by the culmination of the forested zone, is the most prominent ecological boundary in the high mountains governed by climatic factors (Holtmeier 2003). The microclimate, topography, altitude, and herbivory play a significant role in determining the structure and function of plant communities along the timberline. In addition, several anthropogenic, topographic, and climatic factors influence the overall physiognomy and

community structure of the timberline. Often the interfaces resulting from these factors lead to a complex spatial heterogeneity in forest structure and mosaics of forest succession (Timilsina et al. 2007; Shugart et al. 2010). All ecotones are known to be sensitive to biotic and climatic stressors because species are adapted to their own microclimatic conditions. It is predicted that with increasing global temperature, the altitudinal timberlines will advance to higher altitudes, while latitudinal timberlines will move towards higher latitudes in the northern hemisphere (Parmesan 2006; Weiser and Tuasz 2007). However, several authors have suggested that this pattern may not hold true for all regions due to the dependence upon local and regional conditions such as terrain type, orographic influences, herbivory, diseases, and anthropogenic influences (Cairns and Moen 2004; Weiser and Tuasz 2007). Although several authors have documented the floristic structure of high-altitude vegetation in the greater Himalayas (e.g., Naithani 1984; Rawat 1984; Semwal 1984; Singh and Rawat 2000), detailed ecological studies of the community structure, phenological response of major species to inter- and intra-annual climatic variation, and dynamics of vegetation at a landscape level are lacking. Baseline studies covering these aspects along the gradients of precipitation (east-west axis) at selected sites would go a long way towards developing appropriate models for predicting the response of timberline communities to climatic and non-climatic drivers. This paper discusses the results of a geospatial analysis of the timberline ecotone (3,000–4,000 masl) in the Western Himalaya in two Indian states, and looks at recent changes in the vegetation cover at a landscape level, patterns of tree species regeneration, population structure, and phenological response under different conditions.

Study area

An extensive survey was carried out along the sub-alpine-alpine ecotone of the Western Himalayan mountains in the Indian states of Uttarakhand and Himachal Pradesh (Figure 9). The phenology of the dominant timberline forming tree species was monitored within Kedarnath Wildlife Sanctuary (KWS) in the upper catchment of the river Alaknanda, a major tributary of the Ganges. The sub-alpine forests in this area are characterized by a preponderance of shade loving species on north facing slopes (*Betula utilis* and *Abies spectabilis*) and light demanding species on south facing slopes (*Quercus semecarpifolia* and *Rhododendron arboreum*), with low tree species richness. The krummholz formation in the study area is dominated by *Rhododendron campanulatum*. Towards higher altitudes, the krummholz formation gives way to extensive alpine grasslands and meadows characterized by the presence of *Danthonia cachemyriana*, several species of *Carex*, *Kobresia*, and a variety of dwarf herbs. The study area has three main seasons: a long winter (October to April), short summer (May to June), and rainy season (July to September). The mean annual temperature along the timberline ecotone (3,300 masl) ranged from -8.9°C in January to $+25.6^{\circ}\text{C}$ in July, with an annual average of $6.6 \pm 0.7^{\circ}\text{C}$. The mean temperature of the warmest month was $12.6 \pm 1.2^{\circ}\text{C}$, in July. Annual precipitation was $2,411 \pm 432$ mm, of which 89.5% was recorded during June-September; snow cover lasted for 85 ± 22.7 days/year.

Figure 9: Timberline ecotone (3,000–4,000 masl) in the Western Himalaya, and location of intensive study area



Methodology

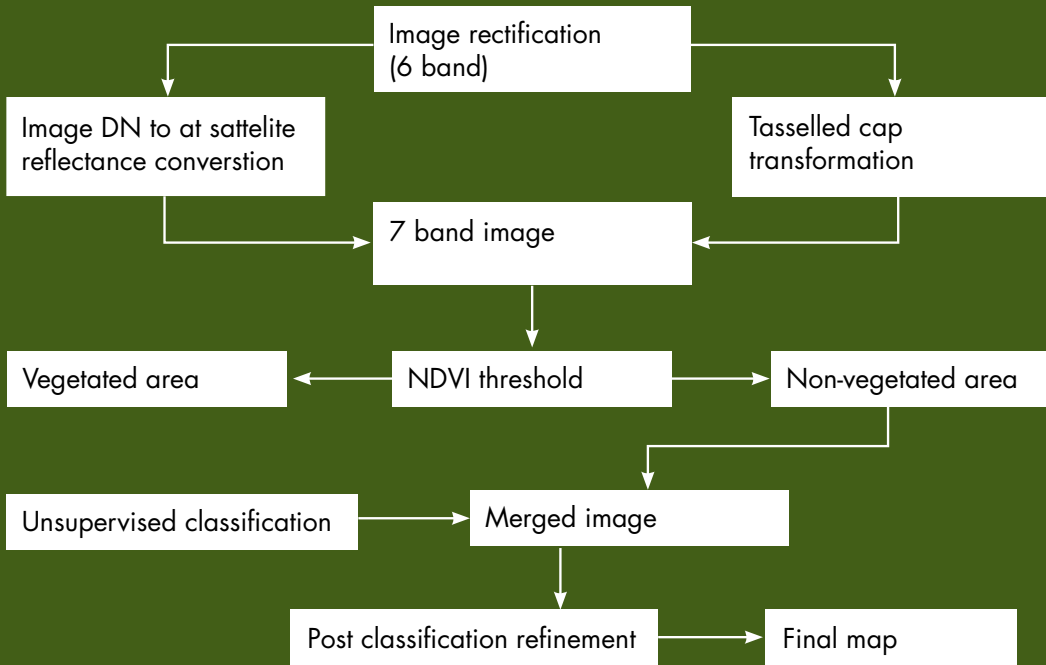
Timberline structure and composition

Vegetation sampling was carried out along the entire timberline in the study area. Forest types were selected based on physiognomy and variation in topographic features. Ten 10×10 m quadrats were laid within each hectare plot ($n=26$) for trees and saplings. A smaller 5×5 m quadrat was laid within each 10×10 m quadrat for shrubs and tree saplings. Twenty-five quadrats of 1×1 m were laid randomly within the hectare plot for herbaceous vegetation. The tree canopy cover, tree height, canopy depth, and canopy width of trees were measured with the help of a densitometer, clinometer, and measuring tape. The tree, shrub, and herb layers were analysed separately for species richness, density, diversity, and regeneration of tree species following Curtis and McIntosh (1950) and importance value index (IVI) calculated following Phillips (1959).

Vegetation mapping and change detection

Figure 10 shows the methodological framework of the classification adopted for timberline mapping. The field data used for image classification and accuracy assessment of thematic maps were collected during the summer in 2009–2011. Data were collected in the form of

Figure 10: **Methodological framework of the classification used for timberline mapping**



geographical locations of different vegetation classes and non-vegetated surfaces using the Garmin-72 global positioning system (GPS). Landsat images downloaded from the EROS data centre online archive (<http://glovis.usgs.gov>) were used for the study. Deciduous species only attain full maturity after April. Hence images from earlier period of the year could not be used. Images from the peak growing season (July–August) show poor discrimination of alpine meadow from deciduous forest, and it is very difficult to obtain cloud-free images in the pre-monsoon months. Thus, images from September and early October from the years 1998 and 2009 were selected for the study.

In the first pre-processing step, multispectral scanner (MSS) images were registered with thematic mapper (TM) images and resampled at 30 m to match the resolution. Radiometric correction was performed by converting the raw digital value of the image to at-sensor spectral radiance ($L\lambda$) using standardized rescaling factors (Chander et al. 2009) and finally to top-of-atmospheric reflectance (Markham and Barker 1986). Relative radiometric normalization (RRN) was used to adjust the reflectance of the target (TM) image according to the base (MSS) image (Hall et al. 1991).

As no training samples or ground truth data were available for supervised classification, an unsupervised classification approach through isodata clustering was used. Each individual subset image was classified into 120 clusters. Data collected during the fieldwork were used

to sort the clusters into 12 land cover classes. To avoid the impact of diffuse sunlight on steep slopes, the normalized difference vegetation index (NDVI) calculated from the reflectance band, tasselled cap derived brightness, and the wetness index were used as additional layers with four multispectral bands.

The change detection method used in the study was based on a vegetation index (VI) differencing technique. Residual difference images were created by subtracting the VI of the MSS image from the TM image. The resultant difference image contains negative, zero, and positive values, which can be interpreted as a decrease, no-change, and increase, respectively, in the vegetation parameters. The threshold for derivation of a change/no-change image was based on the standard deviation of the difference image. A higher standard deviation threshold (2) was selected to avoid changes due to the different radiometric response of the images.

The accuracy of the thematic map was assessed using field inventory data; the accuracy of the change/no-change binary map was assessed from randomly generated points that were interpreted visually by overlaying the images from different periods. The accuracy assessment procedure was performed in Arcview 3.2 kappa extension; all the above mentioned steps were performed using ERDAS Imagine 9.3 software. The classification accuracy of the thematic maps was assessed using error metrics. The overall accuracy was 83% for Himachal Pradesh and 82% for Uttarakhand.

Plant phenological study

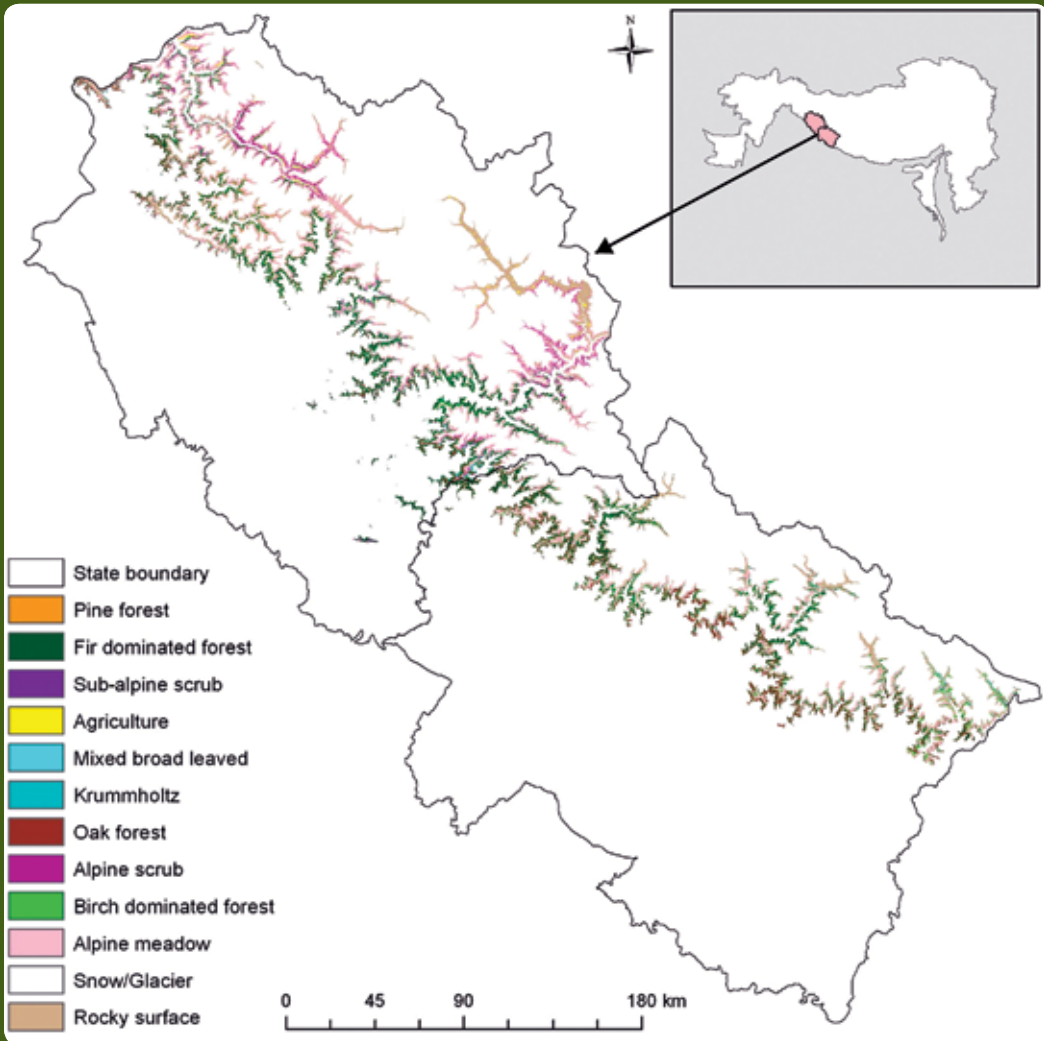
The phenophases of selected species representing the timberline ecotone were studied using the BBCH scale (Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie; Meier 2003). Five timberline species were selected for phenological monitoring in the KWS: *Betula utilis* (Himalayan birch, winter deciduous), *Abies spectabilis* (Himalayan fir, evergreen coniferous), *Quercus semecarpifolia* (brown oak, semi-evergreen), *Rhododendron arboreum* (tree rhododendron, evergreen), and *Rhododendron campanulatum* (evergreen shrub-krummholz). Five individuals were selected and marked along the elevational gradient from 3,300 to 3,450 masl, the upper limit of distribution in the intensive study area. Buds were marked after the onset of winter dormancy. After marking, the buds were monitored for the entire study period, every second day during the active growth period, at 10-day intervals in the later stages of growth, and monthly during the peak of winter. The important phenophases include bud swelling, breaking, leaf separation, senescence, leaf fall, and stem development. After dormancy, bud size was monitored during winter to observe changes in the size and initiation of growth in the late winter months. Shoot length and diameter of the marked buds after bud breaking, leaf dimensions (number, length, and width), and girth of marked trees were also measured to assess growth. The phenological parameters such as the occurrence of different stages and the developmental stages and growth were correlated with the environmental parameters. The phenological attributes of one of the broadleaved deciduous and pioneer tree species are presented in detail in the results section.

Results

Extent of the timberline ecotone and changes

The total area within the elevation zone between 3,000 and 4,000 masl in the study area is 10,965 km², with the greater part in Himachal Pradesh (6,818 km², Figure 11). Although Himachal Pradesh has a larger proportion of the timberline zone, it has less forested land than Uttarakhand (2,101 km² compared to 9,908 km²). Fir occupied the greatest area of any species within the timberline (1,886 km²), followed by oak (1,142 km²), birch (433 km²), and krummholz (412 km²). The area of alpine scrub was smaller in Uttarakhand (223 km²) than in

Figure 11: Thematic map of the timberline zone (3,000 to 4,000 masl) in Western Himalaya



Himachal Pradesh (354 km²). However, Himachal Pradesh had less representation of mixed broad-leaved forest (68 km²) than Uttarakhand (97 km²). The extent of area classified as alpine meadow depends on the snow deposition pattern and is quite variable; Himachal Pradesh had a much greater area of alpine meadow (2,697 km²) than Uttarakhand (955 km²).

The overall area statistics for the timberline ecotone showed that 81.5 km² had undergone major change in the last three decades. The magnitude of change in the last ten years (44.1 km²) was higher than in the preceding decades. Fir dominated forest had the most area of any species and also had the most change in area, followed by birch (with a 12 km² increase in area during 1980-2010, of which 1.8 km² occurred in 1998–2010). There was also an increase in sub-alpine forest and alpine scrub.

The total change in land cover within protected areas was 20.3 km² and outside 61.2 km², mostly as a result of increase (17.8 km² within protected areas and 52.9 km² outside). The increase has been continuous in recent decades in both protected and unprotected areas. Both increase and decrease were greater outside protected areas. Most of the decrease outside the protected area occurred during 1998 to 2010, while that within the protected area was less but continuous, indicating that it may be natural rather than due to disturbance.

Vegetation structure and composition

Figures 12-15 show the population structure of the various forest types along the timberline ecotone. The *Abies spectabilis* community had the highest tree density (650 ± 147 individuals ha⁻¹), with *A. spectabilis* contributing more than 70% of the total number (Figure 12). *Betula utilis* was the co-dominant species in the community followed by *Sorbus foliolosa*. The *A. spectabilis* community showed very poor regeneration with a low conversion ratio of seedlings to saplings, the timberline is generally lowered in the absence of natural regeneration. The *Betula utilis* community had the second highest tree density (526 ± 94 individuals ha⁻¹), with *Betula utilis* contributing 67% of the total (Figure 13). *Sorbus foliolosa* was the co-dominant species; other species had a very low representation. The density of *S. foliolosa* varied most across the microhabitats. *Abies spectabilis* was also present in small patches in some pocket areas. The average total basal area of the community was 14.9 ± 8.6 m² ha⁻¹ with close to two-thirds contributed by *Betula utilis*. The population structure with all girth classes well represented indicates intense regeneration of *B. utilis*, and the high seedling and sapling density indicates favourable conditions for regeneration in recent years. The high girth class trees were only found in the areas of abrupt termination of the forest at the timberline ecotone. Establishment of seedlings beyond the canopy at the timberline ecotone indicated upward movement of the tree species with invasion of alpine meadows.

Although Uttarakhand has five species of oak (*Quercus* spp.), only *Q. semecarpifolia* is found in the timberline ecotone. *Q. semecarpifolia* dominates the sub-alpine forest (65%) on drier aspect (NW, W to S, SE) and forms a sharp timberline with only a narrow ecotone bordered by

krummholtz vegetation. The *Q. semecarpifolia* community had a tree density of 548 ± 162 individuals ha^{-1} (Figure 14). *Rhododendron arboreum* and *Sorbus foliolosa* (6% each) were the major associate followed by *A. spectabilis* (4%) and *Betula utilis* (3%). There was good regeneration all along the timberline ecotone in undisturbed and naturally protected areas and all girth classes were present. Establishment of seedlings and saplings beyond the canopy and towards the alpine meadows was observed in many places (e.g., Tungnath and Rudranath).

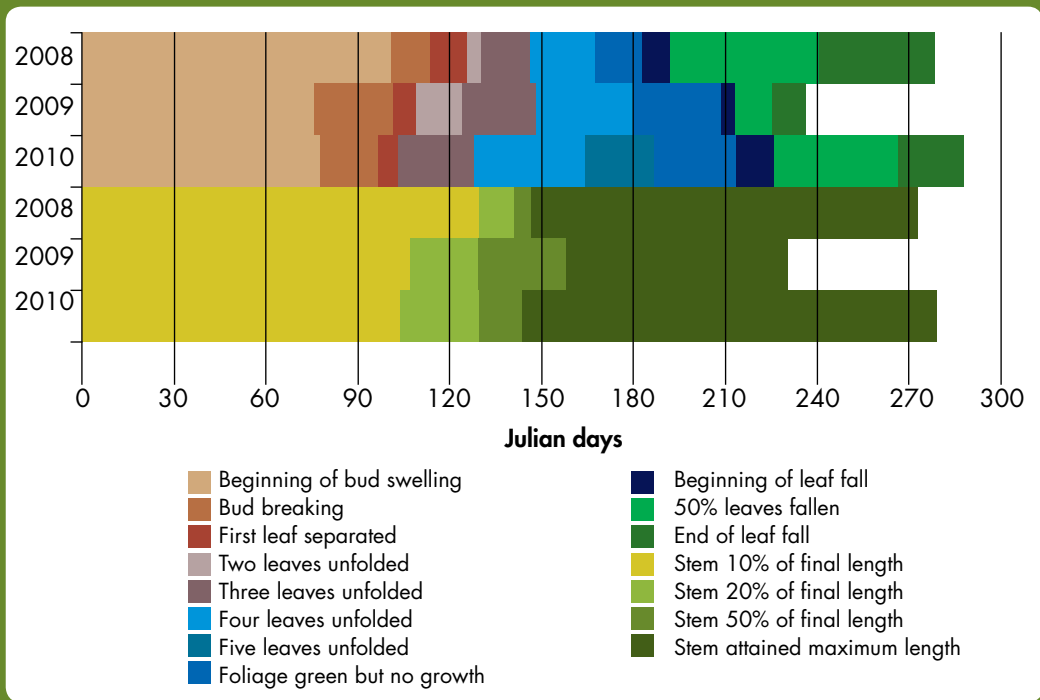
Rhododendron arboreum has a wide range of distribution from warm temperate to timberline ecotone (1,400–3,600 masl) and is well adapted to mild and harsh conditions (Figure 15). This species forms timberlines on rocky slopes above the sub-alpine forests of *Q. semecarpifolia* and was found at many localities with steep and rocky slopes with a south to southwestern aspect facing strong solar radiation. Such areas are unfavourable for large tree species such as *Q. semecarpifolia* due to the ruggedness of the slope, very thin soil layer, and lack of suitable places for seeds to stabilize and germinate, and tree species richness was lowest in this community. *R. arboreum* has a high adaptability and advantages over other species as a result of its small seeds and ability to adapt from a tall tree in the sub-alpine region to a stunted tree in the timberline ecotone. Timberline formed by *R. arboreum* generally had very low stature trees with sparsely distributed individuals and very low canopy cover (27%). The total basal area was $4.6 \text{ m}^2 \text{ ha}^{-1}$ and the total tree density of the community was 530 individuals ha^{-1} . All the individuals were of low girth (<70 cm), but good sapling density was observed (610 individuals ha^{-1}) indicating good regeneration of *R. arboreum* along the ecotone with some upward movement.

Phenological attributes

The average occurrence of different phenophases in *Betula utilis* at 3,300 masl in three consecutive years, calculated in Julian days (from January 1, JD), is shown in Figure 16. Bud swelling started in *Betula utilis* 18 ± 6 days on average after the snow melted. The average date of bud break was 102 ± 11.5 JD at 3,300 masl (timberline on NW facing slopes) and 104 ± 10.5 JD at 3,450 masl (timberline on SE facing slopes). As a pioneer species, *Betula utilis* has the shortest leaf life span and growth period among all the timberline tree species. The average growth period from bud break to initiation of senescence was 100 ± 27.7 days. Initiation of leaf fall began 110 ± 17.1 days after bud break. The first leaf separated on 111 ± 14 JD. Leaf separation was earlier in 2010, a year with high air and soil temperatures. Senescence is initiated by a sudden fall in temperature and started in July/August, on average on 202 ± 16.6 JD. The date of leaf fall also depends on temperature and was later in years with a higher temperature and vice versa. On average, elongation of the stem by 10%, 20%, and 50% was observed on JDs 114, 133, and 150, respectively. Low soil and air temperature had a negative effect on shoot growth, whereas a delayed monsoon and higher air temperature accelerated shoot growth.

The average surface area of individual mature leaves was measured. The average leaf surface area was $2,221 \text{ mm}^2$ in 2010, a year with an extended growth period as a result of an

Figure 16: Duration and day of occurrence of different phenophases in *Betula utilis* at the timberline (3,300 masl) in 2008, 2009, and 2010. The width of each coloured band indicates the duration until the occurrence of the phenophase (average date of snowmelt at 3,300 masl in 2008, 2009, and 2010 was 15 March, 28 February, and 20 March, respectively)



extended monsoon and high rainfall, and 1,612 mm² in 2008, a year with low soil and air temperatures and a short growing period. The leaf area had a high positive correlation with soil temperature at 20 cm depth (Pearson's correlation = 0.547, p (2 tailed) < 0.05). Low soil temperature led to a slow rate of leaf expansion and fewer leaves in a shoot. The average leaf area per shoot was 12,435 mm² in 2010 and 6,292 mm² in 2008. The development of leaves in a shoot and leaf fall at the end of the growth period were highly correlated with all environmental factors (soil and air temperature, precipitation, relative humidity). Air temperature had the highest positive correlation ($r = 0.804$, $p < 0.001$). Higher temperatures and delayed monsoon extended the overall growth period and leaf fall started later and at a slower rate. There was a high positive correlation between the phenophases and air temperature prior to the occurrence of a particular phenophase. Correlation with the average temperature 30 days prior to the phenophase was more significant than correlation with the temperature 15 days prior to a phenophase (Pearson's correlation 0.749, p (2 tailed) = 0.000, cf. 0.693).

Discussion

The fir, *Abies*, clearly occupied the greatest area among the five major species forming the timberline ecotone in the survey area. However, two different species of *Abies* were actually identified within the timberline ecotone, *A. spectabilis* and *A. pindrow*. These species may have a different response to the climatic conditions, but spectral separation is extremely difficult at present. Thus there is a need to set up long-term monitoring sites in places where both species occur. The distribution pattern of the oak, *Quercus semecarpifolia*, the species with the second largest area in the ecotone, is markedly affected by human disturbance, and the reasons for the absence of this species from some areas, including Kugti WS, is yet to be ascertained. Fir forest formed the largest plant community in the timberline areas in Himachal, and oak forest in Uttarakhand. The timberline ecotone vegetation has undergone changes in all the protected areas, but there was no clear pattern for a particular species or geographic situation (elevation, aspect) so that it is difficult to interpret these changes as a response to recent changes in climatic pattern. Although the method used to detect the changes in cover classes along the timberline ecotone is fairly reliable, explanation of the causes of such changes would require in-depth and long-term studies along the high-altitude forest-grassland interfaces. The results of the present study support the finding of field researchers that timberline ecotones have shifted slightly towards higher altitudes during recent decades in response to current warming (Payette and Filion 1985) at both regional and local scales (Masek 2001).

The study indicates that normalized difference vegetation index (NDVI) is able to detect changes in highly rugged topography, but for better results, imagery must be selected on the basis of phenological similarities rather than simply annual dates. The study found an overall increase in the vegetation of the timberline ecotone over the period 1980–2009. Locally, there was some decrease in some areas which may be attributed to both anthropogenic pressure and natural mortality; e.g., die back of *Rhododendron campanulatum* due to disease was noticeable in Great Himalayan National Park (GHNP). Little or no change was found for *Quercus*, whereas in Kugti and *Pinus* showed increased density near the upper limit of the timberline. These observations support the view that an abrupt timberline will respond less quickly than a diffuse timberline. The changes in Kugti WS were more prominent at lower elevations and in GHNP they were more significant at the upper limit of the timberline, thus these sites should be considered for further detailed study. Green biomass has increased in the upper part of the ecotone. Most of the changes on the northern slopes are associated with *Abies* spp., *Betula utilis*, and *Rhododendron campanulatum*. The major species associated with change on the southern slope were *Quercus* and *Juniperus*.

The timberlines in the Western Himalaya are lower than would be expected naturally because of excessive anthropogenic pressure. Dead remains and stumps of many trees were found well above the present timberline. Further evidence for the lowering of the timberline is that the average temperature in the warmest month for the timberline ecotone in the intensive study area was 12.6°C, whereas worldwide 10°C is considered to be the isotherm for the limit of

tree growth and location of the upper timberline (Tranquillini 1979; Körner 2004). Timberlines are known to be controlled thermally, but recent studies related to the effects of disturbance, such as herbivory (Cairns and Moin 2004), indicate that biotic factors are important and can determine the position of timberlines. The increased regeneration observed in many localities in the study area may be due to the more favourable climatic conditions for growth during past decades, and/or to land use changes in the high-altitude regions. Long-term studies are required in these areas through establishment of permanent plots with weather stations. The upper limit of survival of the timberline species is still unknown for these areas as the region has been under high anthropogenic pressure since time immemorial.

Phenological events are constrained at high altitudes by the short growing season delimited by cold temperatures and snow cover. The time of snowmelt appears to have an almost universal effect on high-altitude phenology (Inouye and Wielgolaski 2003), and variations in phenology can usually be linked to variations in the accumulation and melting of snow (Holway and Ward 1965; Mark 1970). Billings and Bliss (1959) and Knight et al. (1977) reported that full development of plants was accomplished more rapidly at high altitudes where snow persists longer.

The climate during the study period fluctuated markedly; the longest duration of snow cover and highest snowfall was recorded in 2007/08. In contrast, early snowmelt was observed in 2009. The highest rainfall was recorded in 2010 accompanied by an extended monsoon; this followed an early dry period during spring and summer. Evergreen and deciduous species have different strategies to overcome climatic constraints and respond differently to interannual climatic variation. More adapted species are less affected by extreme climatic events. Species may differ in the dates of phenological phases and the order in which these events occur, and some phases may be more apparent in some species than in others.

The life cycle of most deciduous plants goes through recognizable phases such as bud break, leafing, flowering, fruiting, leaf colouration, leaf fall, and bare tree. The phenology of *Betula utilis* was strongly influenced by the interannual climatic variation because it is deciduous. The spring phenophases are particularly sensitive to the temperature during late winter and early spring, which are also considered as accurate predictors of phenophase timing (Sparks and Carey 1995; Diekmann 1996; Heikinheimo and Lappalainen 1997; Schwartz 1999; Spano et al. 1999; van Vliet et al. 2002; Galan et al. 2005). A large amount of snow, late melting, and lower winter temperature seemed to have a positive correlation with the growth of *Betula utilis* in the following growing season. The dry period (snow-free soil) during February/March initiates bud swelling in this species, but bud break only takes place after the average temperature rises above 5°C. If this is delayed, there is a longer period from initiation of swelling to breaking.

The average temperature one month before bud break is positively correlated with this event. For *Betula utilis*, the average temperature was 4.9°C one month prior to bud break and 5.9°C

15 days prior to bud break. The time from initiation of bud swelling to bud break was longer when the average temperature prior to bud break was below 3°C, and shorter when the average temperature exceeded 5°C. Early melting of snow had a negative effect on the growth of the species for the entire season (2009), whereas late melting resulted in a form of accelerated growth (2008 and 2010). Although longer duration of snow is associated with lower temperatures for a longer time, it leads to more growth and accelerated development of shoots and leaves in *Betula utilis*. Menzel and Fabian (1999) found that 70% of the interannual variation in bud break in a group of European species was explained by daily temperature patterns, and that average February and March temperatures explained 75% of the variation in flowering time of Japanese cherries. Other climatic variables may also influence the timing of phenophases to some extent. Saavedra et al. (2003) and Molau et al. (2005) noted that the timing of snowmelt can be an important variable for early spring phenophases in northern alpine climates. While snowmelt is strongly influenced by temperature, it is also influenced by the amount of precipitation and other factors.

In the year of late bud break, the development of leaves was quicker than in the year of early bud break, in line with a strategy of high-altitude plants for overcoming the short growing period. Delayed bud break has been suggested to be a potentially defensive characteristic for deciduous trees against early-feeding lepidopteron larvae. Delayed leaf growth can thus be seen as a potentially valuable characteristic that helps defend deciduous trees against insects (Haukioja et al. 1985). Equally, early budbreak or meristem dehardening increases the risk of frost damage to meristems or young leaves (Linkosalo et al. 2000). Braatne (1995) reported that warm conditions early in spring followed by frost appeared to cause extensive damage to birch in northeastern North America.

Leaf fall in *Betula utilis* was associated with the drop in temperature during autumn. A long rainy season leads to a prolonged growth period, which is beneficial for perennial deciduous plants to maximize leaf life span. A longer leaf life span is associated with potentially higher carbon gain by the plant (Kikuzawa 1994) and more efficient nutrient use (Eckstein et al. 1999). Leaf emergence in deciduous species is closer to summer, and the light conditions are more favourable for photosynthesis at the start of the growing season than at the end. Thus, it is probably more favourable for plants to grow and expand their leaves earlier in spring rather than to prolong the photosynthetic season into the autumn (Karlsson 1989; Myneni et al. 1997). In a study twenty years ago in Pindari and Sundardhunga region in the Western Himalaya, Rawal et al. (1991) reported sprouting of *Betula utilis* at elevations of 3,300 and 3,450 masl by 10 May. In the present study, the mean day of bud break at 3,300 and 3,450 masl was recorded as 102 ± 11.5 and 104 ± 10.5 JD, or 12 and 14 April, 26–28 days earlier than in the previous study. This could indicate differences in the climatic conditions of the different locations or a shift in the phenology, it will be necessary to revisit the same locations to confirm which of these is the case.

The process of leaf development in *Betula utilis* depends strongly on the temperature after bud development. Late spring frost in March and April delays this process, and extreme climatic events such as snowfall in April/May after exposure of the soil to extreme frost in February/March lead to retarded development of leaves and shoots. The combination of low winter temperature, sufficient soil moisture after snowmelt, and higher air temperature lead to the greater production of leaves with more leaf area. As a pioneer species, *Betula utilis* has the shortest leaf life span and growing period of all the timberline tree species.

In 2010, the year with the lowest air temperatures, the growth rate of *Betula utilis* after bud break was accelerated and the duration of bud swelling to bud break was lowest. This indicates that a low temperature may trigger growth in the entire growing season. The production of leaves per shoot was also the highest and the average leaf area was 50% greater than in the lowest growth year. The production of one extra leaf per shoot was not statistically significant, but had considerable importance for enhancing the photosynthetic efficiency of the species. An experimental study by Xu et al. (2011) indicated that warming markedly altered structural/functional leaf traits and enhanced the photosynthetic capacity of treeline birch saplings. Such positive responses in treeline birch would be favourable for the growth of the species under future warmer climate scenarios.

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The Timberline Ecotone in the Himalayan Region: An Ecological Review

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*The Himalayan region has the highest and most diverse treeline in the world. Lying between montane forests and alpine vegetation, the alpine timberline is a particularly conspicuous boundary and has attracted the interest of researchers for many decades. However, the timberline in the Himalayas has been much less studied than its European counterparts due to remoteness of these mountains. This review describes the floristic features and distribution pattern of the timberline in the Himalayan region, the climatic factors that influence the distribution, the carbon and nutrient supply mechanism for treeline formation, and treeline shift and recruitment under climate change scenarios. The Himalayan region presents the highest timberlines and treelines in the world and the most diverse in terms of treeline tree species of *Abies*, *Picea*, *Larix*, *Juniperus* and *Betula*. Temperature is the principal determinant of timberline position and distribution. Worldwide treelines are formed where the growing season soil temperature is ca. 7°C. Supplies of water, nutrients, and carbon do not limit treelines on the global scale, but they are modulators of treeline position at the local scale. A response of timberlines to global warming has been observed in the form of increasing tree recruitment and tree growth rather than timberline advance, especially in the eastern Himalayas. A clearer mechanistic understanding of the timberline is needed in order to be able to predict the potential impacts of human activity and related global change in this sensitive region.*

Keywords: carbon and nutrient relationship; climate change; floristic and species composition; timberline; timberline shift; timberline ecotone

Introduction

In a broad sense, the alpine timberlines represent is the upper limit of forest on a mountain (Wardle 1974). Above the timberline, the dense and close forests give way abruptly or gradually to shrubs and/or meadows. The life and growth form of trees change sharply; trees become stunted and deformed by the severe climate. A zone called the krummholz often lies above the timberline, in which case the tree limit can be taken as the level at which krummholz with tall flagged trees is replaced by krummholz with low tree species. The timberline is often regarded as the ecotone or ecosystem interface between montane and alpine communities. The areas below the timberline, including forests and their ecotones, are

referred to as the sub-alpine zone, and the area of low-growing vegetation above it as the alpine zone. The species composition changes greatly from the sub-alpine to the alpine or arctic region due to the high habitat heterogeneity.

The timberline is not an abrupt physical line, rather it is a boundary or transition zone, but viewed from a distance, the ecotonal transition looks quite abrupt and is customarily regarded as a line. The upper limit of natural forests with a steep gradient and increasing stand fragmentation and stuntedness is sometimes called the treeline ecotone (Körner 1998a), or more commonly, as here, the timberline ecotone. Körner defines a tree (1998a) as an upright woody plant with a dominant above-ground stem that reaches a height of at least 3 m, with its crown closely coupled to prevailing atmospheric conditions. Therefore, the treeline is defined here as the altitude above which any trees are lower than 3 m (Körner 2012b). The timberline ecotone is the broad area of 50 to 100 m below the treeline to the line bounding the full forest – the timberline. Since the timberline and treeline are coupled boundaries, the fundamental mechanisms causing their general position should be similar (Körner 1998b).

The Himalayan region, including the Tibetan Plateau, is a unique physiogeographical region with an average elevation above 4,000 masl. The monsoon and westerlies strongly influence the climate (Zheng et al. 1981). The topographic configuration and atmospheric circulation determine the horizontal differentiation of the natural vegetation. From southeast to northwest, the vegetation changes successively with decreasing moisture from montane forest, through high-altitude shrub, alpine meadow, and alpine steppe, to alpine deserts. Spruce fir is the dominant forest type and stands are widely distributed across the Himalayas. The upper limit of the forests – the timberline – varies with topography and climatic conditions. The timberlines of the spruce fir forests on the Tibetan Plateau are at the highest elevations in the world as a result of the comprehensive effect of uplifting and the heating effect of the vast mass of the plateau, called the ‘mass elevation effect’ (or in German ‘Massenerhebungseffekt’) (Schweinfurth 1957). The higher than normal temperature at this elevation in the growing season facilitates the upward movement of the timberline.

Many studies have been carried out on the vertical vegetation zonation and spruce-fir forests of China and the Tibetan Plateau over the last 30 years (Liu and Zhong 1980; Wu 1980; Kuan 1982; Li et al. 1985; Liu 1985; Zheng and Yang 1985; Zhang et al. 1988). However, the vegetation surveys mainly focused on typical forests or the vegetation zone, and there are few studies of the timberline. Li and Chou (1984) estimated the distribution of spruce-fir forests in China and modelled the three-dimensional distribution of spruce forests. They concluded that a decrease of one degree latitude correlated to a 103 m increase in the elevation of the timberline. Zheng (1995) examined the correlation between coniferous forest vegetation and climatic factors such as temperature and moisture in the southeastern Tibetan Plateau (Zheng 1995). However, little is known about the spatial distribution of the timberline and its relation to climate across the Tibetan Plateau. There is still some debate on the physiological mechanism of treeline formation, notwithstanding research over the last ten years (Körner 2012a).

The main objective of this review is to describe the floristic pattern of timberline species and their spatial distribution in the Himalayan region, especially the Tibetan Plateau, identify the relationship between the timberline and climatic conditions, and review the mechanisms of timberline formation and the response of tree growth and regeneration to climate change.

Floristic Features of Timberline Species in the Himalayan Region

Floristic patterns of tree species

Spruce-fir forests are mainly distributed across the southeastern part of the Tibetan Plateau, between 85–105°E and 26–38°N. The coniferous species in the sub-alpine belt of the southeastern part of the Tibetan Plateau (i.e., Hengduan mountain range) and the southern slopes of the Himalayan range are highly diverse, with 16 species of *Abies*, 16 species of *Picea*, six species of *Larix*, and 11 species of *Juniperus* (*Sabina*) reported on the Tibetan Plateau. However, only 14 species of *Abies*, five of *Picea*, five of *Juniperus*, and four of *Larix* can reach the climatic forest limit and become timberline species. In addition, sclerophyllous *Quercus* and deciduous broad-leaved trees such as *Betula* can also form forest limit vegetation in the western Himalayas, southeastern Tibetan Plateau, and northern Hengduan Mountains. For example, *Betula utilis* is a timberline species in Uttarakhand, India. The Hengduan Mountains are a species differentiation centre for fir trees (*Abies* spp.), with nine species reported, of which seven (*Abies ferreana*, *A. squamata*, *A. nukiangensis*, *A. delavayi*, *A. georgei*, *A. georgei* var. *smithii*, and *A. forrestii*) constitute timberline vegetation. The area around Kangding County, in western Sichuan Province, is a species differentiation centre for the genus *Picea* (spruce) with more than ten species dominant in the sub-alpine belt. Of these, however, only *Picea balfouriana*, *P. purpurea*, *P. likiangensis*, and *P. crassifolia* can reach the forest limit and become timberline species, with *P. balfouriana* the most common and widely distributed along the timberline in the eastern Tibetan Plateau. *Larix* is a forest limit genus on sunny slopes. In western Sichuan, *L. potaninii* is a widespread timberline species and can extend to the Bailongjiang (Bailong river) watershed in southern Gansu Province. *L. potanini* var. *macrocarpa* is widely distributed in southwestern Sichuan, northwestern Yunnan, and northeastern Tibet Autonomous Region (TAR). Fir trees can form the forest limit at an elevation of 3,800–4,300 masl, but *Sabina* (now *Juniperus*), which includes a few typical alpine species, can constitute the highest forest limit in the world. *S. convallium*, *S. Sultuarua*, and *S. tibetica* are representative timberline species on sunny slopes in the Tibetan Plateau (e.g., in western Sichuan and eastern TAR). *S. przewalskii* and *S. komarovii* are dominant in the timberline on sunny slopes in eastern Qinghai, southern Gansu, and northwestern Sichuan.

Juniperus indica, *J. recurva*, *Abies spectabilis*, *A. densa*, *A. Pindrow*, and *Betula utilis* are all found in timberlines on the southern slopes of the Himalayas (Schweinfurth 1957; Stainton 1972; Rawal and Pangtey 1994). *Quercus aquifolioides* and *Q. semecarpifolia* can not only extend into the timberline on sunny slopes in the western Himalayas, they can also be part of the timberline in the Hengduan Mountains, for example in western Sichuan and northwestern Yunnan. Timberline species in northwestern Yunnan also include *Abies georgei*, *A. delavayi*,

Picea likiangensis, and *P. likiangensis* var. *balfouriana*. The timberline elevation ranges from 3,600 masl in the southeastern Himalayas to 4,200 masl in the eastern TAR.

Distribution patterns of the timberline on the Tibetan Plateau

The height of the mountains in the southeastern part of the Tibetan Plateau increases gradually from east to west and the timberline rises from around 3,600 masl to 4,300 masl. At the eastern edge of the southern part of the Tibetan Plateau, towards the western border of the Sichuan basin from Tianquan and Baoxing Counties to Jiuzhaigou County, *Abies faxoniana*, *A. Fabri*, and *Picea purpurea* grow at elevations from 3,500 masl up to the timberline at around 3,800 masl. The elevation of the timberline increases gradually with decreasing latitude in the eastern part of the Tibetan Plateau, to its highest position at latitude 30°N (Li and Chou 1984), the natural boundary of spruce-fir species differentiation and distribution. Here in the northern section of the Hengduan Mountains, in the southeastern corner of TAR, *Picea balfouriana*, *Abies squamata*, and *A. georgei* var. *smithii* form the highest timberline in the world at altitudes of 4,300 masl or more. *Abies squamata* and *Picea balfouriana* extend north of latitude 30°N up to the southern tip of Qinghai Province. Further to the north, up to 35°N, these timberline species are replaced by *Picea crassifolia*, *P. purpurea*, *Sabina tibetica*, and *S. przewalskii* and the timberline descends to below 3,500 masl. South of latitude 30°N, towards the northwestern part of Yunnan Province, the timberline decreases to 3,800 masl and lower, and contains *Abies georgei*, *A. georgei* var. *smithii*, and *Picea likiangensis*.

The height of the timberline is also closely correlated with longitude as a result of the 'Massenerhebungseffekt' (Schweinfurth 1957). Spruce-fir forests extend across a wide range on the Tibetan Plateau from the more westerly part at 85°E to the most easterly section at 105°E. From 85°E to 96°E, the timberlines on the south slopes of the Himalayas lie at around 4,000 masl and are formed by *Abies densa*, *A. spectabilis*, *A. delavayi*, *A. delavayi* var. *motuoensis*, and *A. chayvensis*. Further to the east, from 95°E to 105°E, the timberline elevation decreases gradually with increasing longitude, to as low as 3,400 to 3,600 masl in the eastern Qilian Mountains in the northeast part of the Tibetan Plateau. Timberline species such as *Picea balfouriana* and *Abies squamata* are replaced by *A. faxoniana*, *P. purpurea*, *A. forrestii*, and others from west to east.

Climatic Factors Affecting the Position of the Timberline

Temperature is a well-recognized predictor of timberline position and distribution at the global scale. However, there are few weather stations established near the timberline in the Himalayan region and temperatures had to be extrapolated from lower or nearby weather stations to estimate climatic conditions at timberlines. The results are subject to some uncertainty compounded by the lack of information on the topographical and vegetation status at these sites. It is generally accepted that the 10°C warmest month isotherm represents the geographical location of the timberline across the world. Wang et al. (2004) extrapolated

this thermal condition to the timberline in China. He found that the limit of the eastern Himalayan timberline is set by an air temperature of 8.2°C during the growing season and annual biotemperature (ABT) of 3.5°C (Wang et al. 2004). This is similar to the extrapolation on the Tibetan Plateau (Shi 1999).

Schickhoff (2005) extrapolated the temperature at the timberline in the Himalayan region and identified marked differences in the mean temperatures. As a result of the raised temperatures resulting from the mass elevation effect, the mean temperature of 10 to 13°C in the warmest month in the northwestern Himalayas and Karakoram was higher than in the more humid and monsoon-influenced eastern regions and markedly higher than the range of around 10°C usually observed in northern hemisphere continental mountains (Schickhoff 2005). This is the effect of extensive mountain massifs acting as elevated heating surfaces which leads to positive thermal anomalies compared with the marginal ranges or free air. The upper timberline in the Tibetan Plateau and eastern Himalayas develops at much lower mean temperatures and the altitude of the timberline is also lower.

The air temperature at the timberline shows considerable variation in different regions. Holtmeier and Broll (2007) argue that mean temperatures differ so much that air temperature is not a suitable indicator of thermal conditions and isotherms of air temperature should not be considered as the causal factor for the upper timberline.

On-site observations indicate that the average growing season mean ground temperature at a depth of 10 cm of soil along the treeline is around 6.5°C, with very little site-to-site variation. This seasonal mean is a better predictor of timberline position than the warmest month temperatures or a suite of thermal sums tested (Körner and Paulsen 2004). The soil temperature was measured at 10 cm depth at treelines in ten monitoring sites in the eastern Himalayas using the automatic sensor TIDBIT; the results indicated an average growing season temperature of 7.1°C, consistent with previous observations in the eastern Tibetan Plateau (Shi et al. 2008) and quite similar to the worldwide average of 6.7°C (Körner and Paulsen 2004). The slightly higher value than the world average might be due to the elevation mass effect, which increases the elevation of the timberline and its thermal threshold. The growing season soil temperature is proving to be the most stable thermal parameter for the timberline, compared to measurements such as air temperature, accumulated temperature, and length of growing season, and is now a common thermal threshold for forest growth at high elevations at the global scale.

Although soil temperature plays a profound role in seedling establishment, and tree growth and survival, there are very few measurements of soil temperature at timberlines in the Himalayan region. More studies need to be conducted to investigate the relationship between timberline tree growth and soil temperature.

Water, Nutrient, and Carbon Supply in the Timberline Ecotone

Körner (2012c) argues that there are no reasons to assume that water is a limiting factor at the treeline because the water supply is extremely variable across the globe (Körner 2012a), but treelines still usually reach the highest elevation. For example, *Polylepis* grows to 5,200 masl in Bolivia and junipers to 4,800 m in southern TAR (Hoch and Körner 2005; Miehe et al. 2007). Thus, it seems that water is not the limiting factor controlling the height of treelines.

It is often assumed that nutrients become limited at high-altitude treelines because nutrient availability is constrained by low temperature. But there are two facts that argue against this assumption. First, the nutrient contents, especially nitrogen, in organisms at treelines are at the same level as those in closed forest at lower altitudes (Birmann and Korner 2009). Second, treeline positions are no higher in nutrient-accumulative areas and do not reach higher elevations in areas rich in nutrients (Körner 2012c). Furthermore, fertilization manipulation did not lead to raising of treelines. Growth is more limited by temperature than by nutrient uptake (Tranquillini 1979), and low temperature is the key limiting factor for treeline formation.

The debate over the mechanistic factors that limit the altitudinal treeline has continued for more than a century (Tranquillini 1979). Environmental effects on both photosynthetic carbon gain and respiratory-driven growth processes have been used to evaluate limitations at the alpine treeline. Most of the earlier studies focused on correlations between treeline altitudes worldwide and associated mean minimum annual temperatures. According to these more traditional ideas, trees are unable to assimilate enough carbon for survival above certain altitudes. However, Körner proposed that low soil temperatures coupled with physiological drought stress inhibit the carbon processing abilities at the treeline, not the ability to gain carbon via photosynthesis (Körner 1998a; Körner 2003). Körner's hypothesis suggests that the limit at high elevations is not due to photosynthetic carbon gain as such, but rather to the processing of fixed carbon into growth via respiratory physiology. This is also indicated by more recent studies which suggest that an increase in non-structural carbon pools without significant growth is caused by carbon source availability exceeding demand (Körner 2003). Shi et al. (2008) indicated that the highest treelines in the eastern Himalayas actually have significantly higher non-structural carbohydrate (NSC) at treelines than in the lower closed forests. Thus it seems that NSC is not a limiting factor in tree growth at the treeline. This is further supported by the observation of a linear increase in NSC in woody plants with increase of altitude in Wolong Nature Reserve, Sichuan (Shi et al. 2006). Although a carbon limitation phenomenon has been observed in the Gongga Mountains in the eastern Tibetan Plateau, this temporary depletion of carbon occurred during bud burst in early spring (Li et al. 2008).

Impact of Global Warming on Treelines

The Himalayas experienced warming of 1.5°C between 1982 and 2006, an average rate of 0.06°C yr⁻¹, with the greatest average increase in winter (0.07°C yr⁻¹), and lowest in summer (0.03°C yr⁻¹) (Shrestha et al. 2012). Treelines are sensitive to climate warming and may

respond by advancing beyond their current position or enhancing growth. It is usually assumed that the timberline ecotone will undergo significant change in terms of structure and position and it is expected to shift in response to global warming. There is abundant evidence of tree growth enhancement and/or treeline shift in the Himalayas over the past decades.

Treeline shift response to climate change can be monitored using images from remote sensing satellites, which helps to overcome the difficulties posed to direct observation by the poorly accessible Himalayan terrain (Rawat 2012). Panigrahy et al. (2010) mapped the treeline using nearly 20 years of satellite images. Imagery of Nanda Devi Biosphere Reserve in the central Indian Himalayas from 2004 revealed a dramatic increase in vegetation cover and drastic reduction of snow cover in areas that had been glaciated in 1986. Alpine plant species have been found to shift to higher elevations, although the shifting rate varies with species and their sensitivity to climate. Various studies indicate that the ecosystems in the Himalayas have experienced significant changes since 1960 (Panigrahy et al. 2010; Sushma et al. 2010). However, treeline dynamics appear to be more related to changes in snow precipitation than to global warming (Negi 2012). Remote sensing investigations by Singh et al. (2012) indicated that the treeline shifted 388 ± 80 m upwards in the Uttarakhand Himalayas between 1970 and 2006. A study using repeat photography and supplementary measurements in the eastern Himalayas (northwest Yunnan) also indicated glacier recession and an advance in the treeline (Baker and Moseley 2007).

There are very few actual field observations of treeline dynamics in the Himalayas due to the remoteness and poor accessibility, and high cost of expeditions. However, one study indicated that treelines in the Sygera Mountains in eastern TAR had shifted in the past 400 years, whereas others carried out in the eastern Himalayas showed no indications of treeline shift. Most treeline vegetation change is growth and regeneration enhancement rather than actual shift. There was an abrupt recruitment of Smith fir trees in the eastern TAR in the 1970s, but no significant upward movement of the treeline position (Liang et al. 2011). Recruitment of juveniles and seedlings was mostly close to juvenile firs and *Rhododendron* mats and over moss-lichen and organic matter substrates, indicating the importance of availability of microsites for successful Smith fir recruitment (Wang et al. 2012).

The increased warming has significantly extended the length of the growing season. However, the longer growing season has had little effect on tree ring growth. For example, modelling using results from a weather station record at the timberline in the Sygera Mountains of eastern TAR (4,390 m) indicates that the growing season has extended significantly – by 21.2 days – mostly as a result of a delayed end (by 14.6 days) rather than earlier onset (by 6.6 days). Nevertheless, there was no increase in radial growth of Smith firs at the timberline (Liu et al. 2013).

In summary, the timberlines of the Himalayan region are among the highest in the world due to the marked mass elevation effect of the Tibetan Plateau. This area also has the most diverse timberline species and geomorphology, and the tree species diversity results in

abundant timberline forms and growth forms. The air temperature isotherms are not good predictors of timberline elevation, in contrast, the growing season mean soil temperature at a soil depth of 10 cm has a close to constant value at the timberline of nearly 7°C around the world. Low temperature appears to be the most important factor controlling formation of the timberline. The trees in the timberline ecotone are not physiologically inferior to other trees; the low temperature appears to limit the carbon sink ability rather than the carbon source at the timberline. In other words, the timberline is the threshold for limitation of growth caused by low temperature. Water and nutrients do not appear to be key factors for determining the timberline position; at most they are modulating factors in the local environment. With increased global warming, the timberline would be expected to advance to higher altitudes, but as yet the changes observed have been limited to increasing tree recruitment and tree growth rather than timberline advance.

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Forest-Rangeland Ecotones in the Highlands of Balochistan, Pakistan

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The juniper and chilgoza forests in the highlands of Balochistan are important parts of the ecosystems providing numerous ecosystem services and livelihoods to communities. These forests grow at high mountain areas under arid and semi-arid climatic conditions, and harbour unique assemblages of flora and fauna. At different altitudes, these ecosystems exhibit clear ecotones of forest and rangelands. Overgrazing, removal of vegetation for fuelwood, overexploitation of non-timber forest products, and lack of policy and regulations are affecting both the ecosystems. The interface between the forest and rangeland ecosystems is little understood. Further studies are required on the various ecotones in Balochistan.

Keywords: Balochistan; chilgoza pine; forest-rangeland ecotone; juniper

Introduction

Pakistan extends over an area of 80 million hectares of which rangelands occupy around half of the area located mostly in arid and semi-arid regions and forming the major land use type. Around 80% of the land area of Balochistan is rangeland (Ahmad and Islam 2011). In Balochistan, animal production is heavily dependent on grazing resources; the rangelands support 22 million heads of small ruminants providing more than 80% of the feed requirements, and are a significant socio-ecological factor in pastoral livelihoods. The rangelands also provide ecosystem services like carbon sequestration, fuelwood for household energy, nutrient cycling, biodiversity and wildlife habitat, and ecotourism. Unfortunately, in Balochistan these vital natural resources have attracted only limited attention from researchers and very little policy support (Ahmad et al. 2012), and millions of pastoralists remain highly vulnerable to poverty.

Rangeland degradation is a major issue in Balochistan causing environmental problems, ecosystem instability, threats to floral and faunal biodiversity, adaptive changes in traditional pastoral livelihood patterns, including migration routes, and increased vulnerability of poor pastoral communities (Ahmad and Islam 2011; Ahmad et al. 2012). Climate change is now accepted as a reality, with increasing concentrations of greenhouse gases in the atmosphere being a major factor. The predicted scenarios could lead to changes that are significant for

pastoralists, including changes in the length and timing of the plant growing season and changes in the amount and seasonal pattern of precipitation. Rangeland-based adaptation strategies, such as seasonal grassland reserves, revival of traditional grazing systems, and development of forage reserves, are likely to benefit vegetation and soil carbon sequestration and have the potential to play a role in both adaptation to and mitigation of climate change.

Rangelands, particularly in mountain areas, are a major source of fuelwood for household energy. Traditional household energy needs in remote mountain areas are generally met from rangelands as forests are scanty. Small to large shrubs are collected by the pastoral communities for cooking and heating. In the mountains of Balochistan, *Artemisia* is the major species collected for fuel. There are no statistical data describing the actual fuelwood requirements from rangelands, but it is clear that the pressure on rangelands for fuelwood has increased tremendously over the past 20 to 30 years. In Balochistan, contributing factors include the political unrest and recent outmigration of pastoral communities. The people living in the mountain rangelands are particularly vulnerable to climate change and have adopted strategic initiatives such as outmigration and changes in traditional animal production systems. Nomadic and transhumant livestock production systems in Balochistan have evolved over centuries; they involve transboundary seasonal movements of herds and flocks between the downstream plains and the mountain valleys and uplands, from Sindh province to Afghanistan (FAO 1983). There has been a decrease in the relative proportion of the mobile livestock population over the last four decades as a result of changing land use and increasing population, but they still constitute more than half of small ruminants and contribute substantially to the household economy of mountain people through sale of livestock, hides, and wool.

There are different types of pastoral systems operating in Balochistan, but availability of livestock feed round the year is a major issue in all of the systems and mobility is a crucial factor. Pastoralists are compelled to use opportunistic grazing early in the season when grass is not at the optimal growth stage, which has a detrimental impact on both productivity and ecology (Ahmad et al. 2012). Mobile herds and flocks are rarely provided with full immunization despite their higher potential to spread diseases through seasonal migration. Similarly, livestock health, production services, marketing systems, and capacity building are mostly out of the reach of landless mobile herders. Economic and food security opportunities can be supported by strengthening pastoral livelihoods through promotion of, and appropriate policy support for, appropriate forage and energy technologies and capacity building of pastoralists for resource-based value chain development for adapting to and mitigating climate change. This paper deals with current state of the forest–rangeland interface, especially in semi-arid tracts of Balochistan, major management issues, and the way forward.

Forest-Rangeland Ecotones

Ecotones

Ecotones or the forest-rangeland interfaces represent important biological processes. Many fundamental processes and functions occur at biological boundaries at different scales. A treeline is the boundary of the habitat in which trees are capable of growing. Beyond the treeline, they are unable to grow because of inappropriate environmental conditions. An ecotone is a transition area between two adjacent ecological communities or ecosystems. The timberline ecotone below the treeline represents the transition zone between continuous forest and rangeland (Solaimani and Shokriani 2011). Ecotones can influence the fluctuation of materials and energy in the landscape and can be early indicators of ecological reaction to environmental change (Di Castri et al. 1988). The determination and monitoring of ecotones plays an important role in understanding biodiversity distribution and conservation. Ecotones can be classified as ‘environmental’ or ‘anthropogenic’, resulting from natural or human-induced environmental transition over space (Walker et al. 2004). The transition with altitude from dense forest to the rangeland represents an ecotone gradient relating to increasingly harsh environmental conditions (Smith et al. 2003). Local scale environmental factors such as topographic complexity, geology, disturbance patterns, and biotic interactions also influence its relevance (Wu et al. 2007).

The forests of Balochistan

The juniper (*Juniperus excelsa*) and chilgoza pine (*Pinus gerardiana*) forests in the highlands of Balochistan are important ecosystems for the provisioning of ecosystem services and livelihoods to communities, but they are highly threatened. So far, no attempt has been made to analyse the interfaces and ecotones in these important ecosystems. The main objective of the present study was to define the main forest-rangeland ecotones in Balochistan, in the expectation that they will be studied in more detail for future conservation.

The study was carried out within timberline ecotones in the Suleman ranges near Zhob (31°37'10.13" N, 69° 52' 26.43"E) and in the Ziarat area (30°23'06.79"N, 67°43'40.90"E). The region has a Mediterranean climate, characterized by cold winters and hot dry summers. Annual rainfall varies between 250 and 450 mm with heavy spells of snowfall during winter.

Juniper woodland is the most common forest type in the high mountainous areas. The juniper and associated diversity of species constitute a unique ecosystem. These forests are considered to be among the world's oldest; the trees are extremely slow growing and long lived (>3,000 years) giving rise to their local name of ‘living forest fossils’. Balochistan has approximately 141,000 ha of *Juniperus excelsa* forests, with approximately 86,000 ha in Ziarat and Loralai districts. *J. excelsa* typically grows as pure stands of open and multi-storied forest at an elevation of 2,000 to 3,000 masl (Sheikh 1985). These forests are an important

source of fuelwood for local residents and offer protection from soil erosion in the watersheds. They also serve as grazing lands, a popular place for tourists, and a source of various non-timber forest products such as bark for roofing, essential oils, and 'berries', which are used for flavouring and as a remedy for kidney and other diseases (Sarangzai et al. 2010). *Juniper excelsa* is the main tree species, alongwith *Fraxinus xanthoxyloides* and *Pistacia khinjuk*. The main shrubs are species of *Prunus*, *Cotoneaster*, *Crataegus*, *Ephedra*, *Caragana*, *Berberis*, and *Rosa*. The ground cover is mainly formed by *Stipa himalacia*, *Dichanthium annulatum*, *Artemisia maritima*, *Chrysopogon aucheri*, and *Cymbopogon* spp. The forests contain a high plant biodiversity (Figure 17).

Approximately 26,000 ha of the total area falls under chilghoza pine in Balochistan. These forests consist of open to dense stands of mature area that fall between the altitudes of around 2,100 to 3,500 masl and higher. Over-mature trees have dead tops and dead branches. The seed of *Pinus gerardiana* (pine nut) is used as a dry fruit and has high commercial value in both national and international markets. The seed harvest is the major source of income for the local people in the Suleiman mountains (Saeed and Thanos 2006). The broad-leaved associates are *Prunus amygdalus*, *Fraxinus xanthoxyloides*, and *Pistacia khinjuk*.

Wild olive forest and mixed scrub forest (*Acacia* and *Pistachio*) are found below the high-altitude chilghoza and juniper forests at 1,750 to 2,400 masl in the Shingher, Kaisaghar, and Speraghat hills in Zhob and Sherani districts, and the Torghar hills in Killa Saifullah District. In the Zhob area, the herbaceous component is dominated by *Cymbopogon jwarancusa*, *Chrysopogon aucheri*, *Tetrapogon villosa*, *Pennisetum orientale*, *Panicum antidotale*, *Stipa*, *Saccharum* species, and *Poa bulbosa*. Common shrubs in the understory include *Alhagi camelorum*, and *Caragana ambigua*.

Figure 17: Key species forming the forest–rangeland ecotone in Balochistan



Changing Trends of Ecotones

The major factors that have led to ecotone shifts in Balochistan are overgrazing by domestic livestock, vegetation removal, conversion of rangeland into agricultural land, and drought (Islam et al. 2004). Woody species and unpalatable grasses have encroached the central part of the upper and lower ecotones, and heavy grazing has inhibited establishment, survival, and growth of seedlings of trees and other palatable species.

In the upper ecotones, local communities have converted rangeland into agricultural land by constructing stone walls, structures, and bunds to divert rainwater, collecting the silt and clay in the water, and using this to convert the bund into a piece of fertile land suitable for planting apple, apricot, and cherry. This encroachment has been aggravated by the government giving subsidies on electric tube wells by fixing the farmer's share at a 'flat-rate' of PKR 48,000 per year. The number of tube wells has increased at rates of 9% and 6% per annum for electricity and diesel-operated tube wells, respectively, over the last 35 years. The purpose was to encourage farmers to use groundwater for increased agricultural production and to increase consumption of electric power. The subsidy did help to expand irrigated agriculture in Balochistan, but it also promoted poor use of the scarce groundwater resources. Recent droughts combined with an annual lowering of the water table by around 6 m per annum have badly damaged horticulture in Balochistan and have contributed to increasing desertification in the area.

Increasing human and livestock populations in the province have put tremendous pressure upon the rangeland resources for providing fuelwood, water, forage, and recreation. The increase in demand for goods and services, coupled with prolonged and severe drought, has led to rangeland deterioration. Nevertheless, rangelands are still playing a vital role in the economy of the province through the provision of livelihoods to the rural communities. The rangelands provide forage for 33 million heads of livestock (projected population 2012) with an estimated monetary value of PKR 477 billion. Overall, plant species in Balochistan tend to be deficient in total digestible nutrients and in digestible protein and dry matter with respect to animal requirements (FAO 1983; Islam and Adams 2000; Ahmad et al. 2009)

As late as 1950, the vegetation cover in the province was more than 50%. However, the arrival of Afghan refugees in the early 1980s increased pressure on the rangeland health and productivity. Forest and rangeland vegetation near refugee camps was completely wiped out. According to UNHCR (2007), trees and bushes were completely uprooted on close to 175,000 ha of forest and rangeland. At present, there is still a downward trend in vegetation surface cover.

The major indicators of rangeland degradation are shifts in species composition, loss of biodiversity, reduction in biomass production, less plant cover, low ruminant productivity, and soil erosion (Ahmad et al. 2012). Perennial grasses and palatable shrub species are confined to some protected forest areas. The degradation of rangelands in Balochistan is site specific and depends on the existing vegetation, grazing pressure, grazing accessibility, human

population, availability of water, and tribal conflicts (Ahmad and Islam 2011). Highly palatable perennial grass species such as *Chrysopogon aucheri* are gradually being replaced by low palatable species such as *Cymbopogon jwarancusa* and shrubs like *Artemisia* spp. or *Haloxylon* spp. (Ahmad et al. 2000a). In many rangeland areas, these shrub species have again been replaced by unpalatable shrub species such as *Peganum harmala* and *Othonopsis intermedia*, accompanied by clear evidence of soil erosion. Regeneration of most forest and rangeland plant species depends on the production of viable seeds, patterns of seed dispersal, seed predation, seed bank dynamics, and the presence of suitable microsites and environmental conditions for germination and seedling establishment (Aguiar and Sala 1997; Russell and Schup 1998). At present, many natural plant species have very limited regeneration potential due to either heavy grazing or removal of vegetation for fuelwood, which badly hampers seed production, seed dispersal, and establishment of a soil seed bank (Ahmad et al. 2000a,b,c; Ahmad et al. 2007).

Shifts in the forest-grassland ecotone have been observed in many parts of the world, generally in the form of lowering of the treeline and/or reduction or complete loss of the timberline ecotone, with an abrupt change from forest to grassland. These shifts are attracting increased attention due to the implications for global carbon sequestration and land surface atmosphere interactions (Mast et al. 1997; Mather 2000). Transition zones or ecotones between biomes are predicted to be particularly sensitive areas to directional changes in climate. However, for many ecotones, there is little understanding of the key processes that allow dominant species from adjacent biomes to coexist in transition zones, and how differences in these processes affect species responses to changes in environmental conditions (Peters 2002).

Conclusion

In the Balochistan highland forest-rangeland ecotones, it is expected that less palatable shrub species will increase with increasing grazing intensity in the lower rangeland ecotones, and that forests at higher elevations will undergo a decline in diversity, mainly due to tree cutting for fuelwood collection, poorly managed collection of pine nuts and juniper berries, and limited establishment, survival, and growth of tree seedlings. In Balochistan, the ecotones between various ecosystems are not well demarcated or described. Detailed ecological studies are needed to understand the role of the different ecotones, the interfaces, and the shift over time, in order to develop appropriate management and conservation plans.

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Impacts of Agropastoralism on the Timberline Ecotone in the Hengduan Ranges of the Eastern Tibetan Plateau

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The spatial patterns of treelines and timberlines in the eastern Tibetan Plateau show marked regional and slope-wise variation. Within the region, the treeline elevation increases from the southern and peripheral areas to the northwest. Under natural conditions, timberlines and treelines occur in pairs with an altitudinal difference ranging between 15 and 300 m and a clear timberline ecotone in between. However, in places where human activities are frequent, the forests often end abruptly without a treeline or timberline ecotone. In such areas, the timberlines are usually higher on the shady (northern or northeastern) slopes than on the sunny (southern or southwestern) slopes. The difference ranges from 20-30 m in some places to 100-300 m in other places.

Major timberline and treeline species in the region include *Abies* spp., *Picea* spp., *Larix* spp., *Sabina* spp., and *Quercus* spp., with clear differences across the region and among slope aspects. *Quercus* spp. and *Sabina* spp. are usually found on sunny slopes or mountain ridges; *Abies* spp. are the main species in the peripheral parts of the Plateau, where climates are more humid, regardless of slope; and *Picea* spp. are the main species on both sunny and shady slopes further into the interior of the Plateau. *Larix* spp. usually occurs are often seen on sunny slopes or mountain ridges above the timberline.

Migratory pastoralism is one of the major ways in which local societies interact with the timberline ecosystem in the region. Every year, herders and their livestock spend about 60-120 days in the forests and 60-100 days on the high pastures during the migration cycle. Grazing affects the alpine timberline ecotone both directly through the grazing itself and indirectly through grazing-related human activities. Animal browsing, selective foraging, and trampling affect the natural regeneration process, alter the species composition and structure of the forest ecosystem, and affect soil and nutrient recycling processes. Use of fires to open up, maintain, and improve pastures, and herders harvesting timber for construction or fuelwood, can lead to lowering of treelines and timberlines and narrowing or even disappearance of the timberline ecotone, while grazing on fire sites strongly inhibits regeneration in the treeline area. As a consequence, contrary to expectation, many of the timberlines on south-facing slopes that are grazed are lower than on the corresponding cooler north-facing slopes. However, if not disturbed by human activities, timberlines and treelines on the southern slopes are at the same or higher altitude than

those on the northern slopes. In recent decades, the region has witnessed great changes in the human disturbance regimes due to China's rapid socioeconomic development. Such changes will have profound ecological implications on the ecosystem of the timberline/treeline ecotone. How the current changes will affect local social-ecological resilience merits serious study.

Keywords: forest ecotone; grazing; pastoralism; Tibetan Plateau; timberline

Introduction

Human society and the ecosystem in which it exists constitute a complex adaptive social ecological system (SES) composed of cultural, political, social, economic, and ecological domains or subsystems linked across temporal and spatial scales. The structure, functions, and dynamics of the SES result from cross-domain interactions at different scales (Holling 1986; Holling 2001; Gunderson and Holling 2002). Changes in sociocultural components such as policies, values, and social institutions can have significant impacts on the ecosystem and the goods and services it provides, which in turn can affect the economic component of the system and people's wellbeing. Similarly, economic components such as the emergence of new economic opportunities, introduction of market systems, or linking to new markets can have a marked impact on the local ecosystem which in turn has an impact on local society (e.g., redistribution of wealth or inequity).

Treelines represent a unique landscape at a high-altitude across the globe. Körner (1998) has provided the most comprehensive description and analysis of the spatial pattern of global treelines up to now, including various hypotheses related to treeline formation and factors such as environmental stress, disturbance, growth limits, and carbon balance (Körner 1998).

The treeline ecotone (Körner 1999; Körner and Paulsen 2004) (also called, as in this volume the timberline ecotone) is the interface between sub-alpine forests and the alpine zone. It is both an area where different ecosystems interact and a venue for many human activities, and represents a special SES with interactions between social subsystems and biological subsystems. The timberline ecotones on the Tibetan Plateau are usually major summer pastures for pastoral communities, habitats for important herbal plants such as caterpillar fungus (*Cordyceps* spp.), and/or sites for tourism. In particular, agropastoral transhumance is an age-old and widespread indigenous livelihood system in the eastern part of the Tibetan Plateau. The SES we see today is the result of millennia of interactions and co-evolution of human activities and local ecosystems. In recent decades, profound socioeconomic changes have taken place in the mountains of the eastern Tibetan Plateau as a result of China's modernization drive. These socioeconomic changes are bound to have ecological consequences, which will in turn further shape the course of socioeconomic development. Understanding this process will have important implications for sustainable development and building the resilience of the mountain communities of the region.

This paper discusses the interactions between the agropastoral activities and the treeline ecotone ecosystems in the Hengduan Ranges region of the eastern Tibetan Plateau, based on a general literature review of grazing and forest ecosystems and the results of field investigations. We hope that this paper will stimulate the interest of scholars and policy-makers to further understanding of this issue and improve policies to enhance the social-ecological resilience of the mountain regions.

Grazing and Forest Landscapes: A Brief Review

Grazing impacts on forests are complex, multi-faceted, and at multiple scales, and have been widely studied (Putman 1996; Jorritsma et al. 1999; Berlin et al. 2000; Piussi and Farrell 2000; Weisberg and Bugmann 2003).

Grazing affects floral composition and creates habitat heterogeneity, which in turn affects the faunal biodiversity of the forest ecosystem (Milchunas and Lauenroth 1993; Dennis et al. 1998; Krzic et al. 2003). Studies suggest that large scale low-intensity grazing was a key factor in maintaining healthy populations of many endangered and rare species and that cessation of grazing activities has led to a drastic decline in biodiversity (Sickel et al. 2003). Many cases have also been reported in which grazing led to loss of, or no significant change in, biodiversity (Brockway and Lewis 2003). The nature and degree of impact depends on the type of animal, grazing intensity, temporal and spatial distribution of grazing pressure, and stability of the ecosystem itself.

From the forest management perspective, it is believed that grazing severely affects or damages forest regeneration and development (Weisberg and Bugmann 2003). Animal browsing can cause damage to many important tree species and change the species composition, structure, and function of forests and the availability of soil nutrients. Again, the nature and extent of grazing impact on forest regeneration and development depends on the types of animal involved, browsing intensity, and forest species composition (Jorritsma et al. 1999).

Grazing can alter the spatial pattern of vegetation (Adler et al. 2001). Before human directed grazing, grazing by wildlife had a far-reaching impact on the evolution and development of the forest ecosystem. The 'large herbivore hypothesis' (Bradshaw et al. 1999; Vera 2000; Mitchell 2005) suggests that natural forests should be a mosaic matrix of grassland, shrubs, and tree groves, with large herbivores playing a key role in tree regeneration. It is thought that the primeval landscape of Europe was heavily influenced by herbivores, with grazing providing alternative habitats for species dependent on an open environment for survival. The Vera hypothesis suggests that the vegetation of the Eurasian continent in the late Triassic Period co-evolved with various large herbivores to form an open forest structure, similar to what we see today in savannahs. Since most of the animals that once existed in large numbers have now disappeared, the corresponding vegetative structure has also disappeared, and today's forests are dark and dense and not favourable for the previously very abundant forest insects

and herbaceous plants. Austrheim et al. (1999) proposed that human activities, especially the grazing which started in prehistoric times, are major factors controlling the community diversity, species composition, and dynamics of open landscapes such as grasslands. They consider that to maintain the existence of such communities, it is necessary to maintain the constant presence of human factors in order to prevent the communities from evolving into forests. It is believed that in the eastern Tibetan Plateau, fires and grazing have prevented the progressional vegetative succession and kept the sub-alpine shrub meadows in a state of disclimax (Wu et al. 1998). The grazing impact on forest vegetation succession depends on the type of animal, grazing intensity, and the vegetation involved (Kuiters and Slim 2002).

Grazing also affects the vegetative pattern by changing the chemical and physical properties and hydrological features of forest or grassland soil as well as the quantity of organic matter and nutrient recycling processes in the ecosystem (Piuissi and Farrell 2000; Anderies et al. 2002; Smith et al. 2002; Teague and Dowhower 2003).

Grazing impacts on high-altitude landscapes, including alpine treelines, are common worldwide and can be traced back several millennia. Many grasslands or meadows near or immediately below today's treelines are somewhat related to human activities, with fires being one of the major factors (Körner 1999).

Human activities have played an important role in shaping the treeline positions in Europe and North America (Sveinbjornsson 2000). In the Caucasian mountains, nomadic or semi-nomadic pastoralism has been suggested to be the main factor determining the position of the treelines on the eastern and southern slopes, which are lower than those on the north and west slopes, as well as the distinctive vegetation pattern, which is different on different slopes (Dolukhanov 1978). In the Carpathians of Eastern Europe, timberlines were lowered by 300 to 400 m during the 15th and 16th centuries due to grazing. When grazing activities ceased in the 18th century, significant regeneration occurred at the upper limit of the timberlines, and this regeneration was most vigorous where the timberline had been lowered the most (Plesnik 1978).

It is thought that forests once existed on many northern slopes of the Himalayas but were destroyed by humans and their animals. When the forests at the upper boundary of the timberlines were destroyed, they were replaced by the vegetation that had previously only existed above the timberlines, and this became a secondary landscape dominating the treeline zone (Holzner and Kriechbaum 1998).

Internationally, increasing attention has been paid to how the agricultural intensification process (livestock production in particular) is altering natural landscapes that were previously maintained by human activities (Kampf 2002). A lot of research and practical programmes have been carried out on using wildlife or domestic animals for ecosystem management (Valderrabana and Torrano 2000). In many European countries like Germany large

herbivorous animals have been widely used to achieve forest management objectives such as controlling herbaceous invasion, reducing fire hazards, improving species regeneration, and increasing biodiversity. Recognizing the importance of large herbivores in ecosystems, WWF launched its Large Herbivore Initiative (LHI) in 1999 to coordinate the efforts of European countries to reintroduce large herbivores into the ecosystem to address biodiversity conservation issues at ecosystem level or large spatial scales (Berselman 2002).

The Treeline Pattern in the Hengduan Ranges of the Eastern Tibetan Plateau

Treeline positions and treeline species in the eastern Tibetan Plateau show great variation both across the region and among slopes with different aspects. In general, the treeline elevation increases gradually from the southern part and peripheral areas to the northwest interior of the region, reaching the highest altitudes in the Litang-Chamdo region. According to field measurements by the authors using the definitions given by Körner (1998), in the Hengduan Ranges, treelines are mostly around 4,200–4,300 masl in northwest Yunnan (Meili, Baima and Jiawu snow mountains); while in Songpan of Sichuan in the easternmost part of the region, they are mostly 3,800–3,900 masl. Latitude wise, treelines are around 3,600–3,700 masl in Gongga Mountain area and rise up to around 4,400 in Yajiang and Litang and 4,100–4,200 masl in Rangtang of Sichuan (Table 16).

Table 16: Selected timberline and treeline positions in the eastern Tibetan Plateau (masl)

Area	Lat. (N)	Long.(E)	Aspect	Timberline (masl)	Treeline (masl)	Location
Deqin	28.511	98.703	S	4,280	4,346	Meili (Lujiaoka)
Deqin	28.494	98.730	NE	4,305	4,324	Meili (Gongga)
Deqin	28.420	98.766	NE	4,330	4,380	Meili (Nuseshigong)
Deqin	28.323	99.087	NE	4,280	4,365	Baima (East Pass)
Deqin	28.384	98.991	NE	4,398	4,414	Baima(West Pass)
Deqin	28.513	98.925	SW	4,314	4,314	Renzhi (Gongka)
Deqin	28.660	98.938	W	4,364	4,380	Jiawu (Puchangbengding)
Mangkang	29.269	98.678	NE	4,202	4,350	Hongla
Luding	29.544	101.973	S	3,719	3,740	Gongga Mt. (Hailuogou)
Rangtang	32.380	100.725	S	4,298	4,320	Erlinchang
Kangding	30.068	101.312	SW	4,350	4,380	Gao Er Si (Near Pass)
Yajiang	30.009	100.867	S	4,300	4,300	Jiaziwan
Litang	30.218	100.258	N	4,427	4,450	Haizi Lake
Songpan	33.054	103.691	NE	3,921	3,960	Gonggangling

Under natural conditions, timberlines and treelines occur in pairs, with a clear timberline ecotone between them. However, in places where human activities are frequent, the forests often end abruptly without a treeline or timberline ecotone, and the timberline is immediately followed by alpine pastures. This occurs mainly where pastures are still in use or grazing has only stopped recently (mostly on sunny or semi-sunny slopes) and/or where fires have caused significant lowering of the timberline. Where there is both a treeline and a timberline, they are usually separated by a 50 to 600 m wide ecotone area, and have an altitudinal difference ranging from 15 to 300 masl.

Temperature is usually the dominant natural driver of treeline/timberline formation. As south-facing slopes are usually warmer than north-facing slopes, treelines and timberlines on south-facing slopes should be able to reach higher positions than on their north-facing counterparts. In many parts of the eastern Tibetan Plateau, however, timberlines are higher on the shady (northern and northwestern) slopes than on the sunny (southern and southeastern) slopes; in northwest Yunnan, the difference can be as much as 150 m. This is the opposite of what would be expected in an unmodified area. Where the south-facing slopes have a visible timberline ecotone, the timberlines and treelines are often at the same level or higher than those on the northern slopes. It appears that the disappearance or lowering of the timberline ecotone on the south-facing slopes is mainly the result of natural fires or fires ignited deliberately by local villagers to improve the pasture.

The major tree species in the timberline and treeline in the Hengduan Ranges are *Abies* spp., *Picea* spp., *Larix* spp., *Sabina* spp., and *Quercus* spp., with clear differences across the region and between slope aspects (Table 17). As a general rule, *Quercus* spp. and *Sabina* spp. are only found on sunny slopes or mountain ridges; *Abies* spp. are the main treeline species regardless of slope in the peripheral parts of the Plateau where treeline climates are usually cold and humid; and *Picea* spp. are the main treeline species on both sunny and shady slopes further into the interior of the Plateau in areas such as Hongla (Tibet AR) and Litang (Sichuan). *Larix* spp. are often seen on sunny slopes or mountain ridges above the timberline. It is common to see *Abies* spp. and *Picea* spp. extending from the valley bottom or below the timberline and being replaced at the mountain ridges by *Sabina* spp. and *Larix* spp.

Agropastoralism and Treeline Ecotone Interactions on the Eastern Tibetan Plateau

Interaction of agropastoral activities with the treeline ecotone

Agropastoralism in the eastern Tibetan Plateau is a combination of sedentary farming and mountain transhumance (Yi et al. 2008). Every year, local herders and their domestic animals, mostly yaks, migrate between the settlements at the valley bottoms and the summer pastures in the alpine zone, passing through a dry shrub zone and forest belts, to make full use of the resources in different zones along the altitudinal gradient. Usually, the annual migration starts in May, reaches the alpine zone in middle or late June, and returns to the settlements in late

Table 17: Dominant treeline species in the Hengduan Ranges of eastern Tibetan Plateau

Region	South-facing slopes/mountain ridges	North-facing slopes/valley bottoms
Baima Xueshan (Yunnan)	<i>Abies georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu; <i>L. potaninii</i> Batalin var. <i>macrocarpa</i> Law; <i>S. saltuaria</i> (Rehd. et Wils) Cheng et W.T.Wang; <i>S. pingii</i> (Cheng ex Ferre) Cheng et W.T.Wang; <i>Q. aquifolioides</i> Rehd. et Wils; <i>Q. pannosa</i> Hand.-Nazz.	<i>A. georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu; <i>P. likiangensis</i> (Franch) Pritz; <i>L. potaninii</i> Batalin var. <i>macrocarpa</i> Law
Meili Xueshan (Yunnan)	<i>A. georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu; <i>Q. aquifolioides</i> Rehd. et Wils	<i>A. georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu
Jiawu Xueshan (Yunnan)	<i>A. georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu; <i>P. likiangensis</i> (Franch) Pritz; <i>A. forrestii</i> C.C.Rogers; <i>S. saltuaria</i> (Rehd. et Wils) Cheng et W.T. Wang; <i>S. pingii</i> (Cheng ex Ferre) Cheng et W.T. Wang; <i>Q. aquifolioides</i> Rehd. et Wils; <i>Q. pannosa</i> Hand.-Nazz.	<i>A. georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu; <i>A. forrestii</i> C.C. Rogers; <i>P. likiangensis</i> (Franch) Pritz
Hongla Xueshan (Tibet)	<i>A. georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu; <i>P. likiangensis</i> (Franch) Pritz; <i>L. potaninii</i> Batalin var. <i>macrocarpa</i> Law; <i>S. saltuaria</i> (Rehd. et Wils) Cheng et W.T. Wang; <i>S. pingii</i> (Cheng ex Ferre) Cheng et W.T.Wang; <i>Q. aquifolioides</i> Rehd. et Wils; <i>Q. pannosa</i> Hand.-Nazz	<i>A. georgei</i> Orr; <i>A. georgei</i> Orr var. <i>smithii</i> (Viguie et Gausen) Cheng et L.K. Fu; <i>P. likiangensis</i> (Franch) Pritz; <i>L. potaninii</i> Batalin var. <i>macrocarpa</i> Law
Rangtang (Sichuan)	<i>L. potaninii</i> Batalin var. <i>macrocarpa</i> Law; <i>S. saltuaria</i> (Rehd. et Wils) Cheng et W.T. Wang; <i>Q. aquifolioides</i> Rehd. et Wils; <i>P. likiangensis</i> var <i>balfouriana</i> (Rehd. et Wils.) Cheng ex Chen	<i>L. potaninii</i> Batalin var. <i>macrocarpa</i> Law; <i>P. likiangensis</i> var <i>balfouriana</i> (Rehd. et Wils.) Cheng ex Chen; <i>A. squamata</i> Mast.
Songpan (Sichuan)	<i>S. saltuaria</i> (Rehd. et Wils) Cheng et W.T. Wang; <i>P. likiangensis</i> var <i>balfouriana</i> (Rehd. et Wils.) Cheng ex Chen; <i>A. faxoniana</i> Rehd. et Wils.; <i>S. przewalskii</i> Kom.	<i>P. likiangensis</i> var <i>balfouriana</i> (Rehd. et Wils.) Cheng ex Chen; <i>A. faxoniana</i> Rehd. et Wils.
Yajiang (Sichuan)	<i>S. saltuaria</i> (Rehd. et Wils) Cheng et W.T. Wang; <i>Quercus</i> spp.; <i>P. likiangensis</i> var <i>balfouriana</i> (Rehd. et Wils.) Cheng ex Chen	<i>P. likiangensis</i> var <i>balfouriana</i> (Rehd. et Wils.) Cheng ex Chen; <i>A. squamata</i> Mast.

September, where the animals winter on hay and crop residues. Each year, the animals spend about 60-120 days in the forests and 60-100 days on the high pastures. The pastoral activities interact with the timberline ecotone in a variety of ways:

Animal grazing and trampling

Browsing, selective foraging, and trampling by animals impacts the vegetation pattern and succession process of forest communities. The forest belt is the major venue for grazing in the study area; in northwest Yunnan, animals spend two to three months a year on average in the forests during their annual migration between the summer and winter pastures. Forest forage includes understorey herbs, shrubs, and young twigs and leaves of tree saplings. Grazing can affect regeneration, species composition, and structure of the forests, and alter the conditions and recycling of soil nutrients. When the animals reach the alpine pastures, the forest edges

become the area of choice for setting up summer tents or houses since it is easier to get fuelwood and construction materials and is less windy at night. Thus the treeline zone becomes the major venue for the animals.

Use of fires to open, maintain, or improve pastures

Fire is the cheapest tool for opening pastures and is widely used across the world. In northwest Yunnan, this practice lasted up to the early 1980s. During the collective system period from 1949 to the early 1980s, burning of pastures was conducted in a regular and well-organized way. Subsequently, such use of fire was banned by local governments for fear of forest fires. Even after more than 30 years, the vestiges of past fire use in the region are still highly discernible. Interviews with the communities, and field investigations, confirmed that burning for pastures usually happened close to the timberline on the south-facing slopes, since they are warmer and drier and more suitable for human and animal activities.

Burning for pastures caused a lowering of treelines and timberlines in many places in the region. The newly-opened pastures need to be maintained through regular burning (usually once every 10 years) to remove shrubs, maintain the pasture landscape, and improve fodder quality. Since fire has been excluded for more than 30 years in northwest Yunnan, shrubs now cover 50-80% of the area and are 50-100 cm high in many pastures, which has a serious negative impact on fodder quality. The shrub encroachment has effectively reduced the intensity of grazing activities at the forest edge and protected the tree seedlings at the timberline.

Grazing on burned sites of natural or accidental fires

Natural (e.g., from lightning and landslides) or human-caused (accidental or incendiary) forest fires were common in the sub-alpine belts across the region. Herders usually find that fire sites provide good pasture. Grazing immediately following fires can strongly inhibit regeneration processes.

Herders harvesting construction timber or fuelwood at the timberline zone.

Herders need timber and wood for building summer houses, heating, cooking, preparing animal feed, and processing dairy products. A traditional summer house requires 4-5 m³ of timber to construct and has to be replaced every five to six years, and each house consumes around 10 m³ of fuelwood every year. All this timber and fuelwood is obtained from the timberline-treeline area.

Grazing impacts on treeline forest regeneration

To investigate the impacts of grazing on treeline forest regeneration, we studied 12 timberline ecotone sites across northwest Yunnan. The sites were grouped into plots with normal grazing and plots with low or no grazing. A detailed survey was made of seedling and young tree

occurrence in a 20 x 50 m² plot within each site. The results are shown in Table 18. The impact of grazing activities on regeneration is clear. The ecotone sites with low or no grazing had an average of 604 seedlings/ha (Class I), compared to only 56 seedlings/ha in grazed plots. There was a similar difference for saplings (Class II). The proportion of class I and II seedlings is also higher in relative terms in plots without grazing activities than in plots with grazing activities; seedlings and saplings together accounted for 67% of trees in ungrazed plots but only 30% in plots with normal grazing. Ungrazed plots had 2,358 trees on average and grazed plots only 642. This shows that grazing caused a significant reduction in tree seedlings and strongly affected the natural regeneration process in the ecotone. Using spatial point analysis, Zhang et al. (2008) suggested that grazing reduced the space occupation capacity of the timberline tree communities and tree populations disturbed by grazing activities exhibit a degrading or stable population structure with fewer seedlings and a lower seedling survival rate.

The survey also indicated that shrubs in the treeline ecotone could provide protection for tree seedlings and enhance seedling establishment. Natural treeline ecotones usually have a well-developed shrub layer (*Rhododendron* spp., *Spiraea* spp., *Lonicera* spp.) in terms of both height and cover, which decreases with elevation and distance from the timberline. However, the shrub layer above a non-natural timberline, which is more abrupt, is usually lower in height and less dense due to removal by fire and grazing as well as changed microclimate

Table 18: Density of trees in different size classes in the survey plots

Treatment	Sample plot	Size Class					Total
		I	II	III	IV	V	
Normal grazing	1	58	57	148	92	63	418
	2	224	321	279	245	27	1097
	3	0	14	400	114	21	550
	4	0	93	80	180	120	473
	5	0	187	253	133	100	673
	Mean	56.4	134.4	232.0	152.8	66.2	642.2
Low or no grazing	6	17	100	217	100	125	558
	7	11	31	267	56	39	403
	8	12	250	227	31	35	554
	9	2,917	5,208	1,525	467	217	10,333
	10	544	633	856	222	28	2283
	11	725	550	325	300	283	2183
	12	0	40	80	30	40	190
	Mean	603.7	973.1	499.6	172.3	109.6	2,357.7

I = first-year seedlings (<10 cm high); II = saplings (10<50 cm high); III = young trees (>50 cm high and <7.5 cm DBH); IV = poles (DBH 7.5<17.5 cm); and V = adult trees (DBH >17.5 cm (Camarero et al. 2000).

conditions (strong radiation, extreme temperature, and desiccation). Lacking shrub protection, tree seedlings are easily affected by browsing and trampling of domestic animals, and the adverse climatic conditions are also unfavourable for the establishment of treeline species (especially *Abies* spp.).

Grazing and treeline landscape across the eastern Tibetan Plateau

It is clear that grazing and related human activities have caused a lowering of the timberline-treeline zone and narrowing or disappearance of the timberline ecotone in many localities. As mentioned above, the timberlines and treelines in the eastern Tibetan Plateau are usually higher on the cooler northern or northeastern slopes than on the sunny southern or southwestern slopes. The difference ranges from 20-30 m to 100-300 m. Theoretically, the treelines should be higher on the southern slopes in the northern hemisphere. However, the southern slopes are often preferred for grazing, and people remove vegetation at the timberline to improve the pastures (Wu et al. 1998). For example, in Gongga in the Meili Mountains in northwest Yunnan, the timberlines and treelines on the northeastern slope, where there is no grazing, extend up to 4,305 masl and 4,324 masl, respectively; but on the southwestern slopes with grazing, the timberline is at 4,207 masl and there is no visible timberline ecotone. As frequently seen in the region, timberlines and treelines on southern slopes not disturbed by human activities reach the same or greater heights than those on the northern slopes.

Grazing and burning are interrelated factors that affect the alpine vegetation pattern and often work together. As Kramer et al. (2003) pointed out, fire can push ecosystem consumers and producers to a new equilibrium and grazing can help to maintain the new state. For example, on the eastern Tibetan Plateau, fires can convert *Abies* spp. and *Rhododendron* spp. forest into *Rhododendron* spp. shrubland, which can be further turned into alpine meadows by grazing. Seedlings of *Abies* spp. are very rare under rhododendron shrubs, and it is very difficult for rhododendron shrublands to evolve into forest of *Abies* spp. On sunny slopes around 3,900 masl, *Abies* spp. forests were usually replaced by forest of *Larix* spp. After major disturbances such as fires; if well protected, such *Larix* spp. forest can again evolve into *Abies* spp. forest, but the process can be delayed by grazing and other human disturbances.

Changing Agropastoralism and the Ecological Implications for the Timberline Zone

Agropastoral transhumance with a combination of lowland farming and vertical migratory pastoralism is a traditional economic form widely practised in the studied region which complies with the vertical distribution of climatic and biological resources. Human activities in the eastern Tibetan Plateau, especially combined farming and pastoral activities, can be traced back more than 5,000 years (Aldenderfer et al. 2004) and have played an important role in shaping the vegetation landscape of the region.

Over the past three decades, drastic changes have taken place in agropastoralism in the region, as reflected in the type and number of livestock kept, economic importance, pastoral-agro relations, and seasonal migration patterns (Yi et al. 2007; Yi et al. 2008). The trend is ongoing and is seen in all the mountain areas across the Hindu Kush Himalayas. An observable result is the major shift of overall grazing pressure to lower elevation areas, with a decline in both stocking rate and length of annual utilization of the alpine pastures.

Such changes have profound ecological implications. The timberline-treeline pattern (boundaries, structure, and species composition) driven by human factors will change with changes in the anthropogenic disturbance regime. Reduced grazing intensity and cessation of fire use will result in an increase in the cover and height of shrubs at and above those timberlines which have been lowered by fires and maintained by grazing activities. This increase in shrub layer will create microhabitats for the successful establishment of tree seedlings at the timberline, and reduce animal browsing and trampling on the seedlings by making it more difficult for animals to pass, creating conditions for the upward expansion of the timberline forest communities.

The ecological changes will result in changes in the goods and services the ecosystem can provide, which will further impact the local socioeconomic system. The eastern Tibetan Plateau is one of the world's major biodiversity hotspot areas. The timberline-treeline zone provides habitat for many endemic floral and faunal species, including some economically important species (e.g., *Cordyceps sinensis*), and changes in the habitat may threaten their very existence. Grazing was frequently cited as a major cause of biodiversity loss in the region by policymakers and nature reserve managers. However, indiscriminative exclusion of grazing from ecosystems often results in unexpected consequences on biodiversity.

Further Research

From the point of view of both scientific understanding and development, the following questions merit special attention for further studies:

1. Long-term monitoring of treeline changes is needed at a larger temporal and spatial scale, taking into account both socioeconomic and climate changes.

As drastic socioeconomic changes are taking place across the region, it is of both academic and practical interest to know how local ecosystems, particularly the timberline ecotone, is responding to such changes. Monitoring should include the changes in treeline position, biodiversity, and ecosystem services in the timberline ecotones across the region. As the region is also sensitive to climate change, the monitoring must be able to distinguish the different contributions of socioeconomic and climatic factors to the changes in local ecosystems.

2. Reconstructing historical grazing-vegetation interactions in the Tibetan Plateau.

Palaeoecological approaches should be used to reconstruct former grazing-vegetation interactions on the Tibetan Plateau in order to understand the roles of human activities and

climatic factors in shaping the current vegetative landscape of the Tibetan Plateau, especially at the treeline level.

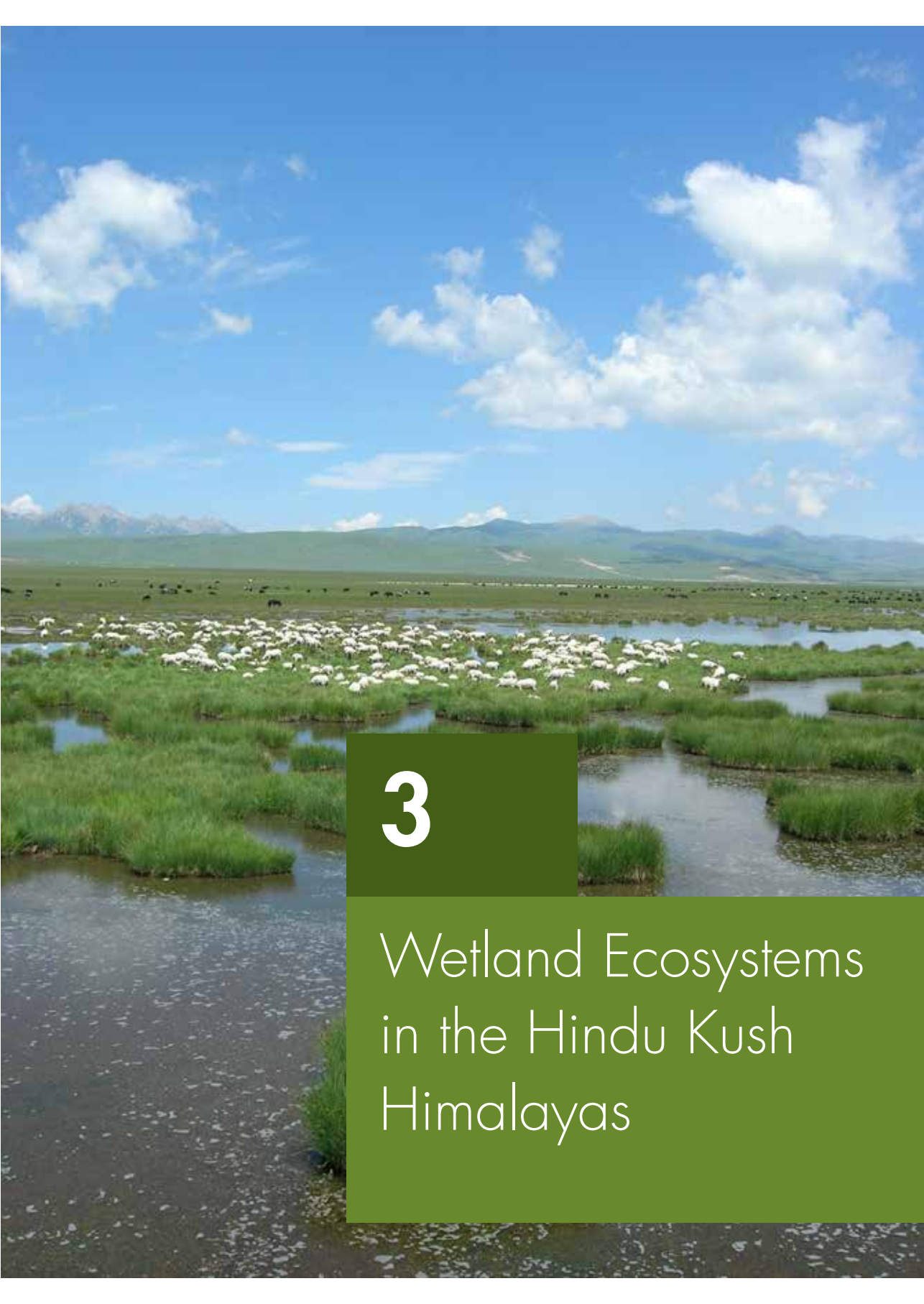
3. How will the current trends affect local social-ecological resilience?

For example, how will the loss of indigenous knowledge and culture, and changes in the local ecosystem, as a result of externally-driven socioeconomic change affect the resilience of local communities?

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3

Wetland Ecosystems in the Hindu Kush Himalayas



Peatlands of Broghil National Park, Pakistan: Human Use and Management Strategy

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A study was carried out in Broghil National Park in Chitral District of Khyber Pakhtunkhwa Province in Pakistan to assess the situation of the peatlands in the park, the trends in peatland use, and the pressure on the peatlands and to recommend a strategy for peatland conservation and management. Field data was collected through semi-structured interviews, focus group discussions, and direct observation through transect walks. Herders, farmers, peat block extractors, and village elites were prioritized as informants. Participatory Rural Appraisal/Participatory Learning and Action (PRA/PLA) tools were also used to assess the situation in the area. Information related to the peatlands was collected on demography, education, socioeconomic factors, livestock holdings, peat utilization, and occupation.

The peatlands in Broghil National Park have been overextracted, resulting in shrinkage of grazing lands and degradation of wildlife habitat. Burning of peatlands causes emission of fumes which ultimately results in respiratory diseases. Exploitation of peat as a fuel for domestic use began about 75 years ago. The pressure on these resources is increasing with the increase in population. Some villages have already used 90% of their peat. If peat consumption continues at the present rate, it is estimated that in 20-30 years time, all the peatlands will have become a wasteland.

Conservation of existing peatlands and restoration and rehabilitation of the degraded peatlands through community participation is important to minimize pressure. Detailed scientific research is vital to obtain complete data on the available natural resources and prepare a strategy for ensuring sustainability.

Keywords: Broghil National Park; Khyber Pakhtunkhwa; peatlands; rehabilitation

Introduction

Peatlands are natural systems with local, regional, and even global functions, but they mean different things to different people. They can be considered as land, wetlands, geological deposits, water bodies, and natural habitat. In many cases, they may be all of these. Human influence on peatlands and their surrounding landscape can affect their form and function. Peatlands are an important interface between water bodies and rangelands.

Peatlands cover only a small portion of the Earth's surface, estimated at between 2 and 3% (Charman 2002; Gorham 1991), but they contain a large accumulation of terrestrial organic matter, fixed from the atmosphere by photosynthesis. Peatlands are an important carbon store, and contain up to one-third (between 250 and 450 Pg¹) of the world's terrestrial carbon pool (Gorham 1991). They represent an important long-term sink for atmospheric carbon dioxide (CO₂) (Gorham 1991; Roulet et al. 2007) and have the potential to moderate concentrations of atmospheric CO₂ (Moore et al. 1998). However, many northern peatlands, including many in the United Kingdom (Holden et al. 2007), have been disturbed by drainage, agricultural improvement, peat cutting, afforestation, burning, and increased atmospheric deposition. Disturbance can significantly alter carbon cycling within peatlands (e.g., Roulet et al. 2007) such that they can become a large and persistent source of carbon, both to the atmosphere as CO₂ and to aquatic ecosystems (Dawson and Smith 2007). The biodiversity value of peatlands demands special consideration in conservation strategies and land use planning.

Use of peatland in Broghil Valley

Historically, the most common use of peatlands in Broghil Valley, besides the use as grazing land, has been as a primary source of fuel. The exploitation of peat as a fuel for domestic use began around 75 years ago when locals came to know through a migrant from China that peat can be used as fuel. Since then peat has been the traditional domestic fuel in Broghil Valley. The peatlands also perform some crucial ecological roles like water storage, offering habitat for migratory birds, as a source of fodder for livestock and wildlife, and as the major carbon sink at that altitude. Peatlands are sensitive to climate change. In the last 40 years, the peatlands ecosystem in Broghil Valley has been under tremendous pressure due to overexploitation to meet household energy needs of the communities that live permanently at high altitude (around 3,700 masl).

The Study

A study was carried out in Broghil National Park with the following objectives:

- to know the existing status of the peatlands,
- to assess trends in peatlands use,
- to assess the usage and pressure on the peatlands, and
- to formulate a long-term strategy for peatland conservation and management in the Park.

The study was carried out in 12 villages in Broghil Valley that depend on peatlands to fulfil their energy and fodder needs. Field data were collected using a combination of semi-structured interviews, focus group discussions, and direct observation through transect walks. The interviews and informal discussions were conducted mostly with herders, farmers, peat block extractors, and village elites. Participatory Rural Appraisal/Participatory Learning and Action tools were also used to assess the situation in the area. Information was collected on demography, education, socioeconomic factors, livestock holdings, peat utilization, and occupation.

Results

Broghil Valley

Broghil Valley is the northern-most valley in Chitral District in Khyber Pakhtunkhwa Province of Pakistan, and lies 250 km to the northeast of Chitral town. Broghil is one of the most important valleys in the region by virtue of its strategic location; it borders the famous Wakhan Strip of Afghanistan, and is connected to Afghanistan in the northwest via the famous Broghil Pass and Darwaza. Broghil National Park (BNP) has an area of 1,348 km² comprising Broghil valley and a small part of Yarkhun Valley, and has been declared a National Park under Section 16 of the Khyber Pakhtunkhwa Wildlife (Protection, Preservation, Conservation and Management) Act, 1975, vide notification No. SO (Tech) Evt/viii-10/2005/kc dated 25-08-2010. It has a number of peatland areas. Located above 3,000 masl, Broghil has relatively harsh climatic conditions. The climate of the area is characterized as dry-temperate. It is hot in summer (July-August), ranging from very hot in the lowlands to warm in the uplands and cool at higher elevations, and has an average annual precipitation of about 1,000 mm.

The forests are very limited and mainly consist of birch, poplar, juniper, willow, and small shrubs. The valley is rich in medicinal plant resources and has more than 80 medicinal plant species. However, the local people lack the capacity to identify, process, and market these valuable plant species.

The alpine pastures and rocky slopes are interspersed with wetlands and provide a congenial habitat for many mammals, some endangered, such as snow leopard (*Uncia uncia*), Himalayan ibex (*Capra ibex sibirica*), brown bear (*Ursus arctos*), blue sheep (*Pseudois nayaur*), wolf (*Canis lupus*), red fox (*Vulpus vulpus*), golden marmot (*Marmota caudata*), and lynx (*Felis lynx*). The small mammals include insectivores, bats, lagomorphs (rabbits and pikas), rodents, and mustelid carnivores. Rock lizards and frogs are found everywhere in the valley. The valley is of global importance as it is the gateway of the Indus flyway to South Asia. WWF-Pakistan and the Pakistan Wetlands Programme identified a total of 83 species of birds in 30 families and 13 orders in the Broghil Valley.

Broghil Valley is characterized by the presence of more than 30 small and large lakes, the peatlands areas, Broghil River, and glaciers. The valley has tremendous potential for ecotourism. There are famous historical passes towards Gilgit-Baltistan and neighbouring Afghanistan, which leads to Tajikistan and China.

The valley has 12 villages and hamlets with 143 households and around 1,489 individuals, 53% male, and an average household size of about 10 (Table 19).

The overall literacy rate is only 10.7% and the number of graduates is negligible, but present school enrolment is encouraging (Table 20).

Table 19: Population in Chitral District and Broghil Valley

Name	No. of HH	Males	Females	Total
Villages in Broghil Valley				
Lashkargaz	16	108	92	200
Garil	10	80	70	150
Chilmarabad	27	160	140	300
Ishkarwaz	18	100	90	190
Medan	3	15	15	30
Arquan	3	12	11	23
Chikar	20	120	100	210
Garumchasma	30	135	125	260
Vadinkhot	3	13	7	20
Kishmanja	3	17	15	32
Jungle	3	7	5	12
Koi	7	32	30	62
Total (estimated)	143	799	700	1,489

Table 20: Education levels in Broghil Valley (enrolled)

Education level	Primary	Middle	Secondary	Inter- mediate	BA/BSc	MA/MSc	Overall literacy rate
No. of individuals	49	65	14	4	2	0	10.7%

There are only two dispensaries available to provide health services to the local communities, both run by Aga Khan Health Services (AKHS). Opium addiction is one of the main health problems. Only 0.37% of the total area is available for agriculture, and even this is poorly productive due to climatic, edaphic, and topographic factors. Buckwheat, potato, alfalfa, and wild beans are grown to supplement nutritional needs and fodder production, mostly in the lower villages.

Livestock raising and animal husbandry are by far the most important sources of livelihoods, contributing about 90% of total income. Livestock are an important source of protein (milk and meat) and cash income. Residents also use animal dung as fertilizer and as a source of household energy.

The seasonal calendar of occupation and income shows that May to November is the peak season for intra- and inter-village activities like agriculture, livestock, and localized trade, while the period from December to April supports off-farm labour outside Broghil (Table 21).

Table 21: **Seasonal calendar of occupations and income**

Livelihoods	J	F	M	A	M	J	J	A	S	O	N	D
Agriculture							High	High	High	High	High	
Livestock	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate
Services	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant
Off farm labour outside Broghil	High	High	High	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	High
Tourism					Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	Low to moderate	
Localized trade					High	High	High	High	High	High		

High
 Low to moderate
 Constant

Human dependence on peatlands

Figure 18 shows the contribution of different sources of energy to household fuel in the valley.

Peatlands are by far the most important natural resource used by the local communities as fuel, contributing 75% of total requirements. Use of peat as domestic fuel started around 75 years ago when a migrant from China, Mirza Rai, demonstrated the burning properties of peat to the people of Broghil. June, July, August, and September are the main months for peat extraction, and October to March and the main months for peat burning for cooking and heating. The timing of natural resource use and supply in Boroghil Valley is shown in Table 22.

A significant proportion of the peatlands have been used up and cutting peat is increasing with the increase in population. The ever-increasing pressure on the remaining peatlands ecosystem is also affecting the natural habitat of the associated wildlife. Some of the villages in Broghil Valley, including Chikar and Iskarwaz, have extracted almost 90% of their share of the communal peatlands. Now these villages are fulfilling their fuel requirements from the government-owned peatland areas. The seasonal trends in peat use vary considerably. During summer (May–September), the daily consumption of peat per household is around 100–150 kg; in winter this jumps to 200–300 kg. In summer, household energy

Figure 18: **Contribution of different sources of energy to household fuel requirements in Broghil National Park, Pakistan**

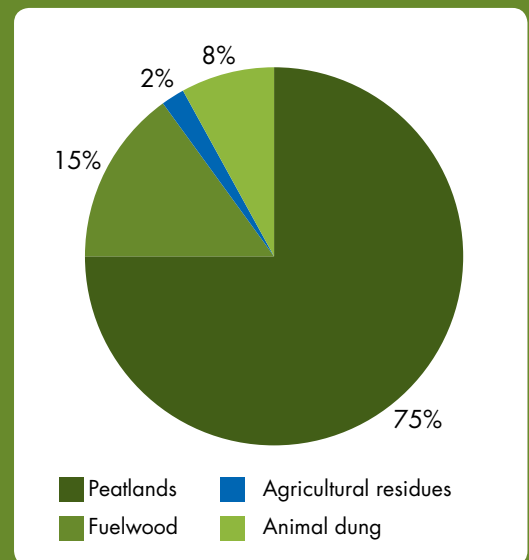


Table 22: Annual timing of natural resource use in Boroghil valley (intensity of use/ supply on a scale of 1 [lowest] to 3 [highest])

Month	J	F	M	A	M	J	J	A	S	O	N	D	Critical months
Fuelwood													
Use	3	3	3	2	1	1	1	1	1	2	3	3	Nov to Mar
Supply	1	1	1	2	2	3	3	3	3	2	1	1	Jun to Sep
Water													
Use	1	1	1	2	1	3	3	3	3	2	1	1	Jun to Sep
Supply	–	–	1	1	2	3	3	3	3	2	1	1	Jun to Sep
Peat													
Use	3	3	3	2	2	2	1	1	2	3	3	3	Oct to Mar
Supply	1	1	1	1	2	3	3	3	3	3	2	1	Jun to Sep
Medicinal plants													
Use	3	3	2	2	2	1	1	1	2	2	3	3	Nov to Feb
Supply	–	–	–	1	1	2	3	3	3	2	1	–	Jul to Sep
Hunting													
Birds	2	3	3	2	1	1	1	2	3	2	2	2	Feb to Mar, Sep to Oct
Mammals	3	3	3	2	2	1	1	1	1	1	3	3	Nov to Mar
Grazing													
Fodder collection	–	–	1	1	2	2	3	3	3	2	1	–	Jul to Sep
Pasture use	–	–	1	2	2	3	3	3	3	2	1	1	Jun to Sep

Source: PLA and questionnaire survey.

requirements are supplemented through other means, e.g., fuelwood, animal dung, and agricultural residues. But in winter, heavy snowfall and low temperatures impair the mobility of local communities and people remained confined to their houses. This increases the demand for energy, which is often met by burning peat.

The use of peat varies from hamlet to hamlet within the valley. In villages at lower elevation such as Kismanjha, Jungle, Pechuch (Garamchasma), Koi, and Vadinkhot, the primary sources of energy are fuelwood, animal dung, and agricultural residues; peat is a secondary source. This is because there are some remains of birch, willow, and juniper forests in these villages or nearby areas.

Excessive utilization of peatlands is leading to loss of habitat for key wildlife species, a decline in both covered area and productivity of grazing lands, enhanced emission of greenhouse gasses (GHGs), and increased respiratory problems within the human population as a result of using peat as a source of domestic energy. According to one estimate, if peat consumption continues at the present rate, in 20-30 years time all the peatlands will be severely degraded.

Recommendations

- Restoration/rehabilitation of the degraded peatlands through community mobilization
- Conservation of the existing meagre peatland resources through collaborative methods
- Development a proper mechanism for marketing of resources, including medicinal plants, livestock byproducts, and gemstones, to supplement income
- Awareness raising in the community with regard to the limited sustainable use of peatlands and associated resources
- Identify and introduce alternative sources of fuel to reduce the pressure on the threatened peatlands
- Design proper fuel efficient stoves in consultation with local communities to minimize the daily use of peat
- Detailed scientific research is vital to develop a complete database on available natural resources, CO₂ emissions, carbon stocking rate, and biodiversity value, and to develop a peatland/rangeland/pasture management plan. The plan should be implemented by involving the local community at the grassroots level.
- Look for options for this community to benefit by linking the peatlands with the REDD+ mechanism

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Evaluation of Carbon Gas Emissions from the Zoige Peatlands: Overview of a Decade Study

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Peatlands are usually located between terrestrial upland and aquatic environments and play an important role in element cycling and energy exchange. Very few studies have been conducted to understand the ecological functions of peatlands in the Hindu Kush Himalayan (HKH) region, especially the emission of carbon in the form of carbon dioxide (CO₂) and methane (CH₄). A long-term study on the Zoige peatlands, China, the largest peatland area in the HKH region, was initiated in 2003. Research over the past decade has included spatial variations of emissions at microtopographic, community, and ecosystem scales and temporal variations of emissions at diurnal, seasonal, and interannual scales. Initial trends have been obtained for the factors influencing emissions at various spatio-temporal scales. However, there are still many knowledge gaps such as i) patterns of emission from drained, restored and pristine peatlands; ii) mechanisms of soil microbial processes relevant to carbon gas production, transformation, and transportation; and iii) emissions generated by waterborne carbon from peatland to aquatic ecosystems.

Keywords: CH₄; CO₂; spatio-temporal pattern; Zoige peatlands

Introduction

The Zoige peatlands on the eastern Tibetan Plateau is the largest alpine peatland worldwide, covering an area of approximately 7,000 km², and located at an average elevation of 3,500 masl (Fei 2006). As major interfaces between upland terrestrial ecosystems and a network of water bodies, the peatlands serve as a vital buffer zone for adjusting regional hydrology, and an important source of water for the world famous Yellow River (SAFS 2006). Moreover, the Zoige peatlands provide critical habitats for numerous endangered and endemic species (Tsuyuzaki 1990; Ekstam 1993; Schaller 1998). In terms of other environmental services, the Zoige peatlands store an estimated carbon stock of 750 megatonnes (Bjork 1993), which is a significant portion of China's peat carbon storage. Because of its immense conservation significance, the Zoige peatlands were included as a Ramsar site in 2008.

Peatlands started to sequester atmospheric CO₂ and play an important role in the earth's climate system after the end of the Last Glacial Maximum (LGM) (Yu et al. 2010). At present, the carbon pool in peatlands accounts for at least 12% of terrestrial carbon stocks (Gorham 1991). Naturally, peatlands are sensitive to environmental change and disturbance. Although peatlands are considered to be a sink of CO₂ and source of CH₄ to the atmosphere, the carbon stocks in peat are tending to become more and more unstable in recent decades under the changing climate and increased human activities (Page et al. 2002; Ward et al. 2007). Peat extraction, construction of drainage ditches, and overgrazing by domestic livestock, along with climate change, is leading to extensive degradation of peatlands. Previous studies have shown that drained peatlands in boreal and tropical zones have already shifted to become strong sources of CO₂, rather than sinks as they used to be (Limpens et al. 2008). CH₄ emissions from peatlands might be reduced as the water table is lowered, but the overall global warming potential (GWP) of drained peatland is much higher than that of pristine peatland. The potential result is a fatal positive feedback between carbon gas emissions from peatlands and climate warming, which would accelerate the degradation process of peatlands, exhaust the carbon pool of peatlands, and ultimately largely change the composition of the atmosphere.

During the last decades, the Zoige peatlands have suffered from both climate change and human activities (Xiang et al. 2009). Between the 1950s and 2000, the annual air temperature increased by 0.23°C per decade and the annual precipitation by 1.75 mm per decade (Wang et al. 2005). With the rising demand for food, fuel, and forage, degradation caused by overgrazing, peat extraction, and construction of drainage ditches increased dramatically. It is estimated that less than 20% of the remaining peatlands in Zoige are intact or pristine (Schumann et al. 2008). In recent years, various levels of government and NGOs have carried out different pilot projects aimed to protect and restore the Zoige peatlands, and several long-term observation sites/stations have been established by local government and research institutions for scientific monitoring and evaluation of typical ecosystems in the peatlands. Considering the ecological functions of peatlands, the Chinese Academy of Sciences initiated long-term studies on carbon gas dynamics and causative factors in the early 2000s. The major objectives were to quantify the spatial variation in emissions, including the role of microtopography, community composition, and ecosystem type, and to assess the temporal variation, including diurnal, seasonal, and interannual climatic pattern scales. This paper gives an overview of the research findings, knowledge gaps, and way forward in terms of peatland research and management.

Progress Achieved

CO₂ emissions

Spatial variation

A comparative study was conducted on the ecosystem respiration in peatlands and grasslands in 2003 during the growing season. The mean flux rates of CO₂ over the three years were

203 mg CO₂ m⁻²h⁻¹ from peatlands and 323 mg CO₂ m⁻²h⁻¹ from grassland. The perennial waterlogging of peatlands limited the decomposition of plant residues, roots, and organic substances, resulting in a lower CO₂ flux. The seasonal changes of CO₂ fluxes in peatlands and grasslands correlated positively with air temperature, with the peak value usually observed in July or August; the diurnal changes in CO₂ flux also correlated positively with air temperature with peak values observed between 11:00 and 17:00 hrs. The CO₂ fluxes had a higher correlation with soil temperature at a depth of 5 cm than at depths of 10 and 15 cm (Wang et al. 2008).

Temporal variation

CO₂ fluxes across the air-water interface were monitored at Lake Medo, a typical, shallow peatland lake, during the summer of 2009. The mean CO₂ flux was $489 \pm 1,036$ mg CO₂ m⁻² h⁻¹. The flux rate was high compared to those of lakes in other regions, and represented a 'hotspot' of CO₂ evasion. The temporal variation in the CO₂ flux was significant, with the peak value at the start of the warm season, and lowest value at the end. The concentration of dissolved organic carbon (DOC) in lake water (WDOC) was high and found to be highly correlated with the CO₂ flux. The fluorescence index of WDOC showed its terrestrial origin. It seems likely that the large area of peatlands in the catchment support the high concentration of DOC in this lake, and the consequent high level of CO₂ evasion (Zhu et al. 2012) (Figure 19).

Net ecosystem CO₂ exchange (NEE) was measured at a long-term peatland observation site using the eddy covariance technique. Analysis of NEE over two years showed that the peatland was a net CO₂ sink with values of -47 and -79 g C m⁻² a⁻¹ in 2008 and 2009, respectively. The peak NEE value was -540 μg CO₂ m⁻² s⁻¹ (the negative value signifies net ecosystem carbon gain from air). The maximal daily integrated NEE was -4 g C m⁻² d⁻¹ during the peak growth season (from July to August). Gross ecosystem photosynthesis appeared to be more variable than ecosystem respiration at both seasonal and interannual timescales at this site. The data suggested strongly that the combination of precipitation and temperature, together with the phenological stage of vegetation, controlled the dynamics of ecosystem carbon gain, even in drought years (Hao et al. 2011).

CH₄ emissions

Most of the work on CH₄ emissions was done at the long-term observation site in the Zoige peatlands (Figure 20).

Spatial variation

Thirty plots were set to measure CH₄ emissions in order to understand the spatial variation of CH₄ emissions at the field scale in two phenological seasons – the peak growing season and the quickly thawing season (frozen soil melts dramatically during this period). The plots included three environmental types: dry hummock (DH), *Carex muliensis* (CM), and

Figure 19: **Sampling in the Lake Medo, the Zoige Peatlands, China**



Figure 20: **A long-term observation site on the Zoige Plateau, China**



Elaeocharis vallecuculosa (EV). There was a very high spatial variation in the rate of CH₄ emissions within and across the different environmental types in both the growing and the thawing seasons. Mean CH₄ emission rates ranged from 1,100 to 37,000 μg CH₄ m⁻²h⁻¹ in the peak growing season, and from 4 to 691 μg CH₄ m⁻²h⁻¹ in the quickly thawing season. Coefficients of variation (CV) averaged 38% among environmental types and 64% within environmental types in the peak growing season; and 61% among environmental types and 96% within environmental types in the quickly thawing season. The key influencing factors in the peak growing season were the standing water table and the plant community height; no significant correlations were found between factors and CH₄ emissions in the quickly thawing season. For extrapolation of CH₄ emissions to larger areas, best results will be obtained by using factors that are easy to determine, like vegetation, the standing water table, and environmental types (Chen et al. 2009).

Temporal variation

An apparent diurnal variation pattern in CH₄ emission was observed with one minor peak at 06:00 and a major one at 15:00. The sunrise peak was consistent with a two-way transport mechanism for alpine peatland plants (convective in daytime and diffusive at night). CH₄ emission correlated significantly with soil temperature. The afternoon peak could not be completely explained by diurnal variation in soil temperature, and may be attributable to changes in CH₄ oxidation and production driven by the plant gas transport mechanism. Diurnal variation in CH₄ emission from peatland is important, especially when the plants are capable of exploiting more than one transport mechanism. Accordingly, sampling strategies for estimating the amount of CH₄ emitted from wetlands have to be carefully designed in order to include this variation (Chen et al. 2009).

The 30 plots were also used to investigate the seasonality of the CH₄ flux in terms of the whole growing and non-growing seasons. Clear seasonal patterns were observed in the different environmental types. The mean CH₄ emission rate was 14,450 μg CH₄ m⁻²h⁻¹ (170 to 86,780 μg CH₄ m⁻²h⁻¹) in the growing season, and 556 μg CH₄ m⁻²h⁻¹ (2 to 6,722 μg CH₄ m⁻²h⁻¹) in the non-growing season. In the growing season, the main maximum values of CH₄ flux were found in July and August, except for a peak value in September in CM sites. In the non-growing season, all the three environmental types showed a similar seasonal variation pattern, in which the CH₄ emissions increased from February to April. The determining factors in the growing season were surface temperature ($r^2=0.55$, $P<0.05$), standing water depth ($r^2=0.32$, $P<0.01$), and plant community height ($r^2=0.61$, $P<0.01$); while in the non-growing season ice thickness ($r^2=0.27$, $P<0.05$; in CM and EV sites) was most related to flux. The study suggests that the seasonality of CH₄ emissions is temperature and plant growth dependent, and that the water table position is very important in shaping the temperature and plant growth dependent seasonal variation and its marked variation in alpine peatland ecosystems (Chen et al. 2008).

CH₄ emissions were also measured at the same site during the winters of 2006 and 2007. Winter CH₄ emissions were roughly estimated to be 94 μg CH₄ m⁻² h⁻¹. The emissions showed high spatial-temporal variations (with a sequence of CM > EV > KT; and average values of 630 and 1,240 μg CH₄ m⁻² h⁻¹ for 2006 and 2007, respectively). The factors involved in the spatial-temporal variation were 1) water table in summer determining the winter amount of 'old' CH₄ stored in peat; 2) ice layer determining the release of CH₄; and 3) plant growth determining both the quantity of CH₄ stored in peat and available substrates for CH₄ production in winter. However, due to the homogeneity of freezing in winter, predictive factors such as plant growth and water table in summer can contribute more to winter CH₄ emissions than in situ freezing conditions. As plant growth and water table are also the key factors controlling the spatial-temporal variation of CH₄ emissions in summer, it seems likely that winter CH₄ emissions represents the 'inertia' of summer CH₄ emissions (Zhu et al. 2011).

Interannual variations in CH₄ emissions were also studied at this site from 2005 to 2007. The weighted mean CH₄ emission rate in summer from 2005 to 2007 was 8,370 ± 11,320 μg CH₄ m⁻² h⁻¹, which is within the range of CH₄ fluxes reported by other studies, with significant interannual and spatial variation. The CH₄ emissions in 2006 (2,110 ± 3,480 μg CH₄ m⁻² h⁻¹) were 82% lower than the mean values in 2005 and 2007 (13,910 ± 17,800 μg CH₄ m⁻² h⁻¹ and 9,440 ± 14,320 μg CH₄ m⁻² h⁻¹, respectively), which corresponded with interannual differences in standing water depth during the growing season in the three years. Significant drawdown of standing water depth is believed to have caused the significant reduction in CH₄ emissions from the peatlands in 2006, probably through changing the methanogen composition and decreasing its community size, as well as activating methanotrophs to enhance CH₄ oxidation (Chen et al. 2013).

Knowledge Gaps and Perspectives

Network of a series sites for peatlands

Most of the studies focused on carbon gas emissions were carried out intensively at sites located in the heart of the Zoige peatlands. This area is a fen in low-lying position with seasonal surface water. The site had nearly 23% of intact peatland. There are no data with high spatiotemporal resolution for drained or degraded peatland. In recent years, the management authorities of Zoige have imposed a ban on draining of peatlands and started to fill the drainage ditches (Figure 21). The rewetting of large expanses of peatland has already resulted in a substantial improvement in the water table, restoration of plant communities, and improvement of soil properties (Zhang et al. 2012). However, the effect of restoration on carbon gas emissions has not yet been studied. A comparison of carbon gas emissions among pristine, drained, and restored peatland would provide a basis to protect the carbon storage of peatlands.

Figure 21: Typical drain-blocking site in the Zoige Peatlands, China



Soil process associated with carbon gas emission

Carbon gases, both CO_2 and CH_4 , released from peatlands are the ultimate products of biogeochemical processes in peat. Physical and chemical parameters such as the water table, soil temperature, redox potential, and substrate content in peat were found to have a significant correlation with gas emission, even though the coefficients of correlation were relatively low. In boreal and northern regions, microbial processes, including aerobic and anaerobic process, are thought to be another key factor controlling carbon gas emission (Fenner et al. 2005). There are some studies on the community structure of methanogen (Tian et al. 2012) and relationship between methanogenic archaea and CH_4 production potential (Liu et al. 2011) in pristine peatlands from the Zoige peatlands. More incubation experiments, together with field sampling and microbe examination, are needed in order to explore the mechanisms underlying the production and transport of carbon gases.

Linkage of carbon exchange between terrestrial and aquatic ecosystems

Peatlands are considerable sources of waterborne carbon (including DOC, POC, DIC) added to aquatic ecosystems as well as a source of carbon gas emission into the atmosphere. CO_2 emissions from lakes in boreal regions are extensively fueled by terrestrial origin carbon (Lennon 2004), especially the carbon from peatlands. Furthermore, drained peatlands tend to

have a higher export rate of waterborne carbon, and a large portion of that carbon will be decomposed by bacteria in aquatic ecosystems (Pastor et al. 2003; Dawson et al. 2004). In Lake Medo, a typical peatland lake in the Zoige peatland, the comparative high CO₂ emission rate was found to be supported by terrestrial DOC, mainly peatland origin DOC. Similarly, the CO₂ emissions from rivers and streams in this region might also be controlled by waterborne carbon from peatland. The production, export, and transportation of waterborne carbon in the Zoige peatlands should be examined.

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A wide-angle photograph of a high-altitude mountain valley. The landscape is dominated by steep, rocky slopes on either side, which are sparsely covered with low-lying green vegetation. In the foreground, a river flows through a rocky bed, surrounded by green grassy banks. The sky is a vibrant blue, filled with large, white, fluffy clouds. The overall scene conveys a sense of a rugged, natural environment.

4

Ecosystem Services from High-altitude rangelands



Rangeland Ecosystem Services in the Hindu Kush Himalayan Region

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There are rangelands in most parts of the world, and wherever they exist, they are important for the national economy, environment, and cultural heritage. Globally, more than 120 million pastoralists rely on more than 5 billion hectares of rangelands for their livelihoods. The geographic extent and resources of the rangelands make their proper use and management essential. While traditional management practices were sustainable, increasing pressure on land and inappropriate management and development policies are now causing degradation.

Rangelands produce a wide variety of goods such as forage for livestock grazing, wildlife habitat, mineral resources, and other products. Many of these tangible benefits are well known. Other services of rangeland ecosystems, such as carbon sequestration and storage, storage and regulation of water, maintaining landscape beauty, and maintaining biodiversity, are less known. This paper discusses the key ecosystem services provided by rangelands in the Hindu Kush Himalayan (HKH) region, their benefits, and their economic value to in situ and downstream communities. Based on a review of the literature and selected case studies, we discuss major constraints and opportunities in the management of the rangelands in the region. Recommendations are made in relation to the valuation of rangeland ecosystem services, a PES (payment for ecosystem services) approach, transboundary collaboration, policy support, capacity building, and knowledge sharing.

Keywords: biodiversity; carbon; climate change; HKH; mountain ecosystem; valuation;

Introduction

Rangelands and their distribution

Rangelands are land areas on which the indigenous vegetation (climax or natural potential) consist predominantly of grasses, grass-like plants, forbs, and shrubs. They include natural grasslands, savannas, shrub land, many deserts, tundras, alpine communities, marshes, and meadows (Society for Range Management 2001). Rangelands are managed principally with extensive practices such as managed livestock grazing and prescribed fire. Grazing is an important use, although the term rangeland is not synonymous with grazing land. Rangelands exist in all parts of the world except Antarctica. Rangelands cover about 75% of the total land area of Australia (Taylor 2004), 36% of the USA (Department of Rangeland Ecology and

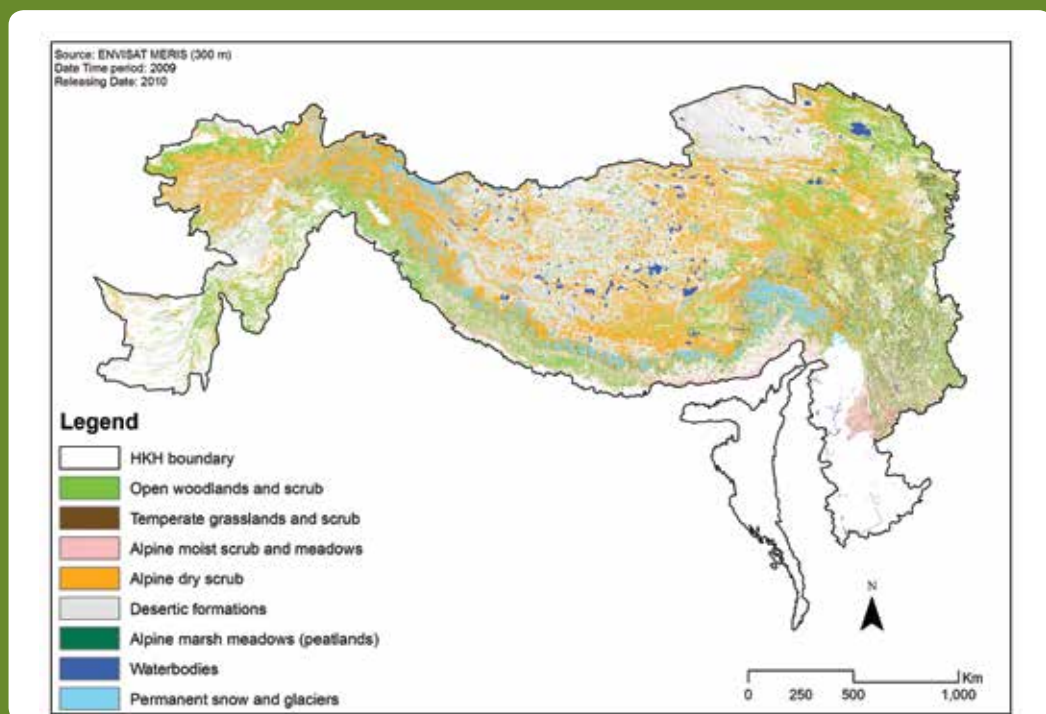
Management 2009), 33% of South America (Yahdjian and Sala 2008), 84% of Kenya (Barrow and Mogako 2007), and nearly 60% of the Hindu Kush Himalayan region (Miller 1996). They are important for national economies, the environment, and cultural heritage.

Most pastoralists are poor and dependent on rangeland resources. The traditional management practices were sustainable, but increasing pressure on land and inappropriate management and development policies are causing degradation of large areas of rangeland. For example, it has been reported that nearly 50% of the Tibetan Plateau grasslands are degraded (Wilkes 2008). The geographic extent and many important resources of rangelands make their proper use and management vitally important.

Importance of the HKH Rangelands

The Hindu Kush Himalayan (HKH) region is the largest and most diverse mountain region in the world, comprising a 3,500 km long complex landscape of mountains, plateaus, river gorges, and plains). Politically, the region comprises all or part of eight countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan. Rangelands form the largest land use system (60%) in the HKH region (Miller 1996). The distribution of different rangeland types in the region is shown in Figure 22; the country-wise distribution is summarized in Table 23.

Figure 22: Map showing major cover classes in rangelands of the HKH region



The largest area of rangelands within the Hindu Kush Himalayan region is located within China. More than half of the Tibetan Plateau's total land area of 2.5 million km² is covered by grasslands; these play an important role in regulating ecosystem services of national, regional, and global importance (Long 2003) and are the basis of livelihoods for 5 million pastoralists, most of whom are poor (Wilkes 2008).

Table 23: Extent of rangelands within the HKH portion of the countries of the HKH region

Country name	Area (km ²)	Area %
Afghanistan	291,880.87	7.57
Bhutan	17,419.636	0.45
China	1,545,542.4	40.09
India	169,381.09	4.39
Nepal	77,826.664	2.02
Pakistan	188,118.4	4.88
Total area (%)	2,290,169	59.41

The ecological richness of the HKH rangelands make them unrivalled in terms of diversity; they extend from subtropical savannas in the Siwalik foothills to abundant alpine meadows in the mountains, and from the spacious steppes of the Tibetan Plateau in the east to the cold, dry deserts of the Hindu Kush mountains in the west. The rangelands contain a diverse collection of plant communities, wildlife species, and human cultural groups.

Pastoralism is a major adaptation to local conditions in the HKH region and contributes significantly to the subsistence livelihood of the mountain people (Bhasin 2011). Over centuries, pastoralists have developed a remarkable resilience through their experience-based migratory patterns. Despite contrasting ecological zones they face similar problems, as shown, for example, in a study of different groups of pastoralists in India (Sharma et al. 2003). The 25 to 30 million pastoralists and agropastoralists in the region tend to be socioeconomically disadvantaged and are faced with serious threats to their livelihoods due to severe rangeland degradation and desertification problems throughout the region (Shaoliang and Sharma 2009). Outmigration is used as a livelihood support strategy and rates within the mountain communities in the HKH countries are strikingly high (Hoermann 2009).

Pastoralism in the HKH is under immense pressure from increasing human and animal populations. Over the last 50 years, the number of people has doubled and the livestock population has quadrupled. Transboundary issues between HKH countries concerning resource use and conservation are also affecting migratory pastoralism and the use of the historical grazing corridors (Chettri 2009). Effective planning and use of the HKH rangeland resources is further complicated by the limited understanding of various factors including

- rangeland productivity causing shifts in the temporal and spatial distribution of resources;
- current and potential future use of rangeland resources for pastoral livelihood diversification and improvement;
- value of rangeland ecosystem services;
- links between rangelands and other ecosystems like forests and wetlands;
- innovative climate change adaptation strategies; and
- gaps in knowledge and local capacity for developing rangeland resources.

These heterogeneous rangeland ecosystems and their integrity are very important for the provision of services that benefit communities far away. The ten main rivers of Asia, namely the Amu Darya, Brahmaputra, Ganges, Indus, Irrawaddy, Mekong, Salween, Tarim, Yellow River, and Yangtze, originate in the HKH mountains and flow through the rangelands. The rangeland ecosystems make up the environment for the headwaters of these river systems, and what takes place in these upper watersheds has a far-reaching effect on downstream areas (Miller 1997). The water that flows from the rangelands is also critical for hydropower development and for irrigated agriculture at lower elevations.

Crop cultivation at high altitudes is restricted by physiographic factors, and grazing by domestic animals enables herding communities to convert otherwise unusable plant biomass into valuable animal products that are either consumed by the pastoralists themselves or sold for income (Miller 1997). Livestock raising forms a part of the livelihood system of the majority of people in the HKH. In the grazing land areas it contributes close to 100% of household income; where agropastoralism is the main farming activity, it contributes 50 to 70%, and in mixed crop livestock farming systems, 10 to 30% (Tulachan and Partap 1997).

The HKH rangelands are also becoming increasingly popular as tourist destinations. Tourism in mountain rangeland environments has the potential not only to improve the livelihoods of the local people, but also to contribute to overall economic development of the countries.

HKH Rangelands and Climate Change

Climate variability affects the amount and distribution of pastures and water points. Although the long-term impacts of climate change are difficult to predict, the most important predictions made by climate change models are of rising temperatures and changes in precipitation with an increased number of extreme events (Mortimore et al. 2009). Erratic and unpredictable rainfall along with extreme weather conditions and longer and more frequent droughts would affect the sustainability and efficient use of rangeland resources. The availability and productivity of grazing areas, and existence of water points, which are critical for livestock survival during the dry season, are bound to decline with marked consequences for mountain livelihoods. The pressures associated with human population growth, economic development, land use change, and climate change are major challenges facing rangeland development professionals and practitioners. Climate change in the rangelands is likely to affect glaciers, temperature, precipitation, water availability, length of seasons, livestock number, and availability of animal feed.

The rangeland herders are among the poorest and most vulnerable communities in the HKH. To cope with the harsh and changing environment, herders move their livestock to areas where water is available and the conditions more favourable according to season. Surveys of pastoral communities conducted recently in Afghanistan, Bhutan, China, India, Nepal, and Pakistan revealed the extent of their hardship and vulnerability. Livestock rearing contributed more than 80% of household income in Afghanistan, Bhutan, and China. Average household

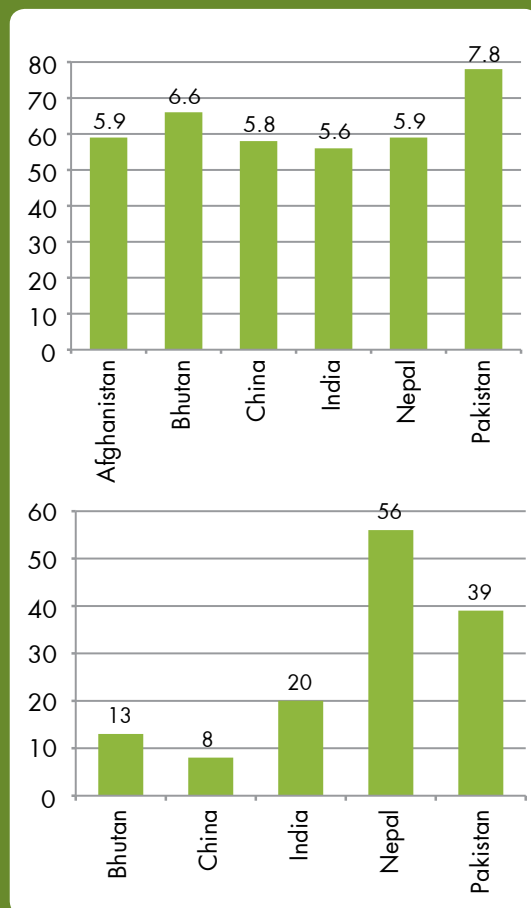
size was around six to eight (Figure 23a) and food deficit was an annual phenomenon and persistent reality for the vast majority of respondents across the region. The majority of households in Pakistan (64%) and Afghanistan (59%) and 42% in Nepal reported that food shortages were worse now than previously. To cope with the increasing food shortages and other problems, at least one adult family member had outmigrated in more than half of the sample households in Nepal and a large proportion of the households in other countries (Figure 23b). The average annual household income ranged from USD 78 to 402 in Afghanistan and USD 536 to 2,781 in India. More than 97% of respondents in China and Nepal, and 42% in Bhutan and Pakistan, depended heavily on animal dung as a source of energy. The respondents called for immediate conservation activities to reverse the deteriorating condition of key plant species in the rangelands (Jasra et al. 2012).

While changes in temperature and precipitation are not uniform across the Tibetan Plateau (Wilkes 2008), or elsewhere in the region, climate change is nevertheless expected to shift the location of climate belts and the distribution of vegetation types. The permafrost that currently covers half of the Tibetan Plateau is predicted to shrink, or even disappear, due to climate change, which will have a direct impact on water resources and the local ecosystem. The lack of knowledge about the impacts of climate change in the rangelands is a limitation for development planning.

Rangeland Ecosystem Services

Rangelands in the HKH provide ecological, economic, and cultural and spiritual services to communities living in and outside these systems (Table 24). Among others, they produce forage for livestock grazing; wildlife habitat that sustains the flora and fauna necessary to support human wellbeing; water storage and supply; maintenance of stable and productive

Figure 23: (a) Household size and (b) outmigration (seasonal and longer-term) among herders in HKH countries

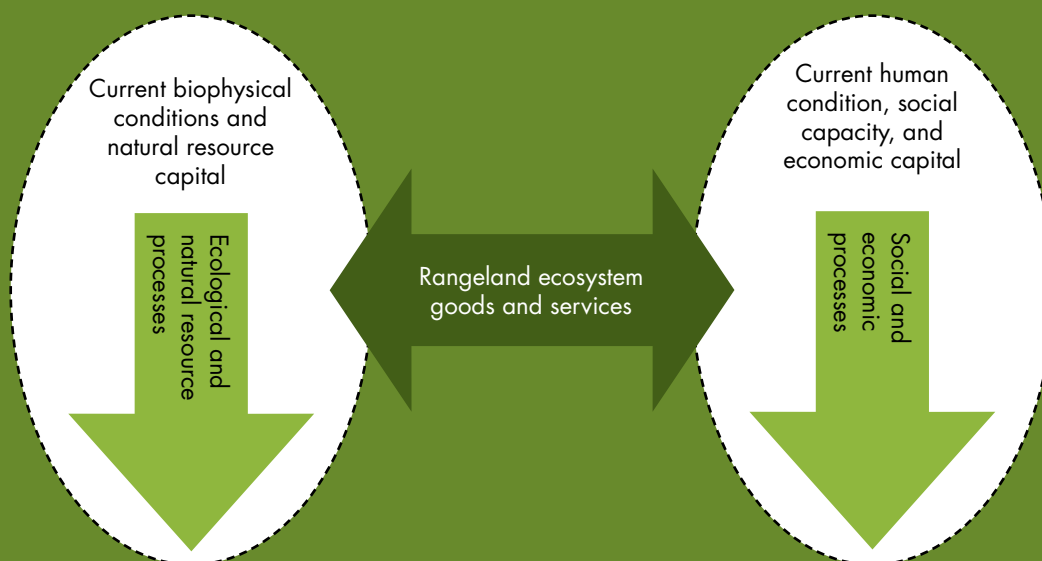


soils; mineral resources and products; sequestering and storage of carbon; and natural beauty. The rangeland ecosystem services provide a link between economic and ecological systems as shown in Figure 24. Biodiversity habitat maintenance, carbon storage, and water regulation are considered primary ecosystem services from rangelands to human beings.

Table 24: Key functions of rangelands

Biological	Hydrological/Atmospheric	Miscellaneous
Domestic livestock	Drinking water	Views and scenes (aesthetics), recreation and tourism
Other food for humans	Water for economic benefit	Cultural, spiritual, and ceremonial
Forage for livestock	Floods for channel and riparian area rejuvenation	Historical/archaeological sites
Fibre	Flood mitigation	Scientific study
Biofuels	Water bodies for recreation/tourism	
Fishing, hunting	Carbon sequestration	
Biochemicals and genetic materials	Clean energy – wind and hydropower	

Figure 24: Rangeland ecosystem services provide a link between economic and ecological systems



Biodiversity

Rangelands are home to significant concentrations of large mammals and plants with an ecological and economic value. Biodiversity provides many direct benefits to people and the economy such as food, fibre, and forage for grazing animals, medicines, fuel, building materials and industrial products, recreation, and hunting. Most rangelands are not 'natural', they have developed as a result of human modification, especially where the dominant subsistence strategy is pastoralism, and this presents a paradox to conservationists. Historically, when the human population was relatively low, the human exploitation of rangelands was not problematic. But this is changing with the increase in human populations and demand for land for other uses, which are having a significant impact on the flora and fauna of the rangelands. Fragmentation, for example, represents a major threat to biodiversity in rangelands.

Species diversity can be affected by livestock grazing and fire. Livestock can also enhance the conservation of particular species or plant communities and structures. Grazers influence diversity by selective grazing and trampling of plant species. Moderate grazing and trampling can increase the diversity of plants by decreasing the dominance of a single species. Grazing can also create gaps in the plant community, making light, moisture, and nutrients more available to other species. The effects of grazing on plant community diversity depend on the grazing intensity, evolutionary history of the site, and climate. It is also known that if grazing is excluded, the number of species may increase in the short term, but may decline over the long term.

Carbon

Global warming is a major concern and is predicted to affect all ecosystems and human livelihoods, particularly in the developing world. It is estimated that average global temperatures will be 2°C higher than pre-industrial levels by 2035-2050 (Stern 2007). In the rangelands, this may change the length and timing of the growing season and the amount and seasonal pattern of precipitation. Although pastoral societies have made a minimal contribution to the global warming process, they are likely to be seriously affected by it.

In most rangelands and grasslands, soil carbon is by far the largest carbon pool. Above-ground vegetation is normally small and consumed by grazing livestock. Litter pools are also a very small percentage of total carbon stocks. An unpublished report by Feng et al. (n.d.) indicates that there is a significant difference in carbon stocks between degraded and non-degraded grasslands on the Tibetan Plateau (Table 25). Degraded grasslands often have low vegetation cover and low biomass. Practices that increase vegetation cover will increase inputs of organic matter into grassland soils, and reduce soil respiration, thus sequestering carbon in the soil. Overgrazing increases the amount of biomass removed from the system. Trampling can also increase the soil temperature increasing respiration and carbon emission.

Table 25: Soil carbon stocks of alpine grasslands at different levels of degradation (t C ha⁻¹)

	Above-ground C (incl. litter)	Below ground biomass C	Soil C	Total C
Lightly degraded	1.61 (1.20–2.05)	5.01 (4.52–5.29)	115.09 (107.01–123.16)	121.71 (112.73–130.48)
Medium degraded	1.09 (0.70–1.67)	4.31 (3.02–5.34)	44.65 (40.14–49.15)	50.05 (43.86–56.16)
Severely degraded (black beach)	0.96 (0.35–1.53)	3.23 (1.35–4.89)	40.31 (32.11–48.54)	44.50 (33.81–54.96)

Source: Feng et al. (n.d.)

Management practices can increase or decrease organic matter input to soils. Rangelands vary greatly in their climatic characteristics, vegetation, and soil types. Research results indicate that some types of rangeland may respond positively to a certain practice with increased rates of sequestration, while the same practice may reduce sequestration rates elsewhere. Hence, rangeland soil carbon management practices need to be site-specific and designed with care.

Considering that rangelands cover about 40% of the world's land area (White et al. 2000), and that the majority of the world's rangelands are degraded to some degree (Dregne and Chou 1992), the carbon sequestration potential of sustainable land management in rangeland areas appears to be huge. A report from FAO (2009) highlights the potential of increased financial benefits from enhanced carbon:

“Typical population densities in pastoral areas are 10 people per km² or 1 person per 10 ha. If carbon is valued at USD 10 per tonne and modest improvements in management can gain 0.5 tonnes C/ha/yr, individuals might earn USD 50 a year for sequestering carbon (Tennigkeit and Wilkes 2008). About half of the pastoralists in Africa earn less than USD 1 per day, or about USD 360 per year. Thus, modest changes in management could augment individual incomes by 15%, a substantial improvement. Carbon improvements might also be associated with increases in production creating a double benefit.

Water storage and flow regulation

The HKH rangelands are also primary catchment areas for annual precipitation. There is little information in the literature about the role of rangelands in storing water and snow and regulating the flow of water in rivers. Nevertheless, it is clear that changes in water storage and regulation in the rangelands may have serious consequences for the water in the rivers flowing from the mountains, and the more than 1.3 billion people who live in the downstream areas. The impact on hydropower generation may also be extensive. Degraded grasslands are typically less able to hold moisture in the soil than non-degraded grasslands, and thus are more susceptible to the impacts of drought and heavy rainfall events. Productivity of grass also depends on soil moisture availability.

Landscape beauty

The beauty of the landscape in the Himalayas attracts hundreds of thousands of tourists and pilgrims to the mountains, including the rangelands. The mountain ranges represent some of the most beautiful landscapes in the world and have immense aesthetic value. The mountain rangelands are significant assets for the tourism industry. With their fresh air and cool climates, breathtaking landscapes and peaks, and prosperous natural and cultural heritage, mountain rangelands are attractive places to enjoy nature and escape from the urban world (Kruk 2011). The demand for trekking, hiking, camping, mountaineering, rock climbing, mountain biking, wildlife viewing, and other forms of non-consumptive mountain tourism activities is ever-increasing, leading to rapid development of the mountain tourism and recreation market (Kruk and Banskota 2007).

Rangeland Ecosystem Services in the HKH Countries

Afghanistan

The rangelands of Afghanistan occupy about 30 million hectares, roughly 45% of the country's territory. The total grazeable area (including marginal lands) is estimated at 70–85% of the total land area; it provides habitat and forage for nearly 35 million livestock as well as numerous wild animals. Over the last 30 years, the population of sheep and goats in Afghanistan has gone down from more than 30 million to approximately 16 million, although livestock production remains the 'backbone of Afghanistan agriculture' and 'crucial for socioeconomic development of the country'. The rangelands are essential for the Kuchi pastoralists, estimated to comprise 20% of the rural population. People in the rangelands gather biomass for fuel and forage, and the rangelands are used by livestock and wildlife for foraging and habitat. The natural resources of the rangelands and woodlands are vital to the survival of communities and nomads as well as to the national economy. However, the many years of war, drought, and migration have devastated both the human and natural resources of Afghanistan, and led to a loss of the traditional ways of using natural resources. Other socioeconomic productivity functions of Afghanistan's rangelands include a range of natural products from fuel and building materials, to fruits and nuts, meat from wild animals, and medicinal plants. The biophysical functions of Afghanistan's rangelands include its critical role as a watershed (and associated regulatory effect on irrigation), in providing a natural soil erosion control mechanism, as a carbon sink, and as a habitat for wildlife.

Bhutan

More than 10% of Bhutan's population are yak herders who reside in the high-elevation rangeland area where they rely mainly on extensive pastoralism for subsistence. These people are entirely dependent on livestock and livestock products. Integrating socioeconomic development of the herder communities with the rangeland ecosystems has been a challenge to all the stakeholders involved. In recent years, the multiple values of the high-elevation landscape (such as for recreation and water conservancy) have gained increasing recognition,

which has unfolded new opportunities for local communities to gain livelihoods. Many world-class trekking routes exist in Bhutan, most passing through rangeland areas, and they have attracted tourists from around the world. Cordyceps (*Cordyceps sinensis*) harvest was legalized in 2004 to provide another avenue of income to mountain communities (Royal Government of Bhutan 2005), with a designated period for collection from May 15 to June 15. Cordyceps are sold through an auction coordinated by the Agriculture Marketing Services of the Ministry of Agriculture. It is estimated that an average household may collect about 100 g, which provides yak herders with 50% of their cash income.

China

China has extensive areas of rangeland; including vast areas within the Hindu Kush Himalayan region on the Qinghai-Tibetan Plateau, the highest and largest plateau in the world (Zhang et al. 2005). The Tibetan Plateau, with its unique ecosystems and extremely rich rangeland resources, has provided some of the most important grazing lands in the region since ancient times (Boxes 2 and 3). The plateau modulates the climate in the region, thus changes in its climate are likely to have a marked effect on the climate of eastern and southwestern China, and further to the whole northern hemisphere and even the entire globe. Environmental changes in the region also influence lowland China, especially in terms of water supply and modulation of the hydrological regime. The high-frigid meadow ecosystem has immense biodiversity resources including many breeds of domestic animals unique in the world. The Qinghai-Tibetan Plateau has attracted the attention of meteorologists, soil experts, environmental specialists, and ecologists from all over the world. The high alpine meadows of

Box 2: Rangelands of the Qinghai-Tibetan Plateau

The Qinghai-Tibetan Plateau is the world's largest and the highest plateau covering an area of 2.5 million km². With its immense reserves of ice and snow, it is sometimes referred to as the 'third pole' or 'the roof of the world'. The rangelands in this region cover about half of the total area and extend from the Himalayas in the south to the Altai in the north, and from the Pamir in the west to the Minshan mountains in the east. Rangeland resources are vital for local livelihoods and livestock, and are an important habitat for many wildlife species, such as blue sheep (*Pseudois nayaur*), kiang or Tibetan wild ass (*Equus kiang*), Tibetan antelope (*Pantholops hodgsoni*), black-necked crane (*Grus nigricollis*), and the endangered snow leopard (*Panthera uncia*) (Miller and Craig 1996; Richard 2000). Thirteen million yak, 41.5 million sheep, large numbers of wild herbivores, and 9.8 million people, inhabit these rangelands. Domestic and wild animals compete for feed in many places. Continuous year-round extensive grazing (either transhumance grazing on the vast plain of the central Plateau or seasonal rotation within certain mountain regions) is a unique land-use pattern. There is generally abundant animal feed in summer and a significant deficit in winter and spring, but inappropriate practices have led to substantial degradation of the rangelands in recent times. Many areas are designated as protected and have a good potential for tourism. Due to the high altitude and harsh environment, agricultural cultivation is not possible on most of the plateau.

Box 3: The Rangeland system of Deqin County, Northwestern Yunnan

Rangelands have a high biodiversity value, as shown in the example of Deqin County in the southern part of the Tibetan Plateau on the northeastern fringe of the Himalayan region. The region is environmentally fragile but is very rich in both biological and cultural diversity. Alpine meadows are found along the vertical gradient; pastoral lands (including grasslands and scrub) cover 2,509 km² (33% of total land). Agriculture, including cultivation and animal husbandry, is the main source of livelihoods and income of both the local people and county government. Yak husbandry is important for subsistence and socioeconomic development. Production of pastures in the alpine meadows and scrub areas has declined. Maintaining rangeland productivity and biodiversity, increasing livestock output to meet growing demand, and improving the living standards of local people are challenging tasks.

the eastern Plateau are by far the most productive grazing areas, renowned for their vast verdant pastures and large yak, sheep, and horse herds. This area is also the origin of the Yellow (Huanghe) and Yangtze (Jinsha) rivers and is called 'the mother of ten thousand rivers'. The terrain is mountainous, valley bottoms are rarely below 3,500 masl, and winters can be harsh, but the abundant rainfall during the summer growing season allows for relatively high grassland productivity. Yaks and sheep are the main livestock in this part of the Plateau, whereas more sheep and goats are raised in the western part.

India

The high-altitude mountain areas of India are dominated by rangelands, with the Ladakh area at the northern tip of the Indian sub-continent in Jammu and Kashmir State a typical example. Ladakh is located between the great Himalayan and Karakorum ranges and is interspersed with bare, rugged mountains. The altitude and climate make agriculture impossible in most areas and the local people, the Changpas, make their living as nomadic pastoralists, following the traditional routes of their forefathers. The lifestyle of these herders is very traditional, and they depend on livestock that rely on rangeland foraging. Local animal products are exchanged with food grains and other supplies as part of an age-old barter economy, and pashmina is sold in Kashmir. The vast majority of the Changpas' livestock are pashmina goats and changluk sheep, but they also raise a few horses, donkeys, and yaks. The extremely cold winters, with temperatures as low as -48°C, and the high elevation enable the production of the finest quality of thick pashmina and sheep's wool. Although the local economy is vigorous and the Changpas have a rich indigenous knowledge base, limited scope for income generation and lack of market options have kept them poor. Currently, the importance of the historic barter economy is declining as more cash-earning opportunities arise in the Leh area. The resulting decrease in locally produced grain is making the Changpa nomads more reliant on subsidized grain from government supply centres. As the small

amount of earnings these people derive from pashmina sales is not sufficient to procure necessary supplies, the Changpa's standard of living (including health and education) is rapidly falling behind that of their neighbours.

Nepal

Rangelands in Nepal cover about 12% of land, mostly in the high-altitude mountain areas. The rangelands in Upper Mustang are typical, covering more than 98% of total land use and comprising 48% of natural vegetation and 50% bare land (LRMP 1986). Much of the Mustang landscape is dominated by pastures, but the prevailing harsh climatic condition doesn't permit to growth of sufficient grass (Kunwar 2003). Agricultural production in the area is very limited due to scarcity of water, lack of proper irrigation, low temperatures for longer periods, and low rainfall. The majority of the land is uncultivated and barren. Animal husbandry is the main source of income. The major livestock are cattle, yaks, dzos (hybrid of yak and cattle), sheep, goats, horses, mules, and donkeys. Goat and sheep trading from China is also a common practice. Upper Mustang is a high-altitude steppe, a fragile landscape drained by the main Kali Gandaki river and its tributaries, in the rain shadow area of Dhaulagiri Himal and Annapurna massif. Rangelands are an important natural resource, and form the basis of the rich biodiversity of the region, supporting a large number of rare and endangered plants, animals, and birds. The vegetation of the area represents high-altitude grasslands that are Tibetan in character. Both domestic and wild animals use these rangelands intensively. The rangelands not only provide grazing lands for livestock, they are also important popular tourist destinations for both domestic and international tourists (Box 4).

Pakistan

The primary use of Pakistan's rangelands is for livestock production, with management systems ranging from nomadic pastoralism, through mixed subsistence farming, to commercial ranching. Pastoralists in the Pakistan rangelands depend heavily on direct consumption or sale of livestock products such as milk, butter, meat, draught power, transport, fibre, dung, income, and tradition. The rangelands are generally unsuitable for crop production due to aridity,

Box 4: Dolpo region of Nepal

The life of the pastoral population in the Himalayas is changing rapidly as previously remote areas modernize and begin to enter the market economy. Herders continue to practise the animal husbandry skills that have been handed down to them through generations. With proper development assistance, the pastoral population should be able to continue to use many of their traditional skills and practices, along with new information and techniques, to better manage the rangelands, increase livestock production, and improve their livelihoods. In addition, there is much potential for tourism in the region.

topography, and extreme temperatures. They support varying mixtures of native and non-native grasses, grass-like plants, forbs, and shrubs, which provide forage for free-ranging wild and domestic animals. While forage production for domestic livestock has been a key ecosystem service of these rangelands, the agropastoral system includes subsistence arable cropping, fruit production, livestock production, and, to an increasing extent, cash-cropping. These rangelands are also very important for nutrient cycling. Crop residues produced in the cropland are fed to the livestock and are partly turned into manure. Livestock constitute the dynamic component of a farming system helping nutrient flows in two ways: transfer of nutrients from ecologically more stable rangelands to the more fragile croplands, and recycling of nutrients from the cropland. Livestock thus serve as the living agency to mediate nutrient flows in these mountain agroecosystems. Some rangeland areas are also becoming popular destinations for tourists, e.g., the Deosai Plateau and Shandur pass, which are famous for trekking, festivals, and sports.

Economic Valuation of Rangeland Ecosystems

Economic valuation can be perceived as the anthropocentric orientation of ecosystem services. An economic perspective on ecosystems portrays them as natural assets providing a flow of goods and services valuable to individuals and society collectively. Examples include the purification of water, reduction of risk from flooding, pollination of agricultural crops, and recreation opportunities from biodiversity and habitat maintenance.

The economic valuation of rangeland ecosystem services has many functions. Economic values may be used as an input into analysing the costs and benefits associated with policies being proposed, or possibly already implemented. For example, with economic value determined, it becomes possible to compare the benefits of different land use options. Identifying and valuing ecosystem goods and services from the rangelands highlights the value of these natural assets to human welfare, which otherwise often remain hidden to the public. This recognition is important for the conservation of rangelands and their benefits. Valuation of total ecosystem benefits will be required to increase the level of conservation and protection of rangelands. Valuation is also the basis for damage assessment and compensation systems.

Heidenreich (2009) in a review did not find any empirical valuation research for temperate grasslands and concluded that the understanding of the total economic value of the goods and services provided by the temperate grasslands is virtually non-existent. Despite their significance, grasslands and rangelands are largely missing in the Millennium Ecosystem Assessment (MEA 2005). Some limited work on estimation of the value of rangeland ecosystems has been conducted in the USA, Canada, South America, and Australia, where the results and lessons provide policy directions for conservation and templates for methodology transfer. Based on case studies, Heidenreich (2009) reported that the total economic value of temperate grassland can range widely from USD 190 to USD 1,618 per hectare per year depending on location, extent, function, and significance to the human

Box 5: Methods for valuation of ecosystem services

1. Market price method: Estimates economic value of ecosystem products or services that are bought and sold in commercial markets.
2. Productivity method: Estimates economic value of ecosystem products or services that contribute to the production of commercially marketed goods.
3. Hedonic pricing method: Estimates economic value of ecosystem or environmental services that directly affect the market price of some other good; most commonly applied to variations in housing prices that reflect the value of local environmental attributes.
4. Travel cost method: Estimates economic value associated with ecosystems or sites that are used for recreation; assumes that the value of a site is reflected in how much people are willing to pay to travel to visit the site.
5. Damage cost avoided, replacement cost, and substitute cost methods: Estimate the economic value based on costs of avoided damage resulting from lost ecosystem services, costs of replacing ecosystem services, or costs of providing substitute services.
6. Contingent valuation method: Estimates economic value of virtually any ecosystem or environmental service. Most widely used method for estimating non-use, or 'passive use' values, asks people to directly state their willingness to pay for specific environmental services, based on a hypothetical scenario.
7. Contingent choice method: Estimates economic value of virtually any ecosystem or environmental service, based on people's opinion to make tradeoffs among sets of ecosystem or environmental services or characteristics; does not directly ask for willingness to pay – this is inferred from tradeoffs that include cost as an attribute.
8. Benefit transfer method: Estimates economic value by transferring existing benefit estimates from studies already completed for another location or issue.

population in the vicinity. As yet, there has been no research to estimate the total economic value of rangeland ecosystems in the HKH region; however, a general framework has been developed recently for valuing the whole range of ecosystem services in the Himalayas (Rasul et al. 2011).

Referring to the limited number of case studies in developed countries, Heidenreich (2009) highlighted the large research gaps in understanding the economic value, and hence the importance, of grasslands. Rangelands have values that include more than goods and services traditionally marketed. Incorporating these non-market values into land-use decision making is necessary for improved rangeland management. Assessment of non-use values (e.g., social and cultural services) and indirect value of ecosystem functions is particularly problematic due to methodological constraints (Box 5).

Discussion

Rangelands are valuable for many ecosystem functions. Rangelands play an important role in regulating ecosystem services that have local, national, regional, and global significance. In addition to livestock production, the rangeland areas in the HKH region provide ecosystem services such as soil and water conservation, carbon storage, biodiversity conservation, and cultural services (including landscape beauty). The HKH rangelands provide the basis of livelihoods for 25 to 30 million pastoralists and agropastoralists (Shaoliang and Sharma 2009), many of whom live in absolute poverty. The rangeland ecosystem services are also essential for existence and economic development in downstream areas. Conservation of the HKH rangelands is necessary for both economic development and to maintain the ecosystem services.

Most rangelands in the HKH region are degrading due to human activities; overgrazing by livestock and climate change are leading to severe, often irreversible, loss of vegetation and carbon stock. There is increasing awareness and concern about climate change and its impact, the role of grasslands in ecosystem services (mainly carbon storage, biodiversity conservation, and water services), and climate change adaptation.

Many of the important HKH rangeland areas are located within protected areas. National park policies restrict the introduction of exotic pasture species. Thus forage improvement and rangeland rehabilitation programmes in these protected areas will have to rely on native forage species. More work is needed to identify indigenous forage species with a potential for forage improvement and rehabilitation, and to determine the most practical ways to produce seed and obtain good grass establishment.

In the past, support to rangeland areas was dominated by support for increasing production, and, through this, reducing poverty. The need to target rangeland ecosystem services is being increasingly realized by national governments. Payment for rangeland ecosystem services, in which downstream and global beneficiaries pay rangeland communities for supplying the ecosystem services of concern, which provides a feasible approach for supporting rangeland maintenance and rehabilitation. This is also relevant in the case of hydrological services (regulation of water quantity and quality), as many primary river systems in the HKH region originate from the rangelands. In China, payment transfer, currently through the central government, is proving feasible. There is much potential for replicating such a programme in other HKH countries. However, information about the value of ecosystem services, the conservation role of rangeland communities, and institutional arrangements for implementing payment for ecosystem services (PES) schemes are limited. The transboundary nature of many rangelands and river basins will necessitate transboundary cooperation for developing PES schemes at a regional scale. Additional work is required to clarify the legal and tenure status for payment for rangeland ecosystem services.

There is confidence, based on pilot schemes, that PES can be a potential approach for better rangeland management in the HKH region. Schemes need to be adapted to suit the local context, scope, and importance of ecosystem services. Schemes can be based on a diversified financing mechanism with input from local, national, and international funds. Setting up a rangeland PES fund could also help in developing a better information collection system and piloting schemes in different contexts. While PES experience in rangelands is limited, whatever is available and has been learned, will be useful for developing relevant PES schemes.

Recommendations

The following recommendations are made for better management of rangelands in the HKH region.

- i) Raise the profile of mountain rangeland ecosystems and their services to the human population, both in the mountains and downstream, and further away in the region and the world.
- ii) Develop sustainable rangeland management strategies based on adaptive comanagement that involves local pastoralists and takes into account their needs, values, and perspectives.
- iii) Assess ecosystem services and their economic value in key mountain rangelands in the HKH region. Methods can be adapted from valuation studies conducted in the United States, Canada, South America, and Australia. Valuation is required for improved rangeland policies, management, and transboundary cooperation.
- iv) Develop PES schemes and pilot in different contexts in priority countries across the HKH region. There is relevant experience, particularly in China, that can help guide the development of appropriate schemes.
- v) Explore the possibility of bundling services for developing PES schemes. For example, payment for carbon storage under the current REDD+ mechanism may be extended to include biodiversity conservation and water services. However, it is important to note that PES schemes are not a 'silver bullet' for resource management, but may complement legislative and policy instruments (e.g., legislation to control grazing, provision of subsidies for inputs or products, investment grants for improved livestock and rangeland management, technical extension services).
- vi) Advocate for policy improvements to support implementation of PES schemes. For example, policy reform will be required in many HKH countries to deal with rangeland tenure, natural resource use, and transboundary issues.
- vii) Take necessary consultation and action at national and regional levels to establish a rangeland PES fund.
- viii) Strengthen local capacity, knowledge, and confidence through PES pilot schemes to address the limited capacity in the HKH region (manpower, expertise, and budget) for undertaking necessary action to promote PES for rangeland ecosystem services.

- ix) Tap into international networks and organizations (e.g., TEEB, Katumba group, FAO, UNEP) to share relevant knowledge, develop local and regional capacity, and for funding of PES research and pilot schemes.

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Payment for Ecosystem Services for Balancing Conservation and Development in the Rangelands of the Indian Himalayan Region

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The concept of ecosystem services is important for understanding human-environment relationships and designing environmental policy interventions. Recently, 'payment for ecosystem services' (PES) has emerged as a policy solution for balancing the goods (mainly derived by individuals) and services (derived by society) from natural ecosystems. Previous experience with incentive-based approaches suggests that it is unlikely that a PES approach will always be able to simultaneously improve livelihoods and increase ecosystem services, and that no single policy fits a range of scenarios. Therefore, to implement a successful PES strategy, the social, economic, and environmental contexts need to be considered in order to determine the policy outcomes. The rangelands of the Indian Himalayan region (IHR) provide important regulatory and buffering services to a large number of people on the Indian subcontinent; the provisioning services they provide are the backbone of the local economy. Rangelands are influenced by policies in at least four sectors: forests, agriculture and animal husbandry, rural development, and land use. The imposition of several policies and acts that are at times contradictory or overlapping has led to conflicts of tenurial rights, unclear land records, faulty land use practices, and resultant degradation of the rangelands in the IHR. With the growing awareness of the crucial ecosystem services provided by the high-altitude rangelands, and their potential role in mitigating climate change-related impacts, future sectoral policies need to converge and focus on maintaining the integrity of these ecosystems so as to ensure the flow of goods and services. This paper deals with the prospects for implementing a PES approach in the IHR rangelands and possible strategies for effective implementation.

Keywords: climate change; Indian Himalayan region; payment for ecosystem services; policy analysis; rangelands

Introduction

Rangelands occupy a considerable area in the Hindu Kush Himalayan (HKH) region, extending across much of the alpine region, the cool temperate and sub-alpine hill grasslands, woodlands, and interfaces between human habitation and surrounding grazing lands. The rangelands in the Indian Himalayan region (IHR) extend across the states of

Jammu and Kashmir, Himachal Pradesh, and Uttarakhand, and the high-altitude areas of West Bengal, Sikkim, and Arunachal Pradesh, covering nearly 35% of the geographical area. The major categories of rangelands in the IHR include warm temperate grasslands, sub-alpine and cool temperate grassy slopes, alpine meadows of the Greater Himalaya, and the steppe formations of cold arid regions or alpine dry scrub (Rawat 1998). The proportion of rangelands in the western Himalayas is much higher than in the eastern Himalayas as a result of the higher latitude, and colder and more arid environment. The eastern Himalayas have only a small area under rangelands as a result of the warmer, more humid forested environment. Irrespective of location, the rangelands in the Himalayan region are closely associated with the local culture and livelihoods, but are also extremely fragile and susceptible to degradation and environmental change. The IHR falls within the biogeographic zones of the Trans-Himalaya and Western and Eastern Himalaya, and contains six biotic provinces (Rodgers and Panwar 1988). The rangelands vary in their climatic and geographical features, as well as their support of pastoral communities.

Recently, understanding and recognition of the multiple functions, ecosystem services, and goods provided by rangelands has increased. Rather than being considered simply as a source of fodder for livestock production, rangelands are now acknowledged for their importance for biodiversity conservation, provision of niche products, carbon sequestration, and soil and water conservation. Rangelands provide important provisioning, regulatory, and buffering services such as livestock production, fuel and fodder, water and climate regulation, and nutrient cycling. The rangelands of the Hindu Kush Himalayan region (HKH) provide livelihood security to about 30 million pastoralists and agropastoralists, and ecosystem services to around 1.3 billion people living downstream (Shaoliang and Sharma 2009).

Conservation and effective management of rangeland ecosystems for sustaining services requires innovative approaches and enabling policies. Payment for ecosystem services (PES) is one of the approaches that can be considered for the management of rangelands. In this paper we assess the scope and challenges of implementing a PES approach for the management of rangelands that would blend anticipation, adaptation, and preparation for future environmental challenges, such as escalating population, climate change, a shrinking natural resource base, and natural disasters, while recognizing the multiple functions of the rangelands. The paper emphasizes the need for redesigning institutions and policies at the various levels of governance.

Ecosystem Services of the Rangelands

Traditionally, the rangelands have been used for livestock rearing and as hunting grounds, ensuring food security and survival of local communities. Though rangelands all over the world provide similar regulatory and buffering services, their economic importance depends on the socioeconomic system in which they are embedded. Goods and services provided by the rangeland ecosystem are supported by ecological processes of succession, migration, adaptation, competition, disturbance, soil formation, and erosion, and various natural

processes. According to Hart (1999), the core rangeland ecosystem processes form the basis of the natural capital, extractable ecosystem goods, and intangible ecosystem services, on which social and economic capitals are built. The Millennium Assessment (MA 2005) has provided a comprehensive list of goods and services obtained from natural resources, while Maczko and Hidingier (2008) described the potential dividends derived from the goods and services of the rangeland ecosystems.

The goods and services provided by the rangelands of the IHR (Table 26) are unique to the region. Both the local and downstream communities are beneficiaries of rangeland ecosystem services. The provisioning services are the most crucial services for the wellbeing and survival of the local communities that depend on the rangelands, especially the pastoral communities. The most important provisioning service provided by the IHR rangelands is livestock production, which includes meat, skin, wool and hair, and milk products. These services benefit communities at both local and regional scales. The benefits provided by the rangelands of climate control, water regulation, flood mitigation, erosion regulation, and carbon sequestration occur at a global scale and also benefit downstream communities. Non-timber forest products (NTFPs) produced in the rangelands, especially medicinal and aromatic plants and valuable fibre (e.g., wool), are highly sought after in the downstream and global markets. The primary producers and collectors of these products receive a relatively low share of the returns due to insufficient knowledge of market chains, lack of processing facilities, and inadequate quality control (Choudhary et al. 2011; Hoermann et al. 2010). There is significant scope to generate more income locally by supporting mountain people to generate new livelihood options and add value to the existing high-value products and services. However, despite the monetary benefits of marketable services of the rangelands, the local communities often do not get the major share of these benefits, due to failures of information, marketing, and policy. As a result, the local communities and institutions lack motivation to conserve the rangelands.

Table 26: Ecosystem services provided by the rangelands of the IHR

Provisioning services	Regulating services	Cultural services	Supporting services
Forage for livestock	Climate regulation	Spiritual, religious, historical	Nutrient cycling
Livestock products/derivatives (dairy products, meat, fur, wools, horns, skin, and hides)	Water regulation	Recreational	Water cycling
NTFP (including medicinal plants)	Flood mitigation	Aesthetic	Primary production
Fuelwood	Erosion regulation	Educational	
Fresh water	Carbon sequestration	Symbolic	
Fresh air			

Source: adapted and modified from MA (2005)

Challenges to Sustainable Management of Rangelands in the Indian Himalayan Region

There are two main categories of rangelands in the IHR: 1) temperate and sub-alpine hillside grasslands and village grazing lands, which are semi-natural and anthropogenic in nature as in many other parts of the world (Lambin et al. 2001), and 2) alpine moist and arid pastures in the Greater and Trans-Himalaya, which are natural ecosystems governed by climatic factors. The first category is believed to be of relatively recent origin (Whyte 1976; Yadava and Singh 1977; Rawat 1998; Blench and Sommer 1999), and has developed through reduction of forest cover, introduction of cattle, fire, and the widespread impact of humans over the last 10,000 years.

The recent rapid increase in human and livestock populations in the Himalayan region has led to increased pressure on the natural resources (Mishra et al. 2001; Awasthi et al. 2003; Harris 2010). In the Indian Trans-Himalayas, even the most remote pasture is utilized for livestock grazing (Bhatnagar et al. 1999). Overstocking seems to be a classic case of the tragedy of the commons, as livestock is individually owned while the land is communally grazed (Mishra et al. 2002). Recent socioeconomic changes have probably contributed to high levels of overstocking. Some of the challenges to sustainable management of rangelands in the region are described in the following sections.

Breakdown of traditional rangeland management systems

The entire IHR is undergoing rapid development. The ecologically fragile environment of the Himalayas is under pressure from construction of dams, roads, mining activities, and other biotic pressures, leading to loss of forest and pasture areas (Ram and Singh 1994). The existing mountain development policies, for example in Himachal Pradesh, are non-holistic, non-compatible, non-coherent, non-complementary, and non-community-oriented, and barely address the key principles and issues (Gulati and Gupta 2003; Hussain et al. 2008). Income insecurity of the herding communities following the shift to a cash economy, as well as the lure of a modern life, has forced many herders to find alternative employment and move to urban areas (Bhasin 2011). In addition, there has been a sudden influx of people from adjacent states and neighbouring countries, e.g., as construction workers, staff of development programmes, and refugees (Goodall 2007). Construction of infrastructure such as roads in remote areas has increased accessibility and the ability to overexploit rangeland resources; sedentarization of herders, increased tourism pressure, and overpopulation of livestock in many pocket areas have led to a breakdown of the traditional rangeland management system (Namgail et al. 2007).

Overgrazing

Overgrazing has caused the near complete loss of edible plant species in the Himalayan pastures, and the pastures are now heavily infested with weeds such as *Stipa*, *Sambucus*,

Aconitum, *Cimicifuga*, *Adonis*, and *Sibbaldia* (Misri 1995; Suttie et al. 2005; Saberwal 1996; Kala and Rawat 1999; Singh et al. 2000; Maikhuri et al. 2001; Nautiyal and Kaechele 2007; Kaur et al. 2010). It has been estimated that the increased cover by unpalatable species has resulted in a 20–50% decrease in the quantity of herbage production in the Himalayan grasslands, and a 10–15% decrease in the quality, compared to the potential (Patil and Pathak 1978).

Impacts of climate change

The direct impacts of climate change on the Himalayan rangelands are seen in changes in evaporation and runoff, vegetation composition and diversity, above-ground productivity and decomposition rates, carbon sequestration effects, increased risk of fire disasters, drying-up of wetlands/peatlands, submergence of pastures close to glacier lakes, and changes in wildlife habitats (Du et al. 2004; Shaoliang and Sharma 2009; Baker and Moseley 2007).

Information failure

The first and foremost factor that hinders effective management of rangeland resources is the information failure that arises from the lack of accounting of ecosystem services, and lack of understanding of how and at what rates the services are produced. In the absence of proper estimates of the stock of ecosystem services, and the fluctuation of services under a scenario of climate change and globalization, it is difficult to determine the net present value of the future flow of services. Confusion regarding the monitoring indicators (what will be monitored, inputs, state of the ecosystem, outcomes) also presents a challenge. Information failure can be dealt with by maintaining national statistics on the extent, conditions, and optimal livestock production function of rangelands through the National Natural Resource Management Systems set up by the Government of India. The information from the National Mission on Strategic Knowledge on Climate Change should also be integrated into this data base.

Market failure

Rangeland goods and services are seen as free goods, which can make proxy pricing difficult. Due to the diversity of resource users, and lack of communication and coordination among them, common resources tend over time to become open access resources, and the rules and norms for sustainable management become ineffective, leading to degradation (Hardin 1968). People living away from the rangelands benefit from their conservation in the form of ecosystem services (e.g., water and carbon sequestration) without having to pay anything, creating a scenario of market failure.

Intervention or policy failure

Lack of a common vision and mandate in the IHR among the development agencies and conservation departments controlling the rangelands and other natural resources, local people, and civil society organizations has created a classic case of policy failure. The

traditional single media focus (air, water, waste, forests) of past and present environmental laws and policies has not been able to secure provision of resources. This has led to the emergence of the concept of environmental laws and policies, with significant consideration given to sustaining ecosystem services and goods. Existing intersectoral policies often conflict and contradict with each other's objectives, resulting in changes in land use practices that affect ecosystem services. Ensuring that land use policy decisions do not inadvertently degrade ecosystems and their capacity to provide services for human welfare is a major challenge for the policy makers (TEEB 2010).

Services and policy interactions are mutual, one is dependent on and affected by changes in the other (TEEB 2010), but the scale at which ecosystem service changes happen as a result of policy decisions is both non-linear and unpredictable. The provisioning services provided by ecosystems have been central to economic and financial decisions and transactions, whereas services which cannot be translated into direct tradable goods have been largely ignored by policy makers until recently. As ecosystem services are neither fully captured by the markets nor adequately valued in monetary terms, they do not receive due importance in policy decisions (Costanza et al. 1997; Costanza et al. 1998; Bernard et al. 2009; TEEB 2008). Assigning a market value to ecosystem services proves useful when measuring trade-offs between society and nature when natural resources can enhance human welfare in a sustainable manner (Pagiola et al. 2004; Dasgupta 2009, 2010; DEFRA 2010; UK National Ecosystem Assessment 2010). Existing markets have 'failed' to conserve ecosystem services because they lack mechanisms to compensate resource users and thus do not send signals that encourage participants to use and manage natural resources sustainably (Whitten and Shelton 2005; Arifin and Hudoyo 1998). There are many other proximate factors, such as demand on existing services, the opportunity costs of conserving services, and unclear property rights, which add to the complexities of understanding the value of ecosystem resources and result in overuse of the common property resources (Gunningham and Young 1997; Collins and Whitten 2007; Bromley 1990; de Groot et al. 2009). As a result, there is suboptimal investment in conservation and management leading to ecosystem deterioration (MA 2005).

Scope for implementing PES in the Indian Himalayan Rangelands

Of the various strategies that have emerged recently to address declining rates of ecosystem service provision, payment for ecosystem services (PES) has become one of the more widely accepted tools (Patterson and Coelho 2009). PES is a voluntary, conditional agreement between at least one 'seller' and one 'buyer' over a well defined environmental service or a land use presumed to produce that service (Wunder 2008). The scheme is based on the assumption that valuing and paying for ecosystem services will help to solve the externalities resulting from market failure (Engel et al. 2008). Such payments, already underway in many parts of the world, benefit the providers of the ecosystem services, mostly poor landholders or disadvantaged communities, and can contribute to poverty alleviation (Pagiola et al. 2004).

PES thus provides an opportunity for 'win-win' scenarios, leading to its wider acceptance among conservation practitioners and policy makers in developing countries (van Wilgen et al. 1998; Miles and Kapos 2008). However, previous experience with incentive-based approaches suggests that it is unlikely that a PES approach will always be able to simultaneously improve livelihoods and increase ecosystem services, and that no single policy is right for every scenario. Therefore in order to implement a successful PES strategy, the social, economic, and environmental contexts need to interact with policy design and together determine policy outcomes.

As for other ecosystems, implementation of PES schemes for rangelands faces two types of challenge: 1) technical challenges, which are related to the difficulty of identifying and valuing ecosystem services; and 2) legal and institutional challenges, which are concerned with the governance and effectiveness of PES for the specific needs of biodiversity conservation (Nsoh and Reid 2013). The technical challenges arise due to lack of data or information on the ecosystem services, their ingrained complexities, opportunity costs, and studies on willingness to accept or pay by the people/local communities. The lack of studies on the intrinsic complexity of ecological functions, and the relationship between ecosystem functions, services, and human welfare, also poses a challenge for PES schemes (Brouwer et al. 2011; Farley et al. 2011; Muradian et al. 2013). Most ecosystem services and goods are considered free, and most of the time it is difficult to develop a proxy price for the ecosystem services, thus making the payment mechanism challenging. Further, the impact of factors such as globalization and climate change on the stock and flow of ecosystem services is unknown and uncertain. Another technical challenge is that of defining a relevant population (stakeholders) dependent on the services, and the beneficiaries of the PES schemes. Property rights distribution issues in the case of common property resources or government-owned land often present an institutional or policy challenge to PES. Confusion regarding the funding process for the PES mechanism presents the major challenge.

All the challenges mentioned above have a temporal and spatial scale element. The geographical scale disparity between ecological processes and decision-making institutions further complicates the PES mechanism. The costs to the local communities of conserving the rangelands are complex and difficult to estimate, and can be disproportionate to the benefits of the services as a result of the geographical scale at which the costs and benefits of the services are distributed. Some policies have impacts that last for long periods, while others may last forever due to irreversible changes, and this often presents a challenge to managers and policy makers on how to simultaneously ensure biodiversity conservation and community wellbeing through PES.

Regulation of property rights

Earlier legislative measures, such as the Indian Forest Policies of 1894 and 1952 and the Indian Forest Act of 1927, governed as they were by colonial and commercial interests, failed to address equitable access to the Himalayan resources. These legislative measures brought

the land resources under government rule and ownership, alienating local communities. The National Commission on Agriculture 1976 recommended promoting a social forestry programme to meet the need of user groups and provided for differential institutional arrangements for different stakeholder groups outside the limits of the reserved and protected forests; this is reflected in the 1988 forest policy and the policies framed thereafter.

Regulation and clarification of property rights (ownership and use rights) is considered crucial for dealing with the issue of market failure arising due to the notion of 'free goods' and 'easy access'. Notwithstanding, property rights, particularly usage rights of local communities, have remained ambiguous in almost all policies, although the Forest Conservation Act 1980 and National Environment Policy 2006 provide for legal recognition of traditional entitlements of forest dependent communities, as provisions made under the Forest Conservation Act of 1980 are not allowed to interfere with the rights of local communities, such as nistar rights (land set apart to meet the requirements of fuel, fodder, timber, and other necessities) (Ramanathan 2002) or concessional use rights provided under the Indian Forest Act 1927.

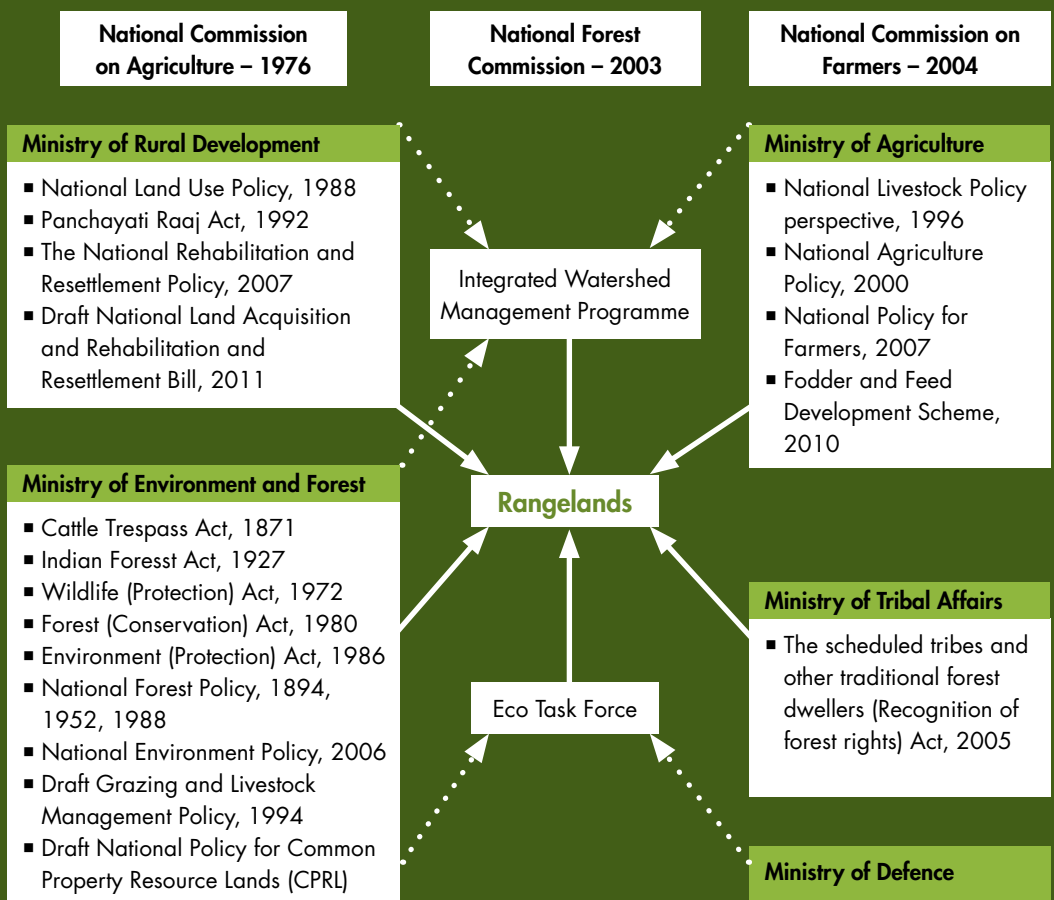
The Indian environmental and forest policy has been modified from time to time to adapt to the changing political-economic conditions. It has contributed substantially to minimizing environmental degradation and maintaining the ecological integrity of natural systems. While the policies of the production era were focused largely on the marketable goods provided by the natural ecosystems, such as timber and NTFPs, the protection era policies were largely regulatory and focused on a 'hands off' approach as far as natural ecosystems were concerned. In the policies promulgated during these two periods, the informatory and market instruments remained at the back. The only market instrument addressed was the levying of duty on timber and forest produce in the Indian Forest Act 1927. A clear mention of ecosystem services and well defined rules to protect and enhance them came only with the National Environment Policy 2006. All subsequent action plans and programmes of the Government of India have stated that the sustainability of ecosystem goods and services is their primary agenda. However, the need to focus on the Himalayas as a separate and unique ecosystem, based on their ecological characteristics and human interface, was not addressed until the National Action Plan on Climate Change in 2009, which has a 'National Mission for Sustaining the Himalayan Ecosystem' as one of its eight missions. With the growing awareness of the crucial ecosystem services provided by these ecosystems, and their potential role in mitigating climate change related impacts, the emerging policy focuses on maintaining the integrity of the ecosystems and thus ability to provide regulatory and buffering services.

Analysis of Indian Policy for PES for the IHR

The Indian national policies and legislative measures recognize the Himalayan rangelands as a unique complex system that provides ecosystem goods and services. The policies and measures include regulatory measures such as taxes, tolls, fees, permits, administrative charges, formulation of management plans, and setting of standards; encourage the use of market-based instruments, such as provision for consistent pricing, value chain analysis,

subsidies, and quality control; and have provision for persuasive instruments, such as dissemination of information, training and extension, education, and research. The Government of India's (GoI) national policies on natural resources have substantially contributed to minimizing environmental degradation and maintaining the ecological integrity of natural systems. However, the policies have not given adequate attention to rangelands, especially Himalayan rangelands, as a separate and unique ecosystem based on their ecological characteristics and human interface, although the issues of other ecosystems such as wetlands have been adequately addressed. Figure 25 shows the major policies and legislation that impact the IHR. The IHR is influenced by policies in at least four sectors: forests, agriculture and animal husbandry, rural development, and land use. However, rangelands are considered as 'common land' or 'wasteland' which can be used for tree plantation or easily diverted for other uses. Robust traditional institutions used to exist in the IHR to ensure their sustainable management, however, as a result of rapid socioeconomic and political transformation, these institutions have mostly become defunct. The imposition of

Figure 25: Policies and legislation controlling the Indian rangelands



several policies and acts, which are sometimes contradictory and overlapping, has led to a lack of clear tenure for local communities, confused land records between the revenue and forest departments, and other such issues of land rights and responsibilities. All these factors have accelerated the pace of rangeland degradation in the IHR.

Trends in Indian legislation related to ecosystem services

The overall trends in the legislation related to ecosystem services can be summarized as follows:

- **Production era (1927–1972):** During this period, forest management was closely linked with commercial interests since the 'need for realization of maximum annual revenue from forests' was considered vital and the relevance of forests to meet the needs of development and foreign trade were given prominence in management.
- **Protection era (1972–1988):** This was the period when the realization of forest and wildlife degradation was highlighted by conservationists in India and influenced by global debates and measures to provide legal protection to flora and fauna in their natural habitat.
- **Community participation era (1988–2006):** The Indian Forest Policy of 1988 represented a complete turnaround in the government's position on local people and forests and was the start of community participation in forest and wildlife management. The policies and acts formed during this era recognized and legalized the links between human welfare and ecosystems.
- **Climate change and globalization era (2006 onwards):** It was only with the promulgation of the National Environment Policy 2006 that impacts of climate change were addressed in policy.

Conclusion and Way Forward

The analysis shows that Indian legislative measures and policy have been mainly regulatory in nature. It is only in the recent era of climate change and globalization that all three instruments (market, information, regulatory) are being addressed, albeit the focus remains regulatory. Market instruments are particularly weakly represented in the legislation and policies. PES has not yet been taken up as a part of any policy. Policies are inconsistent and promote overstocking and unsustainable use, which in the long term could hamper the ecosystem services. The informatory, regulatory, and market instruments need positive synergistic interactions. A policy portfolio approach combining several measures would be the best choice for ecosystem conservation.

The major challenges for ecosystem services are measurement, bundling, scale-matching, property rights, distribution issues, sustainable funding, adaptive management, education and politics, participation, and political coherence (Farley and Costanza 2010). Implementing PES in the context of weak institutions is also challenging (Wunder 2007) due to unclear property rights and distribution issues. Most PES programmes have been implemented in the developed world where the institutional framework and property rights are strong (Clements et al. 2010); in the context of the rangelands of the Indian Himalayas, where the traditional institutions

have been eroded and a hierarchy of institutions exists, implementing PES poses a challenge. Here, we propose a multi-layered nested framework for the role of institutions in implementing PES (Figure 26).

Since ecosystem services are bundled together and are the joint products of intact ecosystems and their loss is irreversible, collective institutions should take the lead in PES (Jack et al. 2008; Farley and Costanza 2010). Any project, including PES, has conception and planning as the initial step, which needs support from global, national, and state level institutions. Fundraising needs to be done at all the spatial scales from global to local. The local level institutions in the IHR include the van panchayats, traditional institutions, and NGOs, and their participation is needed in managing access to information, conflict resolution, monitoring compliance, and enforcing laws, regulations, and contracts.

Recognition of the Himalayan rangelands (Central Rangeland Regulatory Authority) as a unique ecosystem that provides important ecosystem services is the first step. Geographic mapping and accounting for the rangelands ecosystem services in the rangeland areas need to be done to create baseline information. This baseline information can be used to obtain alternative land management regimes or scenarios, and to assess the levels and types of services that could be supplied under alternative land management regimes. Further, generation of baseline information will help in forecasting changes in services and societal

Figure 26: Framework depicting the role of institutions in PES implementation



need under alternative demographic, land-use, and climate change scenarios. There is an urgent need to have consistency in inter-sectoral policy to enable adoption of market-based instruments, including PES.

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