High altitude survival

Conflicts between pastoralism and wildlife in the Trans-Himalaya

Charudutt Mishra

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Charudutt Mishra

Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus van Wageningen Universiteit
prof. dr. ir. L. Speelman,
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Propositions

1. Classical nature conservation measures will not suffice, because the new and additional measures that have to be taken must be especially designed for those areas where people live and use resources (Herbert Prins, *The Malawi principles: clarification of thoughts that underlay the ecosystem approach*).

2. The ability to make informed decisions on conservation policy remains handicapped due to poor understanding of the way people use natural resources, and the impacts of such resource use on wildlife (*This thesis*).

3. It is easy to understand that 'too many' livestock in rangelands can compromise livestock production and the conservation of rangeland wildlife; how many is too many is the critical question (*This thesis*).

4. Bureaucracies should be catalysts for the advancement of knowledge rather than impediments as they sometimes become.

5. No modern war has been waged without the loss of innocent lives, and the war against terrorism will not be any different.

6. Killing countless more innocent people to bring to 'justice' the killers of innocent people violates the foundations of justice.

7. There is a theory which states that if ever anybody discovers exactly what the universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable. There is also an hypothesis, which I support, which states that this has already happened (after Douglas Adams, *Hitchhiker's guide to the galaxy*).

8. The surest proof that intelligent life exists elsewhere in the universe is that none of it has tried to contact us (after Calvin, *The indispensable Calvin and Hobbes*).

Accompanying the Doctoral Thesis *High altitude survival: conflicts between pastoralism and wildlife in the Trans-Himalaya*

Charudutt Mishra

November 2001, Wageningen

to sn, kiran, and
amitabh mishra
...in admiration, gratitude,
and much love

Contents

Abstract

Mishra, C. 2001. High altitude survival: conflicts between pastoralism and wildlife in the Trans-Himalaya. Doctoral Thesis. Wageningen University, The Netherlands. ISBN 90-5808-542-2

How harmonious is the coexistence between pastoralism and wildlife? This thesis is a response to repeated calls for a better understanding of pastoralism and its impacts on wildlife in India. Based on studies in the high altitude rangelands of the Trans-Himalaya that have a grazing history of over three millennia, I attempt to understand an agro-pastoral system and its conflicts with wildlife, with the ultimate aim of guiding conservation policy and management. Though the bulk of the thesis addresses the issues of resource limitation and competition between livestock and wild herbivores, an attempt is also made to understand the social aspects of livestock grazing. At the level of the family, which is the basic unit of production, the agro-pastoral system appears to suitably maximize production while mediating environmental risk. However, the families undergo substantial financial losses due to livestock depredation by the snow leopard *Uncia uncia* and the wolf *Canis lupus*. The endangered carnivores are persecuted in retaliation. Rangeland vegetation appears to be at different stages of degradation due to intensive and pervasive human use, and a global comparison reveals that the Trans-Himalaya fall at the low end of the range in terms of graminoid biomass. Animal production modeling and analysis of stocking densities reveal resource limitation for large herbivores at the landscape level, with a majority of the rangelands in the 12,000 km^2 study area being overstocked. Studies on the diet of bharal *Pseudois nayaur*, a wild mountain ungulate, and seven species of livestock, reveal substantial resource overlap. This, together with resource limitation, results in resource competition. Bharal get out-competed in rangelands with high stocking density, where reduction in bharal density is brought about by resource-dependent variation in fecundity and neonate mortality. Theoretical analyses reveal a consistent morphological pattern in species body masses in the Trans-Himalayan wild herbivore assemblage, arguably brought about by the interplay of competition and facilitation. The analyses also suggest possible competitive exclusion of several wild herbivores by livestock over the last three millennia. The results of the thesis are relevant to land use planning and conservation management.

Keywords: Pastoralism, agriculture, wildlife, Himalaya, competition, bharal, yak, livestock, snow leopard, wolf, herbivore, ungulate, resource, rangeland, steppe, mountain

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My parents and brother have had a major influence not just in my personal life, but in my professional one as well. This thesis is dedicated to them, a small tribute to their unstinting support, encouragement, and tolerance.

A. J. T. Johnsingh has been one of my mentors. To say that you have played an important role in my life would be an understatement. You have taught me natural history, shown me how to appreciate nature, and, above all, taught me to care for it. Without you, this thesis and so many other things would never have become possible.

My other mentor is one of the most exceptional and inspiring people I have ever known, H. H. T. Prins. These four years of knowing you and working with you has been a turning point in my professional life and way of thinking. Herbert, yours has been one of those contributions that I can never adequately acknowledge, so I'll not even try. Thank you for everything.

A special thanks also to Aparajita Datta, who has been a colleague and friend for the last ten years (and wife for the last two!). Loony, I am grateful to you for your support, for the stimulating discussions, for reviewing all those manuscripts, for the help in fieldwork, and above all, for egging me on and maintaining your confidence in me in moments when I lacked it myself.

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This thesis is a product of concern for a fascinating ecosystem on the roof of the world – for the barren yet spellbinding landscape of the Trans-Himalaya, for its rare and unique wildlife, for its rarefied but crisp and pure mountain air – and indeed for its custodians, the Trans-Himalayan people. Over the last few years of living with them, I have developed a deep love, respect, and admiration for these very gentle, and yet physically and mentally very tough people. The warmth that Spitians have shown me in those frigid heights has been unparalleled, their help indispensable. Two people who have been my closest associates, friends, guides, and family are Tandup Dorje 'Sushil' and Lobsang Gialson 'Sherpa'. Together we have worked, sported, eaten *momos*, got drunk, partied, watched *nabo* and *shingu*, eluded rock falls, risked avalanches, faced blizzards, crossed glaciers and high passes, and negotiated cliffs, landslides and ice-cold rivers. Without your presence and enthusiasm, and indeed your courage, this work would have been impossible.

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November 2001, Wageningen — Charu

Chapter 1

On pastoralism and wildlife conservation: an introduction

Pastoralism and wildlife conservation: the problem

The impression has thus arisen that there can be harmony between wildlife and pastoral exploitation. This idea is fuelled by statements such as '...*Confronted with this stark reality (of coexistence between wild herbivores and livestock), in their lop-sided perception of the heritage at stake, preservationists have repeatedly sought either piecemeal eviction of the Maasai from literally the whole of their homeland, or definite subjugation of interests of this indigenous community...*' (Parkipuny 1989). Partly as a reaction to the preservationists' type of criticism by local community leaders, and partly based on the idea that wildlife and livestock can indeed live in harmony together on the same land, some conservation authorities reacted by recommending a type of management of conservation areas, and even national parks, in which there is a place for pastoral people... But how harmonious is the relation between pastoralists and large game?

(Prins 1992)

The preceding sentences are reproduced from a paper written a decade ago that asked if there was harmonious coexistence between pastoralism and wildlife in East Africa, and whether or not livestock and wild herbivores competed for food. These sentences, even today, succinctly sum up an important conservation concern and associated debates in many parts of the world. In essence, they also capture the spirit of the present thesis.

India's preservationist wildlife conservation policy aims at curtailing consumptive use of resources in areas designated as wildlife reserves (Mishra 2000). In the context of livestock grazing, this is easier said than done; India has the world's largest livestock population of 449 million (in 1994, WRI 1996). Although wildlife reserves constitute less than 5 % of the country's total area, three-fourths of them are grazed by livestock (Kothari *et al.* 1989). The few restrictions that the Government has been able to impose on resource use in wildlife reserves have resulted in local hostility and absence of local support for conservation programmes. Human-wildlife conflicts in the form of loss of crops, livestock, and even human lives, to wild animals further aggravate the situation (Madhusudan and Mishra *in press*). Against this background, the merits of the preservationist approach in India are being increasingly questioned on social, ethical, and even ecological grounds (Saberwal 1996, Mishra 2000).

Yet, the ability to make informed decisions on conservation policy remains handicapped due to poor understanding of the way local people use resources, and the impacts of such resource use on wildlife. How does livestock affect wildlife? Do livestock and wild herbivores compete for food? Do pastoralists keep too many livestock? How many is too many? Can there be harmonious coexistence or is there always conflict between pastoralism and wildlife? Can there be effective solutions to such conflicts? Time and again, the Indian scientific community has been reminded of its responsibility to work towards a better understanding of pastoralism and its impacts on wildlife (Rodgers 1988, Mallon 1991, Krishnaswamy 2000). This thesis is a step in that direction, and tries to understand a traditional agro-pastoral way of life and its impacts on wildlife. It focuses on resource limitation and competition between livestock and wild herbivores in the high altitudes of the Indian Trans-Himalaya (Fig. 1.1). In the following sections, I briefly outline the conceptual framework for the study, followed by the organization of the thesis.

Resource limitation and competition: the framework

A resource is defined as a substance or factor consumed by an organism that can lead to increased growth rates as its availability in the environment is increased (Tilman

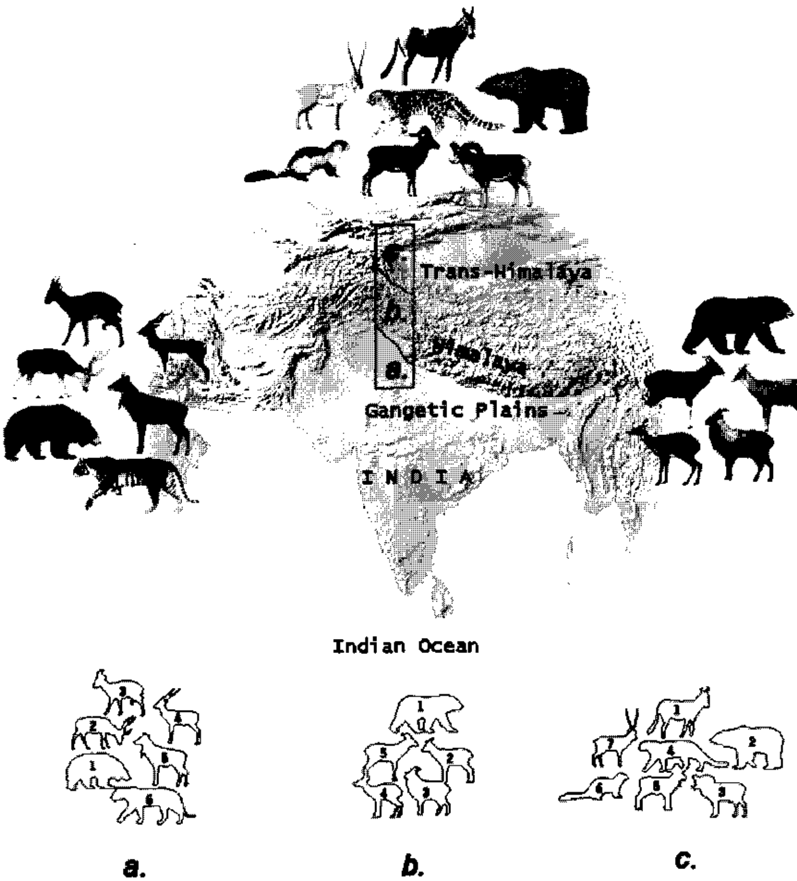


Fig. 1.1 The northern part of the Indian sub-continent includes the Gangetic Plains and the Himalayan Mountain Range. North of the Greater Himalaya, in its rain-shadow, lies the Trans-Himalaya, covering over 2.6 million km^2 of the Tibetan Plateau and the Tibetan Marginal Mountains. As one moves up from the Gangetic Plains to the Himalayan Mountains, tropical moist deciduous forests make way to sub-tropical and temperate forests. At the tree-line, *krummholz* vegetation lies interspersed with alpine meadows. As one crosses over to the Trans-Himalaya, these moist forests and meadows are abruptly replaced by dry alpine steppe vegetation. These changes in vegetation are associated with changes in wildlife, such as the large mammal assemblages shown in the figure.

a. The Gangetic Plains have dry to moist deciduous forests, scrublands, grasslands and woodlands. Some representative large mammals from the area include: **1** sloth bear *Melursus ursinus*, **2** chital *Axis axis*, **3** barking deer *Muntiacus muntjak*, **4** black buck *Antilope cervicapra*, **5** nilgai *Boselaphus tragocamelus*, and **6** tiger *Panthera tigris*

b. The Himalayan Mountain Range includes the Siwalik Hills (maximum altitude 1500 m) that overlook the Gangetic plains, the Middle Himalaya (up to 2500 m), and northernmost Greater Himalaya that include several of the world's highest peaks. Some representative large mammal species from the entire range include: **1** black bear *Selenarctos thibetanus*, **2** goral *Nemorhaedus goral*, **3** Himalayan tahr *Hemitragus jemlahicus*, **4** musk deer *Moschus moschiferus*, and **5** serow *Nemorhaedus sumatraensis*

c. The Trans-Himalaya is characterized by an absence of forests, the generally sparse vegetation being dominated by low shrubs, graminoids and forbs. Most of the area is above 3500 m altitude. Representative large mammals shown in the figure include species from the plateau as well as the mountains: **1** kiang *Equus kiang*, **2** brown bear *Ursus arctos*, **3** Tibetan argali *Ovis ammon*, **4** snow leopard *Uncia uncia*, **5** bharal *Pseudois nayaur*, **6** longtailed marmot *Marmota caudata*, and **7** chiru *Pantholops hodgsoni*

1982). Species or populations compete for resources '...if and when resources from a limited supply are not available or are reduced for one species due to the effects or presence of another species' (Wiens 1989, p.3, also see Prins 2000). The role of competition as a force structuring species assemblages has long been ingrained in ecological thought. Almost a century ago, experiments by Tansley (1917) had recorded that the presence or absence of a species in a given area could be determined by inter-specific competition. Subsequently, Gause (1934) demonstrated that the joint placement of pairs of similar species that compete for the same resource could cause species extinctions as a result of competition, a mechanism called competitive exclusion. Yet, the contemporary tenet on its influencing the species composition of ecological assemblages has long remained polarized. Ecologists have either strongly advocated (Hutchinson 1959, Karban 1989, Denno *et al.* 1995, Hudson and Stiling 1997, Prins and Olff 1998) or relegated the importance of inter-specific competition in structuring species assemblages (Connell 1983, Lawton and Strong 1981, Schoener 1983). The role of competition in structuring large herbivore assemblages remains even more obscure, both in practice and theory. This owes largely to the logistic difficulty in manipulating large herbivore populations and measuring competition at the population level (Kie *et al.* 1991). Against such an enigmatic backdrop, it is hardly surprising that the millennium-old debate over competition between wild herbivores and livestock has remained a heated controversy (Stover 1985, Prins 1992, Noss 1994). Recent reviews indicate a remarkable worldwide scarcity of information on competition between these two groups of herbivores (Putman 1996, Prins 2000).

Species populations are believed to often compete indirectly through their effects on resource availability, rather than by directly preventing each other from accessing the resource, i.e., competition often occurs when the amount of resource available for one species gets reduced due to resource use by another (Huisman 1997; see Fig. 1.2). This is called resource competition. Large herbivores rarely if ever prevent members of other species directly from accessing a resource, a mechanism called interference competition (Prins 2000). This thesis therefore focuses on resource (forage) competition between livestock and wild herbivores.

In order to understand the mechanism of resource competition, we start by graphically examining the relationship between consumer species populations and resource availability in their habitats (Fig. 1.3). It is assumed that the consumer populations and resource availability are inter-dependent. Thus, not only is the intrinsic population growth rate (r; the rate at which a population changes over time) of consumer species resource-dependent (variation in resource availability causes variation in growth rate), but also, conversely, the resource availability in the habitat is consumer-dependent (increasing consumer populations decrease resource availability). In this highly simplified system we see that r for each species population increases in a similar fashion with an increase in resource availability (Fig. 1.3*a* and *b*). However, the equilibrium resource level, represented by the point on the resource axis that corresponds to zero population growth rate, is greater for species B (Fig. 1.3*b*; represented by B*) than for species A (Fig. 1.3*a*; A*). As the resource availability in the habitat declines below B*, r for B becomes negative. Similarly, as the resource availability declines below A*, r for A becomes negative. Obviously, declines in resource availability below these points (A* or B*) are accompanied by respective population declines of A and B. These equilibrium resource levels of each species in a given habitat could then be considered as their points of resource limitation.

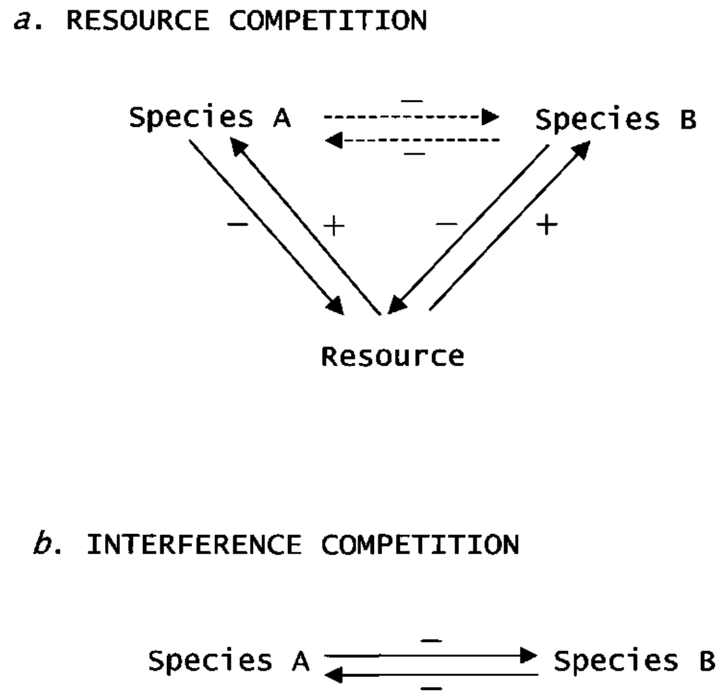


Fig. 1.2

a. Resource competition, where two species, by using the same resource, have a negative effect on each other indirectly. Solid and broken arrows represent direct and indirect interactions, respectively (modified from Begon *et al.* 1986, Huisman 1997).

b. Interference competition, where two species have a direct negative effect on each other.

In situations where the two species share the resource and reduce its availability jointly, species A will generally be the superior competitor (Fig. 1.3*c* and *d*). This is because initially (when populations are close to zero), both A and B will have a high r and their populations will expand rapidly (Fig. 1.3*d*). However, increasing consumer populations will cause the resource availability in the habitat to decline, and this will be accompanied by a decline in r for both species. Nevertheless, even as r declines, both populations will continue to grow (albeit at a decelerating rate) until the resource availability in the habitat becomes equal to B* (Fig. 3*d*). At this point, r for species B becomes zero. Since the population of A still continues to increase, the resource availability declines further and the population of B starts decreasing. The population of A stabilizes (growth rate becomes zero) only when the resource availability in the habitat reaches A* (Fig. 3*d*). Thus, in this model system, A is the superior competitor, and could potentially cause the competitive exclusion of B (Huisman 1997).

Getting back to the real world of plants and herbivores, resource limitation in large herbivores often manifests itself in a loss of body condition of animals, increased mortality and reduced fecundity (Clutton-Brock *et al.* 1988, Sæther 1997). At high density, livestock, or for that matter, any herbivore species could significantly reduce resource (forage) availability in rangelands. This can be brought about by instantaneous effects of forage consumption, as well as long-term changes such as a reduction in plant cover, changes in plant species composition, etc. (Prins 1989). As the forage availability in rangelands becomes limiting (assuming similar resource

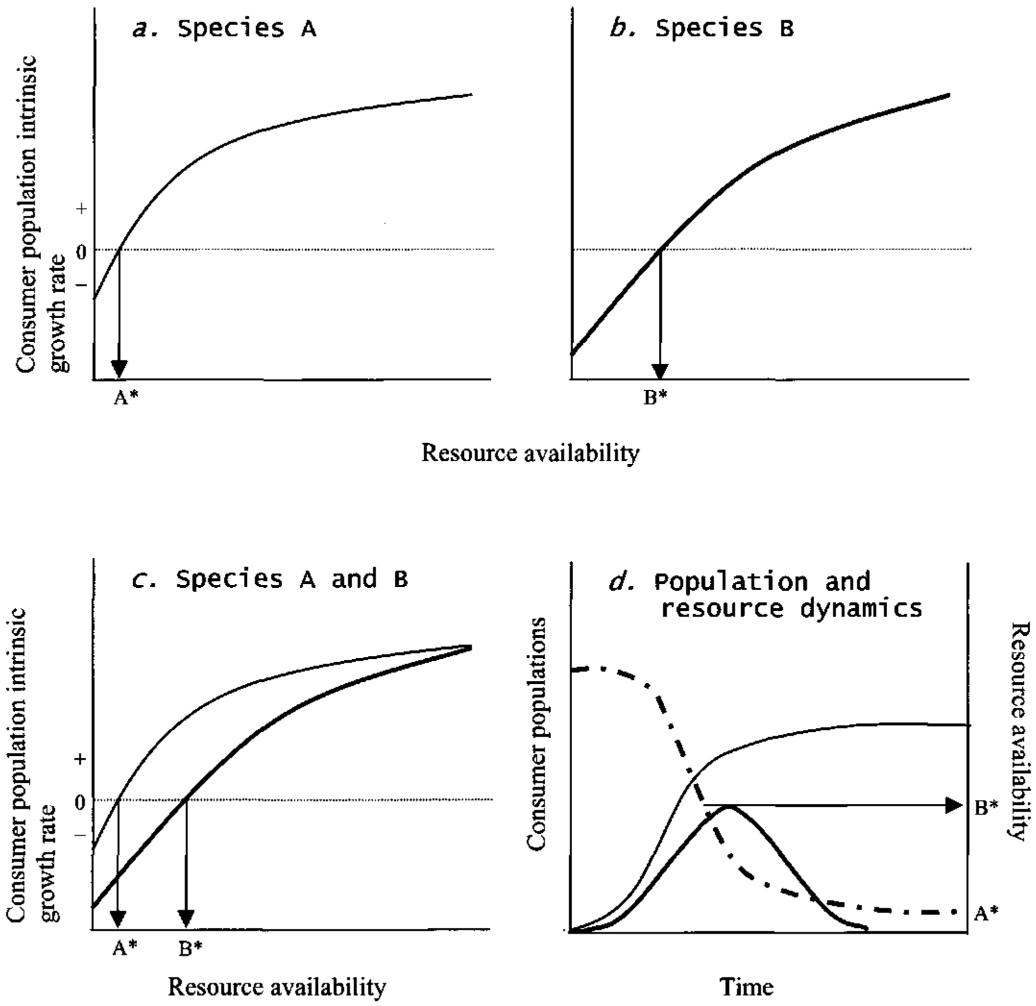


Fig. 1.3

a and b. Graphical representation of intrinsic population growth rates (vertical axes) of consumer species A and B in relation to resource availability (horizontal axes). Hatched line represents zero growth rate, where consumer species undergo no net change in population (number of births equal number of deaths). A* and B* represent equilibrium resource levels, and can be considered as points of resource limitation (see text).

c. When A and B occur together and compete for a common resource, species A will be the superior competitor since A* < B*.

d. Graphical representation of the dynamics of competing populations and resource availability over time. In the beginning, populations of both A and B increase rapidly, accompanied by a reduction in resource availability (broken line). As the resource availability declines below B*, the population of B starts decreasing. B may be driven to competitive exclusion as the population of A continues to increase. The population of A stabilizes as the resource availability equals A* (after Huisman 1997).

limitation levels for livestock and wild herbivores), resource competition can be expected.

At this point, an important question raised earlier surfaces again, how high is high livestock density? How does one establish whether large herbivore density in a rangeland is high enough to cause resource limitation? There are many possible ways of addressing this question. One could estimate, through measurements of available forage, an 'optimal' level of 'energy consumption' for a given rangeland (Prins 1992). As the forage harvest by herbivores approaches and exceeds this level (a condition called overstocking), one can expect that wild herbivores begin to get out-competed (Prins 1992). In the case of livestock, sustained overstocking becomes possible because the effects of competition and resource limitation, especially on adult mortality, are altered by provisioning (supplemental fodder) and medical care. 'Overstocking' is generally not seen in systems that have only wild herbivore species (Prins 1989). Thus, livestock populations can continue to grow even as the resource availability in the habitat declines below the equilibrium resource availability discussed earlier (Fig. 1.3). Wild herbivores, which are not provisioned, cannot. Generally speaking then, livestock would be superior competitors compared to wild herbivores. 'Inflated' densities of livestock (overstocking), often coupled with increasing human populations and land use changes, have the potential to cause competitive exclusion of wild herbivores – this has been called *the pastoral road to extinction* (Prins 1992).

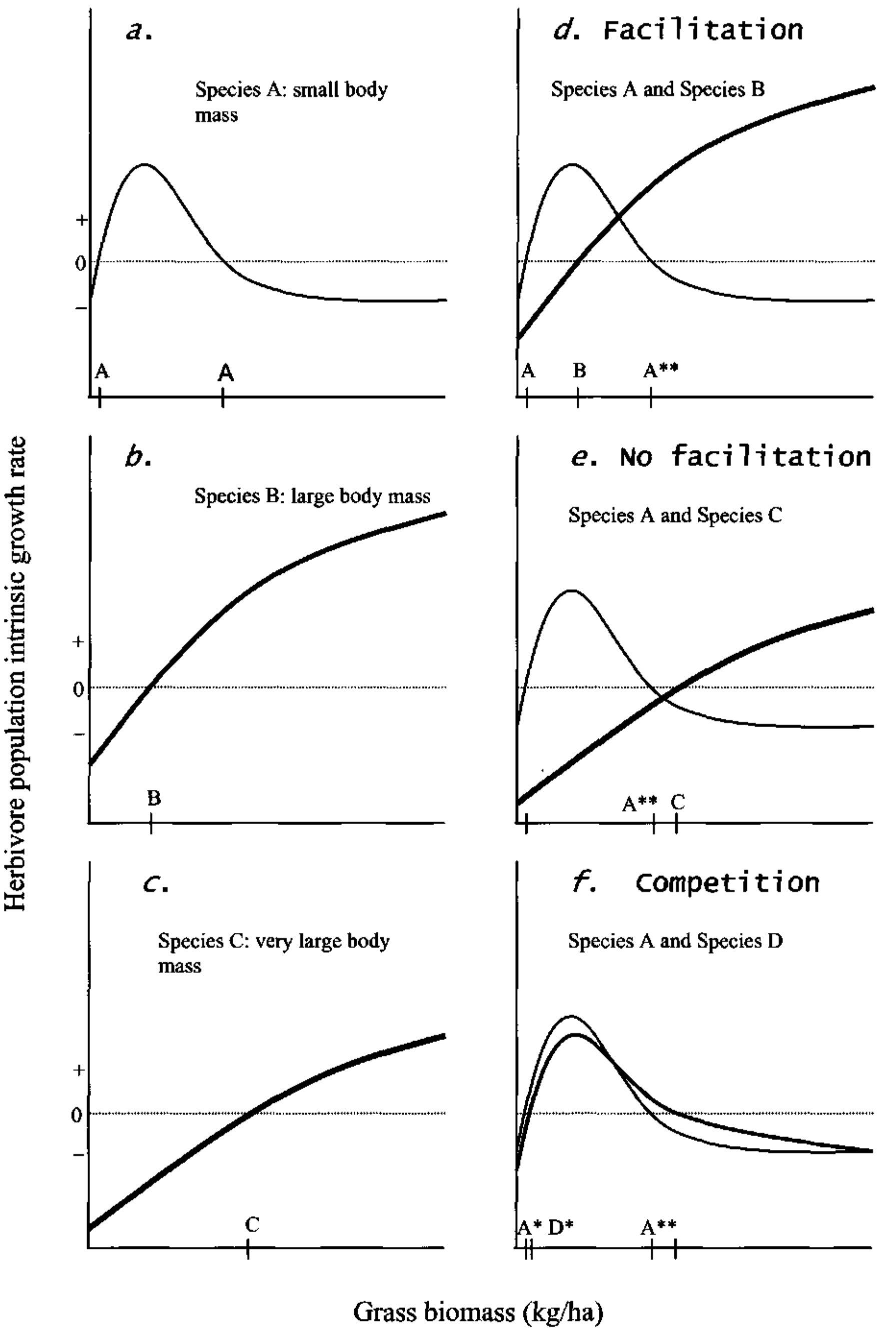
While overstocking in rangelands strongly points to resource limitation, it need not imply competition between livestock and wild herbivores unless there is overlap in resource use. Competition would occur if wild herbivores share the same resources, i.e., eat the same species of plants. If they do, more direct evidence of competition would be if high livestock density is associated with a loss of body condition, increased mortality and reduced fecundity of wild herbivores, as mentioned earlier.

Any discussion on competition among large herbivores would be lop-sided without mentioning facilitation. Large herbivores that predominantly feed on grass, called grazers, present an interesting paradox. One species of grazer, by feeding on grass and reducing its biomass may compete with another species, as seen earlier. Under different conditions, however, it may actually benefit another grazer species, through a mechanism called facilitation (Prins and Olff 1998). Two issues are involved here. Firstly, the quality of grass is inversely related to its standing biomass, and, secondly, large grazers are better suited at handling high biomass forage compared to smaller ones (McNaughton 1979, Mattson 1980, Van Soest 1982, Michulnas *et al.* 1995, Voeten 1999). A large grazer, by feeding and reducing the standing biomass of grass,

Fig. 1.4 Graphical representation of competitive and facilitative interactions among large grazers in relation to their relative body masses (redrawn from Prins and Olff 1998). Horizontal axes represent standing biomass of grass, while vertical axes represent the intrinsic growth rates of herbivore populations. Points marked on horizontal axes represent equilibrium grass biomass when grazers undergo no net change in population (as in Fig. 1.2). ***a***, ***b***, and ***c*** depict how intrinsic growth rates of different sized grazers respond to standing biomass of grass, while ***d***, ***e***, and ***f*** depict species interactions.

a. For a small-sized grazer (species A), the growth rate rapidly increases at low grass biomass. As the biomass of grass continues to increase, its quality declines. Thus, beyond a threshold, the intrinsic growth rate starts declining due to reduced grass quality with increasing grass biomass.

***b* and *c*.** For large and very large sized grazers (species B and C, respectively), the intrinsic growth rate increases with increasing grass biomass, since large grazers are capable of handling high biomass, low quality forage.



d. Species B facilitates species A. These species are neither 'too similar', nor 'too different' in their body masses. The larger species B brings down the grass biomass to a level where the grass quality is suitable for A. In a constant environment, A could actually outcompete B. However, environmental variation in productivity allows co-existence.

e. There is no facilitation, since the body mass difference between species C and species A is 'too high'. C maintains grass at a relatively high standing biomass, and as a result, its quality is not good enough for A.

f. Species A and species D are 'too similar' in body mass, and, consequently, there is competition.

can thus enhance forage quality, and thereby facilitate grazing by a smaller species. Alternately, when the body masses of the two species are very different, the smaller species may not benefit from facilitation. This is because the equilibrium biomass of grass maintained by the larger herbivore might still be too large for the grass quality to become suitable enough for the smaller species. Further, if the body masses of these species are very similar, they may compete for resources. This is perhaps best explained graphically (Fig. 1.4). In situations where there is facilitation, the smaller grazer could eventually emerge as the superior competitor if it has a lower equilibrium resource level (Fig. 1.3) (Actually, the smaller grazer might have more than one equilibrium resource level as seen in Fig. 1.4*a*. This has potentially important implications in understanding herbivore-habitat dynamics as shown by Van de Koppel and Prins 1998, but is peripheral to the present discussion). However, spatial and temporal variation in grass production and harvest may allow coexistence of species (Prins and Olff 1998). Finally, in relation to resource availability, facilitation is likely to be the dominant interaction amongst herbivores at high graminoid biomass, while competition becomes important at low biomass (Van de Koppel and Prins 1998).

Based on theoretical arguments and some empirical evidence, it has been recently suggested that in large wild grazer assemblages, one can expect an 'optimum' difference between body masses of grazer species, ultimately brought about by the interplay of competitive and facilitative interactions (Prins and Olff 1998). Such morphological relationships (in this case a constant weight ratio) between the members of a guild have been observed in other taxa (carnivores, birds etc.), and are believed to be proximately brought about by character displacement (a co-evolutionary response) and species sorting (an ecological response), both being consequences of competition (Dayan and Simberloff, 1998). Whether many wild herbivore assemblages are indeed structured by such processes, and whether they do follow constant weight ratios, remains to be seen.

The preceding paragraphs broadly outline the ecological framework on which the bulk of the present thesis is founded (Chapters 4 to 7). The first section of the thesis (Chapters 2 and 3), however, is purely a product of living with and trying to understand a remarkable people and their fascinating way of life.

Pastoralism and wildlife conservation: the thesis

This thesis is a response to repeated calls for a better understanding of pastoralism and its impacts on wildlife in India. Focussing on the high-altitude rangelands of the Trans-Himalaya (Fig.1.1) that have a long grazing history, I attempt to understand both ecological and social dimensions of livestock grazing, with the ultimate aim of guiding conservation management and policy. The thesis is organized in two sections. In the first section (Chapters 2 and 3) we try to understand the social aspects of livestock grazing, land use, and human wildlife conflict in Spiti Valley of the Indian Trans-Himalaya (Fig. 1.5). The second section (Chapters 4 to 7) focuses on resource limitation and competition between livestock and wild herbivores.

A detailed description of what is now a Buddhist agro-pastoral system, a way of life that probably dates back several millennia, sets the social backdrop for the thesis (Chapter 2). The chapter focuses on the diversity of social, agricultural, and livestock husbandry practices in Spiti Valley of the Indian Trans-Himalaya. We describe land use and access to resources, and establish how the agro-pastoral production system strives to mediate risks posed by climate, geology, and wildlife. We conclude the chapter by discussing several examples of local innovation and experimentation, which point to a highly adaptable and dynamic production system.

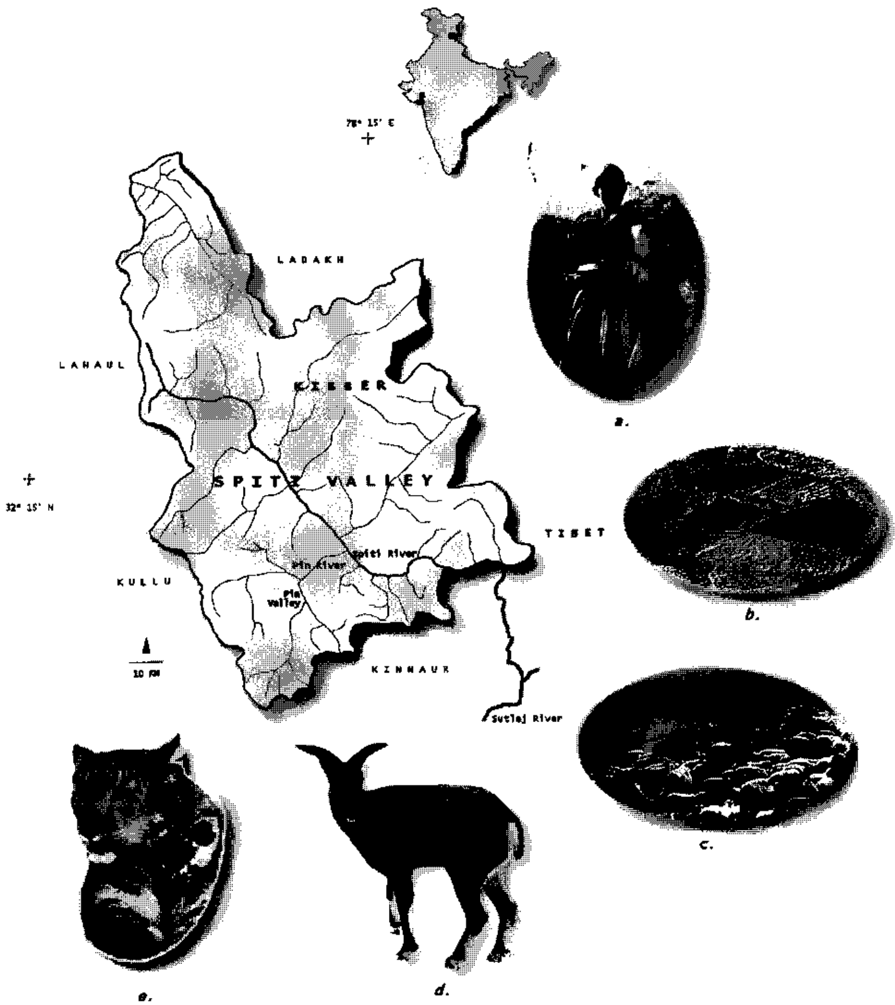


Fig. 1.5

a. Most of the Trans-Himalaya, including the Spiti Valley (12000 km^2), has been inhabited by pastoral and agro-pastoral people for several millennia. Most people are Buddhist.

b. The people of Spiti Valley raise single crops of barley, green pea, black pea, and potato during the short growing season.

c. Livestock includes the yak, cow, their hybrids called *dzo* and *dzomo* (males and females, respectively), sheep, goat, horses and donkeys.

d. Three species of large wild herbivores presently occur in Spiti, ibex *Capra ibex*, bharal *Pseudois nayaur* (seen in the figure), and woolly hare *Lepus oiostolus*.

e. Large carnivores in the area include the snow leopard *Uncia uncia* (seen in the figure) and the wolf *Canis lupus*. See chapter 2 for a detailed account of the study area and its agro-pastoral system.

When human habitation and large mammal habitats are interspersed with each other, as is the case in most Indian wildlife reserves, conflicts between humans and wildlife are unavoidable (Madhusudan and Mishra *in press*). In chapter 3, the costs borne by the agro-pastoralists for living with wildlife are evaluated. I analyse the alleged financial losses due to livestock depredation by large carnivores, the snow leopard *Uncia uncia* and the wolf *Canis lupus*, and their retaliatory persecution by the agro-pastoralists. Both these carnivores are globally threatened. The chapter sheds some light on the issue of harmonious co-existence (or the lack thereof) between pastoralism and wildlife.

Several Trans-Himalayan wild herbivores, the natural prey of these carnivores, are also threatened with extinction. In the second section of the thesis, I shift the focus from the pastoral society to the ecological impacts of pastoralism, especially on this wild large herbivore assemblage. In chapter 4, we first set an ecological backdrop by briefly describing the vegetation formations in a 31 km^2 rangeland in Spiti. The formations are described in terms of their plant species-composition and resource availability (forage biomass). We also outline the potential changes in rangeland vegetation in response to the principal forms of human impacts – livestock grazing, collection of fuel, and water harvest for agriculture.

I then present evidence for resource limitation at a much larger spatial scale by establishing that most of the rangelands across the 12000 km^2 Spiti Valley might be overstocked (Chapter 5). Reduced livestock production due to overstocking has been a subject of much deliberation in the worldwide debate on overgrazing, but evidence for it is remarkably scarce. Using empirical data on animal performance together with simple animal production models, we first estimate an optimal stocking density that would maximize livestock production in these rangelands. We then look at the stocking density in rangelands belonging to 40 of the *c.* 60 villages in the valley, in order to evaluate what proportion of them might be overstocked?

After establishing resource limitation (Chapter 5), we ask whether the bharal *Pseudois nayaur*, the most abundant of the three large wild herbivores present in Spiti, and livestock compete for forage (Chapter 6). We examine the diets of bharal and all seven species of livestock that share the rangelands. After evaluating resource overlap, we test several predictions related to demography and morphology of livestock and bharal to ascertain whether there is resource competition between them.

We were intrigued by the fact that Spiti Valley has only three species of wild herbivores compared with nine in the neighbouring regions of the Trans-Himalaya. In Chapter 7, we explore the causes of rarity of herbivores in Spiti Valley against the backdrop of competition theory. We revisit the *pastoral road to extinction*, and, taking recourse to recent theoretical advances in herbivore community ecology, specifically ask if this low species richness in Spiti Valley could be a consequence of competitive exclusion by livestock?

In Chapter 8, the main findings of this thesis are revisited. This is followed by a discussion on how the ideas of harmonious coexistence between pastoralism and wildlife generally come to prevail. Contributions of the present thesis in a broader scientific and conservation context are highlighted. In the light of the findings, I discuss the needs and possible approaches for better conservation management in the Trans-Himalaya. Finally, in line with the spirit of field biologists who are '...more concerned with what is missing in a situation than with what is present' (Soulé 1986 p. 1), the limitations of this thesis and avenues for future work are outlined.

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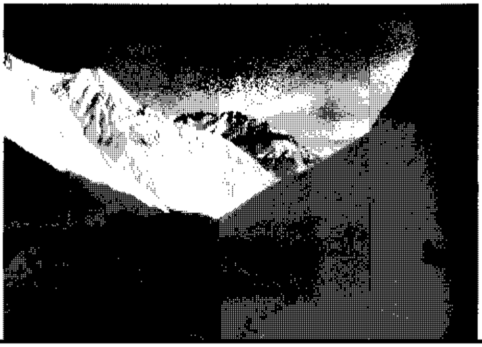

The high altitude Spiti Valley in the Trans-Himalaya is characterized by a short growing season. Most of the area remains snow-clad in winter (right). Snowmelt is an important source of soil moisture for agriculture as well as for rangeland production.

The agro-pastoral people of Spiti Valley have constantly experimented and evolved their production system. There have been radical changes in economy and land use especially over the last two decades. Yet, Spitians maintain strong Buddhist values, and retain several aspects of their traditional way of life. Part of the indigenous population comprises of celibate monks who are associated with any of the several monasteries in the region (right). The agro-pastoral way of life described in the Chapter is perhaps still characteristic of many regions in the Trans-Himalaya.

Abstract

We describe the diversity and dynamism of social, agricultural, and livestock husbandry practices in a traditional mountain production system in the Indian Trans-Himalaya. These are interpreted in the context of their role in mediating environmental risk. The production system is a little known Buddhist agro-pastoral system in the Spiti Valley (*ca.*12,000 sq. km) in the Himalayan state of Himachal Pradesh. The local population (ca. 10,000) belongs to one of the three Buddhist sects *Gelukpa, Shakyapa,* or *Ningmapa,* is related by blood, and shares a common Tibetan dialect. Family is the basic unit of production, though families are highly dependent upon the community to meet production goals. A village council appointed on rotation and functioning democratically is responsible for village administration, and is the arbiter of all decision-making pertaining to collective work and settling disputes. The council ensures equal access of families to common resources, as well as equitable distribution of responsibilities among them. Systems of primogeniture, celibacy, and polygamy seem to have prevented the fragmentation of land holdings and limited population growth. The diversity of practices in the agropastoral system seems adapted to the risk-prone mountainous environment, the risks being climatic, geological, and those posed by wildlife. The system seems to aim at maximizing production while mediating environmental risk. The production system comes forth as highly dynamic, characterized by continuous innovation and experimentation.

Introduction

The diversity of practices and dynamism (ease of change) in traditional mountain production systems of south Asia have been the focus of recent studies (Bishop 1998, MacDonald 1998). 'This (diversity) reduces risk in an environment where there is high dependence on natural forces and maximizes access to the full range of resource available. Flexibility in response to the stresses of mountain habitats is also a key to successful human adaptation to mountains' (Bishop 1998, p. 22). The emerging consensus seems to be that indigenous production systems are generally efficient and well adapted to the mountainous environment (e.g. Brower 1990, Miller and Bedunah 1993, Bishop 1998, MacDonald 1998). As expressed by MacDonald (1998, p. 289) '...such diversity is a contextually rational response to local environmental conditions as it acts to reduce environmental risk and minimize the vulnerability of local villagers'.

In this article, the diversity and dynamism in a little known Trans-Himalayan production system are described and interpreted in the context of their risk-mediating roles. We define risk as the possibility of suffering loss or harm from environmental causes (both natural and human induced) or social disparity. Risk mediation is the reduction or elimination of this possibility, as well as the minimization of its impacts in case such a loss or harm does occur. The production system in question is a Buddhist agropastoral one in Spiti region of the Indian Trans-Himalaya bordering Tibet. In the concluding part of this article, we analyze several examples of local experimentation, innovation and change, all of which point to a highly dynamic and adaptive production system in Spiti. A single large village, Kibber (altitude 4200 m), was the focus of intensive study. Most of the information on the agro-pastoral system comes from a participant-observation study of this village (1996 and 1997 to 2000), combined with extensive, semi-structured interviews of the local villagers. Periodic, though not extensive, observations and interviews were also conducted in the village Sagnam (3700 m) of the Pin Valley region of Spiti. This was done to get a better representation of the entire region, since Pin Valley harbours a different social setup than the rest of Spiti.

Spiti and its production system

The 186,000 km^2 of the Indian Trans-Himalaya, the rain-shadow region of the Greater Himalaya, includes parts of the Tibetan Plateau and the Tibetan Marginal Mountains. Spiti region (31°35' to 33°0' N and 77°37' to 78°35' E; altitudinal range 3350 to 6700 m) in the Trans-Himalayan Lahaul and Spiti District spans an area of over 12000 sq. km in the catchment of the River Spiti. The Greater Himalaya in the South, Ladakh in the North and Tibet in the East flank the region. The present-day Sino-Tibetan speaking inhabitants belonging to the Mongoloid stock are thought to have occupied the rain-shadow regions of the Greater Himalaya around the beginning of the first millennium BC, and the earliest written records for Spiti date back to 630 AD (Handa 1994). Buddhism was introduced in the region in the 8th century AD. The present local human population (ca. 10,000) is entirely Buddhist, belonging to the *Gelukpa*, *Ningmapa*, and *Shakyapa* sects. The inhabitants are agro-pastoral, though in some villages, the men also work as guides for trekking tourists and mountaineers. A few people have jobs in the local state Government offices or work as daily wage laborers in Government departments. The region is visited in summer by transhumant pastoralists from Ladakh in the north (largely for barter trade) and from the main Himalaya in the south (for grazing). Locally, families own most of the agricultural land, whereas the grazing land is common to the village with equal access. The village community may own some agricultural land collectively, and in Pin Valley, some families own small pastureland where they have priority access to fodder. Lineage allegiances and associations through marriage (more common within the village rather than outside, especially in larger villages) are quite strong.

The climate in Spiti is arid, with most of the precipitation in the form of snow. The agricultural production is thus entirely dependent upon snowmelt, brought to the terraced fields around villages from glacial ponds by long channels (several km) dug along the contours. Limited irrigation water and early autumn frost are the main climatic constraints on agriculture. Crop diseases are very rare, and pest outbreaks unheard of. The main crops presently grown are barley, green pea, and a local variety of green pea (henceforth called black pea, translated from the vernacular). The black pea is grown largely for fodder, although people do consume a fraction of the seeds. In addition, potato, and mustard are also grown. There are fruit (apple and apricot) orchards in a few of the low-lying downstream villages.

The main agricultural activities begin around mid-April with ploughing and sowing, following which the irrigation channels are repaired and the sown fields levelled for irrigating. The fallow lands are also ploughed around this time. In Pin Valley, no fallow is left, and the ploughing is done only once in the beginning of the season. Irrigation starts around mid-May. Fields with green peas are weeded after three bouts of irrigation, while the barley fields after seven or eight. In Pin Valley, barley fields are weeded thrice, after first irrigation, third or fourth irrigation, and the fifth, when the seeds are about to set. Similarly, black pea is weeded only once, before irrigating. The plant is uprooted and stored around the first week of July as winter fodder. The fallow is ploughed around the same time. Mustard and potato are planted a month later than the other crops, and harvested around the end of September. Green pea is harvested thrice between mid-August and early October before it is uprooted. Barley harvest starts around the third week of September and is complete by the first week of October. The fallow is ploughed once again after the harvest. The fields are manured around the first week of November. There is a period of rest up to March as far as the agricultural activities are concerned. Towards the end of March, dust and ash are sprinkled on the fields to accelerate snowmelt, and once again the main agricultural cycle begins. Winter is the time for festive occasions (such as marriages and local festivals) as well as devoted to the reading of Buddhist scriptures.

Livestock reared includes yak, cattle, *dzo* and *dzomo* (male and female hybrids respectively of yak and cattle), horse, donkey, sheep and goat. Yak and *dzo* are used for ploughing, and donkeys are used as draught animals. All species except horse and donkey are used for milk and meat. Horses, apart from their role in religious ceremonies, are mainly kept for trade. Sheep provide wool, while yak hair is used for making ropes. Horses and yaks are free ranging over most of the year, especially in summer. The other animals are penned in the houses, and herded every day communally to the pastures. In extreme winter, all animals (including yaks and horses) may be penned and stall-fed.

All decision-making pertaining to collective work, settling disputes, and access to common resources (such as grazing practices, collection of fuel and fodder, water for irrigation, etc.) is done by a village council. Kibber Village is administratively divided into three groups of houses (*Dhontoth, Dhonsham,* and *Dhonhar* groups). The council includes one member called a *numberdaar* from each of the three groups, and an additional 'head' *numberdaar*, all appointed on rotation for one year. The decision-making is based on majority. Serious decisions are made in consultation with 5-10 village elders.

Diversity in the production system

In the present section, we analyse the diversity and flexibility in Spiti's agro-pastoral and social systems, respectively. Together these embody a production system befitting the region's inherently risk-prone mountainous environment. The risks are largely climatic, geological, and those posed by wildlife. However, it must be clarified that while discussing the risk mediating effects of this diversity, we do not impute causality, i.e., the original motivation for adoption of some of the practices may not have been related to risk mediation, though they serve the purpose nevertheless. Another word of caution pertains to the representativeness of the study villages. Mishra (1998) has pointed out the difficulty in describing "typical" Indian villages, a problem arising from high diversity at the countrywide level. In Spiti, even at the level of half a district, the problem remains. There are differences in the production system even between adjoining villages. However, as shall be seen later, these differences are only an extension of the high diversity and dynamism that characterise Spiti's production systems at the village level. The picture of the production system that emerges from this section should at best be viewed as an abstraction approximating the gamut of Spiti's varied village systems.

Social mechanisms of risk mediation

Most of Spiti has been traditionally characterised by a primogeniture system of inheritance where the eldest son inherits all the land and property, while the younger siblings become celibate monks and nuns. The number of nuns is much smaller, as a result of which a section of the female population remains unmarried in their natal homes. As elsewhere in the Trans-Himalaya, there is no evidence of female infanticide (Wiley 1997). The systems of primogeniture and celibacy prevent the fragmentation of land holdings and limit population growth. In a sample of thirteen villages including Kibber, the population growth rate in the last two decades was only 0.09 %, as compared to the countrywide average of 2.17 % over the same period

(Mishra 2000). In Pin Valley, similar effects are accomplished through a flexible system that allows polygyny as well as polyandry. Part of the celibate population also emigrates to monastic schools in other distant parts of India.

The flexibility and diversity of labour arrangements in Spiti's production system allow efficient and timely mobilisation of manpower, while stringent locally enforced (at the village level) regulations ensure equitable distribution of responsibilities. All communal endeavours (maintenance of irrigation channels and roads within the village, cultivation of crop-fields belonging to the village temple, renovation of the common meeting house or temple etc.) necessitate the participation of at least one member from each family. Depending upon the perceived seriousness of the task, the village council may impose fines ranging from US$ 1.70 to 11.90 (1 US$ = 42 Indian Rupees; the per capita income for Himachal Pradesh being US$ 248 in 1994-95, see Mishra 2000) daily on families failing to participate. However, the system is flexible enough to allow proxy labour arrangements which may be arranged privately among families. Peak or unforeseen labour demands of a family are met by voluntary work groups that, like in other tribal highland communities of India, operate on a reciprocal exchange basis (Mishra 1985). These include activities such as manuring, sowing, weeding, harvest, threshing, repair of houses, slaughtering of animals etc. Such a system allows amelioration of periodic labour shortages and the control of further loss in case of hazards (MacDonald 1998).

There is a high potential for disparity in access to common resources such as dung and forage (for stall-feeding) collected from the pastures, with larger families having the obvious advantage due to their larger labour base. Does this cause asymmetric exploitation of common resources, or is such disparity neutralised? Stringent regulations operate to ensure equitable access of families to common resources. Kibber pastures have been divided into two groups. While dung collection is not regulated in one of these, the village council decides upon the period of collection in the other. In Sagnam, regulations on dung collection from pastures, which was earlier restricted to the months of May and October, broke down about six to seven years back. Out of date collection by members of 20 families in Kibber in 1998 resulted in imposition of fines equivalent to approximately US$ 4.80 per 100 kg of dung. Similarly, after the harvest, when livestock are grazed in the crop fields for a few days, dung collection is prohibited. The village council announces the date for the commencement of dung collection, and the owners of respective crop fields have no priority over the accumulated dung. In Pin Valley, on the other hand, the owners do have exclusive rights, but these rights last only for the first three hours of collection.

Regulations on collection of plant biomass from the pastures, apart from equalising access, also reflect conservation objectives that try to reduce the risk of pasture degradation. In Kibber, as many as seven species are collected from the pastures. Among these, the collection of *Allium* and *Cousinia* sp. for fodder is allowed only for one day each in a year. Similarly, the exploitation of two other fodder species collected together is restricted to two days. Grass collection is allowed for three days. There is no temporal regulation on the collection of the two shrubs (*Caragana* and *Lonicera* sp.) used for house building and fuel. However, *Caragana* collection is spatially regulated in that currently it is totally prohibited in one of the two groups of Kibber pastures. All collection dates, pertaining to both dung and plants, are restricted to periods with the lowest labour demands of agriculture and other activities, thus neutralising to a substantial extent the potential disparity in access to these common resources. At the same time, no collection is allowed on days of festivity such as marriage celebrations. This is to ensure the participation and collective sharing of responsibilities during such occasions by the entire village. There are similar regulations on fodder collection in Pin Valley. Collection of *Cousinia* in the nearby pastures and of *Artemisia* (also for fodder) in the distant ones is restricted to the month of October, the dates decided by the village council. In the privately owned collection areas (usually collectively owned by four or five families), the owner families have exclusive rights for the first five days of collection, after which collection is open to all families.

Regulations also pertain to livestock causing crop-damage. Despite communal herding, the onus is on respective families to prevent their livestock from entering the fields. In Kibber, two families earlier shared the responsibility, rotating among all families daily, to catch such straying animals. The animals would be released only upon payment of fines (ranging from US$ 0.12 to US$ 0.36 per animal depending upon the species) by the owner, the amount to be shared between the two families on duty. Since the last six years, the system has changed with one family being responsible for the entire year, and duties to be rotated among families annually.

Thus, while the risk mediating characteristics of the above practices and regulations are evident, the social system in Spiti also comes forth as rational (*sensu* Macdonald 1998). The rationality is evident in the practices that prevent land fragmentation and control population growth; both necessitated by the near impossibility of creating additional agricultural land in the arid mountainous landscape. Similarly, the amelioration of consequent labour shortages through flexible mobilisation of manpower is equally rational in the local context of extremely low human density (0.78 per sq. km compared to a countrywide average of over 300 per sq. km; Mishra 2000). Furthermore, in such a system where the family, despite being the basic unit of production, is highly dependent upon the community to meet production goals, maintaining community integrity is paramount. This is achieved through regulations that ensure equitable distribution of collective responsibilities as well as access to common resources. Having written about equality, however, it is important to mention that the community is caste-divided. The families belonging to the second caste, together with those of recent settlers and younger siblings who shunned celibacy (see later), have much smaller or no land holdings. Disregarding the moral issues involved, the second caste may be considered a 'service class' (*sensu* Mishra 1998), providing essential services such as blacksmithing and labour and others such as butchery and music. This is a patron-client relationship (*ibid.*) in which the families belonging to the second caste are paid customarily fixed shares of the agricultural produce and fodder. In addition, these families have usufruct agricultural rights in crop-fields owned by the village community.

The agricultural system

As mentioned before, early autumn frost is one of the main climatic risks to agriculture in Spiti. How has the production system traditionally mediated this risk? Polyvarietal planting increases genetic diversity and is believed to reduce the risk of disease and pest outbreaks common to monocultures, and of climate by distributing crop phenology temporally (Morren and Hyndmann 1987, MacDonald 1998). As many as four varieties of barley, locally called *kneu, soa, nenak, eumo*, were traditionally grown in Spiti. Among these, *kneu* was the most preferred for human consumption, while *soa* had a marginally higher yield. The diversity brought about by polyvarietal planting of the staple crop seems to have been a strategy to mediate

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% (n = 36) of younger adult male siblings are no longer monks. Similarly, while 13.6 % of Spiti's total human population (n = 1414) was comprised of celibate monks in the year 1845 (Handa 1994), a sample of 40 villages shows that such monks comprise only 6.5 % of the present population. It is evident that the rate of population growth is likely to escalate in the near future.

Agricultural innovations

Experimental planting of green pea by a single Kibber family in the year 1983 initiated a small agro-economic revolution in Spiti. The economics of this change has been discussed elsewhere (Mishra 2000). It would suffice here to say that this was one of the most successful experiments of the past few decades, its swift and radical effect being the transformation of a barter based economy to a market driven, cash based economy. By 1986, most families in Kibber were planting the crop, and presently, it is one of the most significant exports from Spiti, it's per family return as high as the per capita income of Himachal Pradesh in general (*ibid.*). In Pin Valley, the first villages adopted this crop *ca.* 5 years back, and many others are currently in the process of doing so. This change has affected the traditional risk mediating practice of polyvarietal planting. The green pea crop has largely replaced barley, thereby reducing the area available for barley production. Consequently, in Kibber and surrounding villages, the practice of polyvarietal barley planting is completely abolished, with only *kneu* now being cultivated. In Pin Valley region, where green pea cultivation has not yet become widespread, two to three varieties of barley are still planted, except the *eumo* that was given up a decade ago.

Experiments with wheat in Pin Valley were not successful. In Sagnam, it was first tried 15 years ago, and once again subsequently. Failure of the crop to reach maturity each time has now led to its rejection as a potential crop. Potato, on the other hand, was adopted here some time in the early 1970s. Together with mustard, it is especially planted in those fields where, in a given year, black pea is to be planted (decided by the system of crop rotation) but the latter's yield is known to be marginal. Another recent change has been in the timing of mustard sowing, which traditionally was delayed, usually done about a month after green pea and barley. This was done to reduce the risk of damage to the crop by snowfall in spring. However, for the past few years, this laborious practice has been given up in favour of simultaneous planting which is much easier. This has obviously augmented the risk, with 75 % of the crop getting damaged in the spring of 1997, all of which had to be resown.

One more interesting, partly successful agricultural experiment merits mentioning. Kibber and surrounding villages, being among the highest in the region, harvest their green peas the last. This harvest, stretching into the month of October, is 'off-season' for the rest of the country, a time when no other region produces green peas. Thus, the harvest from these villages yields maximum monetary returns. Since 1998, the entire village of Kee, which is 300 m lower than Kibber, have been delaying the sowing of green pea by two months, with the objective of delaying harvest to par with Kibber. The objective has been fulfilled, in fact, their harvest is even later than Kibber's. However, this is at a cost of marginally reduced yield.

Changes in the livestock production system

Evidence for increase of livestock holdings in Spiti has been presented elsewhere (Mishra 2000). Apart from this overall enlargement of livestock population, several other changes have taken place. In Kibber and surrounding villages, until two decades back, female yaks were not reared. All yaks (males) were procured in barter from the adjoining Changtang. This practice has subsequently changed, presently, 40 % of Kibber's adult yak population comprises of females. Thus, the yaks are now bred in this region and rarely procured from Changtang. This might be the cause of Spiti's increasing yak population, as opposed to most other yak rearing communities in the Himalaya where its population is known to be declining (see *ibid.*). In Pin Valley however, the traditional practice continues, and even today, there are no female yaks there.

Other changes in the livestock production system represent responses to a changing environment. In Sagnam, as in Kibber, all livestock of the village except horses and yaks (also, unlike in Kibber, donkeys) was earlier herded together. However, unlike in Kibber, the herders were permanent, though they would be accompanied by two people rotating among all the families daily. Increasing demands for grain by the herders led to the termination of their services by the village council three years back. Presently, three people rotating daily among all the families herd the livestock.

The remaining examples of such adaptation pertain to intensified killing of livestock by wild carnivores. Prior to 1997, there were no wolves in Pin Valley. After wolves moved in, there was a sudden escalation in the rate of livestock depredation. Donkeys, which earlier used to range free, became the common victims. Now, since 1998, donkeys are taken to nearby pastures by the owners every morning, brought back in the evening and penned inside the house. Similarly, prior to colonisation by wolves, all adult horses used to range free, while sub-adult horses were collectively herded. Presently, many owners willing to take up additional duties of collective herding graze even the adult horses along with the sub-adults. In the village Gete where a similar human-wildlife conflict related to livestock depredation by the snow leopard intensified in the last decade, people responded by improving their summer corrals. All families covered their corrals with chain-link fences, an act that totally eliminated the risk of losing livestock to wild predators once penned (Mishra 1997).

After word

The present analysis suggests that the agro-pastoral production system in Spiti, at the level of the family, represents a repertoire of locally appropriate practices that strives to maximise production while mediating environmental risk. The system is highly dynamic and consequently adaptable to changing natural and socio-cultural environments. By the time this study was over, of the 70 odd families in Kibber, more than 40 had televisions in their homes and were watching satellite tv. Most houses got telephone connections that are functional for a few months in a year. More than six small locally run hotels have sprung up in the village to cater to increasing tourism. The present state of agropastoralism in Spiti is perhaps best described by reiterating Bishop (1998, p. 9) who studied an agropastoral system in the Nepal Himalaya, '...even in a place as seemingly isolated..., people are changing in response to global patterns, while maintaining knowledge and activities that have been part of people's lives in these mountains for generations.'

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Chapter 3

Livestock depredation by large carnivores in the Indian Trans-Himalaya: conflict perceptions and conservation prospects

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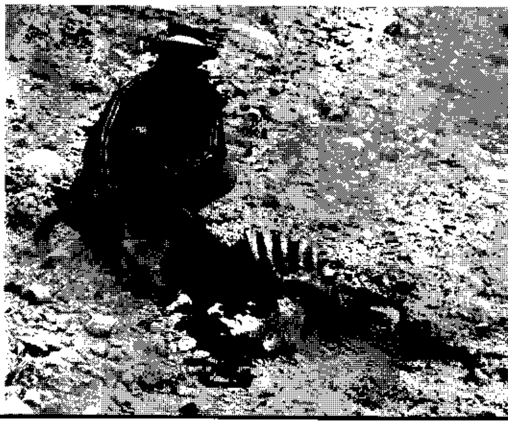 

Loss of livestock to snow leopard and wolf is a serious conservation issue in the Trans-Himalaya. The villagers suffer substantial financial losses due to livestock depredation, and, in retaliation, persecute the carnivores. The photograph (left) shows a cow killed and partly eaten by wolves. Wolf litters (right) have been regularly captured and destroyed. *The conflict in Spiti Valley is evaluated in the chapter.*

Abstract

Livestock depredation by the snow leopard *Uncia uncia* and the wolf *Canis lupus* has resulted in a human-wildlife conflict that hinders the conservation of these globally-threatened species throughout their range. This paper analyzes the alleged economic loss due to livestock depredation by these carnivores, and the retaliatory responses of an agro-pastoral community around Kibber Wildlife Sanctuary in the Indian Trans-Himalaya. The three villages studied (80 families) attributed a total of 189 livestock deaths (18 % of the livestock holding) over a period of 18 months to wild predators, and this would amount to a loss per household equivalent to half the average annual per capita income. The financial compensation received by the villagers from the Government amounted to three percent of the perceived annual loss. Recent intensification of the conflict seems related to a 38 % increase in livestock holding in the last decade. Villagers have been killing the wolf, though apparently not the snow leopard. A self-financed compensation scheme, and modification of existing livestock pens are suggested as area-specific short-term measures to reduce the conflict. The need to address the problem of increasing livestock holding in the long run is emphasized.

Introduction

The intimate interspersion of people in protected areas often results in conflicts between humans and wildlife (Rodgers 1989). Most wildlife protected areas in India support various forms of land use such as agriculture, livestock grazing, and collection of minor forest produce. Livestock grazing is especially widespread, and livestock holdings form an important component of the local pastoral and agricultural economy. Kothari *et al.* (1989) report livestock grazing in as many as 73 % Wildlife Sanctuaries and 39 % National Parks in India (of the 101 and 14 surveyed protected areas respectively in those categories), with livestock densities up to 150 per km^2. Not surprisingly, livestock often greatly outnumber wild ungulates within many protected areas. Such a disproportionate presence of wild and domestic ungulates results in killing of livestock by wild predators, and thereby a conflict of interests between local communities and wildlife managers.

Human-wildlife conflicts are acute when the species involved is highly imperilled while its presence in an area poses a serious threat to human welfare (Saberwal *et al.* 1994). Such is the conflict between wild carnivores and pastoralists in the Trans-Himalaya, until recently one the least represented of all the biogeographic zones in the Indian protected area network (Rodgers and Panwar 1988). The Trans-Himalaya biogeographic zone harbours at least 12 mammal and bird species listed in Schedule I of the Indian Wildlife (Protection) Act, 1972 (Anon. 1992). Among these, the snow leopard *Uncia uncia* is globally threatened, and is categorised as endangered (in danger of extinction) by the IUCN (1990). The Tibetan wolf *Canis lupus chanku*, represents another globally-threatened species, categorised as vulnerable (IUCN 1990). Both these species are in conflict with humans in most parts of their range, specifically due to the damage they cause to livestock (Schaller 1977, Fox *et al.* 1988, Mallon 1988, Oli *et al* 1994, Meriggi and Lovari 1996, Novell and Jackson 1996).

The purpose of this paper is to examine the conflict between these wild predators and agro-pastoralists around Kibber Wildlife Sanctuary, which is an area of acute conflict in Spiti Region of the north Indian state of Himachal Pradesh, and to propose measures that might be taken to reduce the conflict. The paper first establishes the economic loss to local communities due to the perceived wild carnivore predation on livestock, and then qualitatively describes the retaliatory persecution of the carnivores.

Study area

Kibber Wildlife Sanctuary (32°5' to 32°30' N and 78°1' to 78°32' E) was established in the Spiti Region (Lahaul & Spiti District) of the Indian state of Himachal Pradesh in the year 1992 for conservation of Trans-Himalayan wildlife. The sanctuary occupies an area of 1400 km² in the river Spiti's catchment. Bordered by Ladakh on the north and Tibet on the east, it is a mountainous cold desert where altitudes range between *c.* 3600 m and 6700 m above mean sea level. Temperatures range between -30°C and 3°C in winter, and between 1°C and 28°C in summer (Rana 1994). The vegetation of this area has been broadly classified as dry alpine steppe (Champion and Seth 1968).

Large mammalian fauna of the area includes bharal, *Pseudois nayaur*, relatively few ibex, *Capra ibex*, and their predators, namely the snow leopard and the Tibetan wolf. Other fauna includes the red fox, *Vulpes vulpes*, pale weasel, *Mustela altaica*, stone marten, *Martes foina*, and the Himalayan mouse hare, *Ochotona* sp. During the course of this study, 45 species of birds were identified, including several species typical of this alpine habitat such as chukar, *Alectoris chukar* and Tibetan snowcock, *Tetraogallus tibetanus* (C. Mishra, unpublished data 1996).

Thirteen villages are located along the boundary of the Sanctuary supporting a total human population of 1985, according to the 1991 census. The main occupations of the inhabitants are agriculture and livestock rearing. Most agriculture-related activities are restricted to the short growing season (from May to September). The main crops cultivated are barley *Hordeum vulgare* and green peas *Pisum sativum*. Livestock includes goats and sheep, cattle, '*dzomo*' (female hybrid of cattle and yak), and yaks. Donkeys are the beasts of burden, while horses, apart from being used for religious ceremonies, are mainly raised for trade. All these animals graze in the sanctuary.

Methods

Secondary data from the 1991 census of the human population for all the 13 villages bordering the Sanctuary were collected from archival records (unpublished) maintained at the Office of the Additional Deputy Commissioner, Desert Development Project at Kaza in Spiti. Of these, the largest village, namely Kibber, was selected for the study: Kibber Village accounted for 16% of the human population of the 13 villages. Two small nearby villages called Gete and Tashigang were later included in the study to raise the coverage to 19 percent. I also searched the archival records for data on human population and livestock holding of the sample villages in the past. The exponential growth curve equation was used to calculate human and livestock population growth rates.

At least one member from each family in the three villages was interviewed. Interviewees were asked whether they had lost any livestock in the previous one and a half years (1995 and January to July, 1996) to wild predators. They were also asked if they had applied for and received financial compensation from the Office of the Director, Pin Valley National Park at Kaza, which functions as the local wildlife department for Spiti. The species, age, and sex of livestock reportedly killed by wild predators were recorded. Interviewees were asked about the composition of their present livestock holdings. To estimate the current average market value of different classes of livestock species by age and sex, a butcher (Kibber village), two horse traders (one from Kibber and another from a nearby village called Chichim), and two other people (Kibber), who were frequently involved in trading livestock, were interviewed. This market value refers to the average amount of money required to buy an animal of a particular species. Financial compensation rates were obtained from the Office of the Director, Pin Valley National Park.

The focus of this particular study was the perceived livestock loss to the wild predators, and therefore the cases of mistaken, but unintentional, attribution of livestock deaths to wild predators were included. However, it is important to keep in mind that the proportion of such mistaken cases could have been substantial, even greater than the genuine cases of depredation. Precautions were taken against intentional exaggeration. All the information provided by the respondents from Kibber was crosschecked using the knowledge of two local villagers who served as my field-assistants. This could not be done for the other two villages. The survey was conducted after I spent about 3 months in the area in the year 1996, during which time the villagers had realized that I had no immediate say in policy making or implementation of any wildlife management programme, including financial compensation.

Chi-square goodness of fit was employed to test whether the reported frequency of predation on different livestock species deviated significantly from the expected frequency (Zar 1984).

Results

The 80 families of the three study villages, namely Kibber, Gete, and Tashigang, owned 1,054 heads of livestock in August 1996 when this survey was conducted (Table 3.1). Most of the families owned goat/ sheep (95 %) and at least a cow or *dzomo* (female hybrid of yak and cattle; 89 %). Fewer had donkeys (79 %) and yaks (65 %), while only 55 % of the families owned horses. A total of 189 livestock deaths (18 % of the livestock holding) over a period of 1.5 years preceding the survey was attributed by the villagers to wild predators. This amounted to 1.6 livestock heads/ family/ year and an annual loss of 12 % of the livestock holding.

Market values of livestock varied by species, age and sex (Tables 3.2 and 3.3). Using data in Tables 3.2 and 3.3, the alleged economic loss due to wild predators amounted to US$ 15418, which translated into US$ 128 per family per year (1 US$ ≈ 31.4 Indian Rupees, 1994-95).

Table 3.1 Livestock population, alleged kills by wild predators, and the percentage economic loss in three villages adjoining Kibber Wildlife Sanctuary, Indian Trans-Himalaya.

	Yak	*Horse*	*Cow/ Dzomo*	*Donkey*	*Goat/ Sheep*
Livestock population	139	75	126	125	589
Alleged kills	31	26	0	18	114
Ratio of alleged kills to relative abundance	1.24	1.94	0	0.79	1.07
% economic loss	15.4	37.4	0	5.1	42.1

Table 3.2 Market value (US$) of goats and sheep by age and sex around Kibber Wildlife Sanctuary, Indian Trans-Himalaya

	Goat		Sheep	
Age	Male	Female	Male	Female
4 months	8.0	6.4	15.9	12.7
6 months	15.9	12.7	31.8	25.4
12 months	31.8	25.4	57.3	44.6
18 months	51.0	31.8	63.7	60.5
≥24 months	63.5	57.3	63.5	60.5

Of the 131 reported cases in 1995, villagers had applied for monetary compensation in 54 cases and received compensation for 28 cases (amounting to US$ 307). Considering an average perceived annual loss of US$ 10279, the compensation for 1995 amounted to 3 % of the perceived annual loss. It must be noted here that 'perceived loss' also includes those deaths for which the villagers may not have been certain about the cause.

Perceived kills of goat, sheep (combined) and horses accounted for 42.1 % and 37.4 % of the economic loss, respectively. In terms of the proportion of livestock heads, yaks (16.4 %) followed goat and sheep (60.3 %) (Table 3.1). Among all livestock species, only horses were reported to be killed significantly more in proportion to their relative abundance (χ^2=37.32, df = 4, $p \leq 0.01$). Except for cow and *dzomo* which were not preyed on, all the remaining species were reportedly killed with a frequency proportional to their relative abundance (Table 3.1).

Between 1971 and 1996, the three study villages underwent a 6.5 % increase in human population (from 353 to 376), an average annual growth rate of 0.25 %. The period between 1971 and 1987 saw a 52.2% (from 115 to 175) increase in the livestock population of Gete and Tashigang (growth rate = 2.6 %). Livestock data for Kibber village for the year 1971 were not available. Between 1987 and 1996, the livestock population in all the three villages increased by 37.7% (growth rate = 3.5 %).

Retaliatory measures of the villagers

Spiti in general, and the villages around Kibber Wildlife Sanctuary in particular, have been areas of high conflict between agro-pastoralists and wild predators. Although the locals are Buddhist, wolves are killed; the villagers locate wolf dens and capture the pups. The pups are then paraded live around the neighbouring villages, where people reward the captors with money. The litter is then destroyed, often using dynamite. According to locals, wolf litters were destroyed around the study villages almost every year in the 1980s. Wolf has reportedly not littered in this part of the Sanctuary for the last 4-5 years, and has rarely been sighted. Almost all the livestock kills reported in this paper were attributed to the snow leopard.

Local information revealed that a litter was destroyed in 1996 near Hikkim, one of the 13 villages bordering the Sanctuary. Locals also brought a live litter of four pups (captured near a distant Spiti village called Losar) to the Office of the Director, Pin

Table 3.3 Market value (US$) of different livestock species by age and sex around Kibber wildlife Sanctuary, Indian Trans-Himalaya

	Yak	Horse		*Dzomo*	Cattle		Donkey	
Age		Male	Female		Male	Female	Male	Female
6 months	31.8	0.0	0.0	0.0	0.0	0.0	9.6	4.8
1 year	63.6	127.4	95.5	41.4	15.9	31.8	9.6	4.8
2 years	95.5	254.8	159.2	82.8	57.3	63.7	25.5	8.0
3 years	127.4	382.2	302.5	95.5	63.7	79.6	44.6	25.5
4 years	175.2	477.7	350.3	127.4	63.7	95.5	63.7	25.5
5 years	207.0	573.2	382.2	127.4	63.7	95.5	63.7	25.5
6 years	222.9	573.2*	382.2**	127.4	63.7	95.5	63.7	25.5
≥7 years	238.9	--	--	127.4	63.7	95.5	63.7	25.5

* male horses usually sold off by this age

** the price of female horses starts declining with age ≥ 6 years

Valley National Park during the course of the study (C. Mishra, personal observation 1996).

According to the locals, there was only one case where an adult snow leopard was killed after it was accidentally trapped inside an indoor pen in Kibber village 4-5 years ago. Except for this incident, the snow leopard are only occasionally persecuted, by driving them off livestock kills.

Discussion

The conflict

Conflicts between humans and wildlife in India are escalating due to increasing human population, loss of natural habitats, and in some regions, increasing wildlife populations as a result of successful conservation programs (Rodgers 1989, Saberwal *et al.* 1994). In Kibber Wildlife Sanctuary, though the killing of livestock by wild carnivores is not a recent phenomenon, the number of kills has increased in the last five years, both according to the local people and the Government officials at the Office of the Director, Pin Valley National Park. This period coincides with the declaration of the area as a wildlife sanctuary in 1992. However, the escalated conflict has little to do with increased protection to wild carnivores. This is evident from the continued persecution of the wolf in the area. Human population in the study villages has also remained almost constant in the last 25 years. The increased conflict seems related to the drastic increase in livestock population in the last decade, which has accompanied a change from subsistence to commercial agriculture and animal husbandry (Mishra 1997). Shifts in carnivore diets in response to changes in relative abundance of prey species have been documented (Kitchner 1991, Chellam 1993). Livestock, due to their reduced escape abilities compared to wild herbivores, become especially vulnerable to predation (Nowell and Jackson 1996).

Actual rate of predation on livestock in Kibber is not available. This is important but not easy to establish, since the losses attributed to wild predators are usually exaggerated, either deliberately, or due to inability to ascertain the cause of death (Kruuk 1980, Hoogesteijn *et al.* 1993, Mizutani 1993, Oli *et al.* 1994). High predation levels on livestock by snow leopard and wolf have been reported from other parts of their range (Schaller 1977, Fox *et al.* 1988, Mallon 1988, Oli *et al.* 1994, Nowell and Jackson 1996). In Kibber too, livestock seems to constitute important prey for the snow leopard. Although robust estimates of wild ungulate populations are not available, I counted about 60 bharal, an important prey of the snow leopard (Jackson 1991, Chundawat 1994), within the ecological unit (*c.* 30 km^2) that encompasses the pastures of the three study villages. Field surveys indicated that during the spring-summer season when this study was carried out, the bharal number did not exceed 100 individuals, which is one-tenth of the livestock abundance in the area.

Oli *et al.* (1994) assessed the impact of perceived snow leopard predation on livestock in Manang district of Nepal, and found that the loss per family represented a quarter of the average annual per capita Nepalese income. In the present study, the perceived loss to wild predators per family and per individual was almost twice as great as in the Nepalese case, amounting to 52 % and 11 %, respectively, of the annual per capita income of Himachal Pradesh (US$ 248) for 1994-95 (World Bank 1996). The loss was only marginally reduced after incorporating the amount received as financial compensation (50 % per family and 10.6 % per individual of the average annual per capita income).

For reasons discussed earlier, the levels of livestock depredation and the consequent economic loss presented in this paper surely exceed the actual loss due to wild predators. There is little doubt, however, that a serious conflict exists between the wild predators and the agro-pastoralists. Even during the course of four months spent in field, seven goats/ sheep and a horse belonging to the study villages were reportedly killed by wild predators, and another horse injured. The identity of the predator was mostly unavailable, with the exception of the horse which was killed by snow leopard; this was indicated by canine puncture marks on the throat and pug-marks nearby). In any case, the tendency of people to attribute, often unintentionally, most cases of livestock death to the wild predators, accentuates the conflict. This is because when peoples' tolerance towards the wild predators is in question, it is the loss they perceive, rather than the actual loss, which can lead them to retaliate.

Reducing the conflict

Contemporary management strategies to minimize livestock depredation by wild carnivores involve elimination of specific animals causing damage, improved anti-predator and general livestock management, and compensation for livestock lost to predators (Nowell and Jackson 1996). In India, Schedule I species (Anon. 1992) such as the Tibetan wolf and the snow leopard cannot be destroyed by law for reasons such as livestock depredation (Sawarkar 1986). Oli *et al.* (1994) outline specific management strategies to reduce the snow leopard-pastoralist conflict, and emphasize the need for financial compensation schemes. Such a scheme does exist within the wildlife department (Office of the Director, Pin Valley National Park) in Spiti. However, in the year 1995, people applied for compensation for only about 41 % of the perceived livestock predation cases. Low compensation rates (6 to 20 % of market value), bureaucratic apathy, and the time and costs involved in securing compensations discouraged people from applying for such schemes. It is clear that the compensation scheme, as it exists now, can do little to reduce the human-wildlife conflict in this area. Such disinterest in existing Government financial schemes, for similar reasons, has been reported from elsewhere in India (Saberwal *et al.* 1994).

Preliminary discussions with the locals indicated a willingness from most families to contribute an equivalent of US$ 1 (4.8 % of the average monthly per capita income) per month if a self-financed compensation scheme is developed in the area. If such a scheme could be developed by the local wildlife department along with non-governmental organizations (by setting up a committee of the village community to manage the funds and decide the compensation rates), it would surely be an improvement on the existing scheme. Such a fund would need to be strengthened with corpus grants (where the capital remains untouched and only the interest is spent) from national and international conservation agencies.

In summer, the livestock are penned adjacent to houses at night. These pens are small enclosures (up to 10 m X 20 m) with *c.* 1.5 m high walls and no ceiling. Snow leopard occasionally raid these pens. The kills inside villages, for obvious psychological reasons, cause greater resentment among the locals. In some houses in Gete, one of the study villages, people have covered their pens with chain-link fences, which according to them has substantially cut down instances of kills inside the village. Providing chain-link fences to the locals would be a small but important step in reducing the conflict. For this, I estimated a one time investment of about US$ 75 per family. This cost could be met either by the state, conservation agencies, the village community fund mentioned above, or a combination of these.

It is important to note that such management schemes can provide only a short-term remedy. The conflict in the long run is likely to intensify unless the problem of growing stock sizes is addressed. Persecution by humans in response to livestock depredation in historical times has eliminated several carnivores including the tiger *Panthera tigris*, lion *Panthera leo*, and puma *Felis concolor*, from large parts of their former range (Novell and Jackson 1996). In Kibber the wolf has faced the brunt of the agro-pastoralists' retaliation. This is despite their belief that most livestock kills presently made are by the snow leopard. The persecution of wolf is possibly related to the relative ease in locating dens and capturing litters. So far there seems to have been no attempt to eliminate the snow leopard. Such cases, however, have been reported for Trans-Himalayan Buddhist communities elsewhere (Fox and Chundawat 1988). With losses equivalent to half the average annual per capita income for every family at stake, it is highly probable that unless urgent extenuatory management measures are undertaken in Kibber Wildlife Sanctuary, active elimination of snow leopard would be resorted to in the near future.

The existing herding practices are indeed partly responsible for the conflict. For instance, yaks and horses are free-ranging at least in summer, which makes them vulnerable to predation. Clearly, research efforts need to focus on how herding practices could be improved, monitoring the abundance of prey species, establishing actual livestock losses to wild predators, and assessing the ecological impacts of the expanding livestock holdings.

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Chapter 4

Rangeland vegetation in the high altitudes of the Spiti Valley, Indian Trans-Himalaya

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Abstract

The Trans-Himalayan ecosystem in the rain-shadow of the Greater Himalaya represents a vast rangeland system with a long history of pastoralism. Despite their economic importance and a unique wildlife assemblage, the rangelands and their vegetation have received little attention. We describe the vegetation in the high altitudes of Spiti Valley, Indian Trans-Himalaya, in terms of its structure and species composition. The 32 km^2 intensive study area was dominated by variations of the *Caragana versicolor* formation which covered over 70 % of the rangelands, the other formations being moist sedge (6 %) and open steppe/ desert vegetation (24 %). Different variations (types) of each of the formations are described. Most of the vegetation is under different stages of degradation due to intensive livestock grazing and fuel-wood collection. The mean graminoid biomass in the rangelands (at peak standing crop) was 170 kg/ ha (95 % CL 128-228 kg/ ha), contributed by species such as *Festuca olgae, Stipa orientalis, Carex infuscata* etc. Moist sedge vegetation, which is restricted in area but forms important forage patches for herbivores, showed increased production under intensive and persistent grazing (compared to moderate grazing), and seems resilient to grazing under conditions of water-logging. Water harvest for agriculture has over time resulted in a loss of this vegetation and other important grazing patches for herbivores. Compared to livestock, wild herbivores seem to have been disproportionately affected by this reduction in forage production due to historical land use patterns. A comparison with other ecosystems reveals that at a global level, the Trans-Himalayan region falls at the low end in terms of aboveground graminoid biomass.

Introduction

The arid Trans-Himalayan region, covering the Tibetan Plateau and the Tibetan Marginal Mountains in the rain shadow of the Greater Himalaya, is spread over 2.6 million square kilometres. The region represents a vast rangeland system, with a history of pastoralism that dates back several millennia (Schaller 1998, Handa 1994). The region also harbours an impressive assemblage of large wild herbivores with species such as the wild yak *Bos grunniens,* kiang *Equus kiang,* Tibetan argali *Ovis ammon,* Tibetan antelope *Pantholops hodgsoni,* and bharal *Pseudois nayaur*. Yet, the rangelands have received little attention from range ecologists, and there is limited information available on the vegetation, its structure, species composition, and its responses to livestock grazing (Miller and Bedunah 1993).

Spiti Valley located in the Indian Trans-Himalaya is spread over 12,000 km^2. Intensive use over centuries has caused noticeable vegetation impoverishment along the main river valley between 3500 m to 4000 m. In some of the side valleys, as well as at higher altitudes, there is greater plant biomass, though these rangelands are under intensive use currently, especially for livestock grazing, but also for collection of fuel, fodder, and medicinal plants (Kala 2000, Mishra 2000).

In this paper we describe the main vegetation types (their structure and floristic composition) in the high altitudes of Spiti Valley (largely between 3900 to 4800 m). We focus on an intensive study area of 32 km^2 on the Kibber Plateau, a part of the Kibber Wildlife Sanctuary (32°5' to 32°30' N and 78°1' to 78°32' E). The vegetation is also described in terms of the above ground forage biomass. We also evaluate the productivity response of moist sedge vegetation, which, though restricted in area, forms important foraging patches for livestock as well as wild herbivores.

Study area

Spiti Valley (31°35' to 33°0' N and 77°37' to 78°35' E; altitudinal range 3350 to 6700 m) in the Trans-Himalayan Lahaul and Spiti District is surrounded by the Greater Himalaya in the South, Ladakh in the North and Tibet in the East. Biogeographically, the region belongs to the Sino-Siberian sub-zone of the Boreal zone of the Himalaya (Singh 1997). The arid and cold area has been described as a cold desert, with an annual rainfall of less than 200 mm and snowfall of about 155 mm of water equivalent (Sharma *et al.* 1991).

Kibber Wildlife Sanctuary (1400 km^2; 32°5' to 32°30' N and 78°1' to 78°32' E), in the northern catchment of the river, encompasses an altitudinal gradient of 3600 to > 6000m above mean sea level. All available rangelands within the sanctuary are grazed by livestock of surrounding villages. The livestock includes domestic yaks (*Bos grunniens*), cattle, *dzo* and *dzomo* (male and female hybrids of yak and cattle, respectively), horses, donkeys, sheep and goat. The local Buddhist inhabitants are largely agro-pastoral, growing single crops of mainly barley and peas. The fields are irrigated with water diverted from springs or glacial ponds fed by snowmelt.

Methods

The rangelands are divided (and named) by the local pastoralists into several smaller units that we call pastures. The 19 pastures in our intensive study area varied from a few ha to about 3 km^2. In each of the pastures, after careful examination, we identified one to a few visually distinguishable vegetation types. Within each such vegetation type, two methods were applied for collecting vegetation species composition data. The first is a detailed sampling method. Sample plots were selected in each visually distinguishable vegetation unit. Plot size varied from 5 x 5 m for relatively dense vegetation to 10 x 10 m for very open sparse vegetation. A total of 28 such plots were sampled. Data recorded in each of the plots included terrain characteristics (land form, slope relief type, surface stoniness or rock outcrops), plant cover, height of the vegetation (average and maximum) for each stratum (herb and shrub), and cover and abundance of each plant species was estimated using a 14-point scale (Van Gils *et al.* 1985). For details about the vegetation description see Kent and Coker (1992).

In addition to detailed plot descriptions a rapid sampling procedure was applied for quick reconnaissance survey and rapid comparison, in which we recorded only the dominant species of a larger area.

In order to include greater spatial variation in plant composition within a vegetation unit, point-intercept transects (50 to 250 points, each 1 m apart) were distributed across the vegetation. In total, 91 transects (4550 points) were distributed across the pastures. We recorded whether each intercept pointed was touching a plant (species identity), soil, rock or litter.

Wherever possible, plants were identified in the field. Voucher specimens were taken in case of doubt. These were later identified in the herbarium of the Wildlife Institute of India and of the Forestry Research Institute, both in Dehradun, India. We have followed the nomenclature according to Aswal and Mehrotra (1994).

Biomass assessment

Graminoids constitute the most important group of forage for livestock in these rangelands (see Chapter 6). To get an estimate of forage availability, we clipped above-ground graminoid biomass from 123 plots covering a total of 1434 square meters spread across the dominant vegetation types. The plot sizes ranged from 0.0625 to 25 square meters depending upon the heterogeneity of vegetation and abundance of graminoids. The clipped biomass was sun-dried and weighed. In the case of tussock grasses (*Festuca olgae*), we derived a relationship between grass cover and standing biomass (mean biomass ± SD for 100 % cover = 2772 ± 1731 kg/ha). Point intercept transects (50 to 250 points) were distributed across the vegetation to estimate tussock grass cover, and the derived relationship was used to calculate mean grass biomass. All clippings were done between 22 July and 5 August (2000), the approximate period of maximum aboveground biomass in any year.

With the aid of a Leica Vector rangefinder, we estimated the total area covered by each of the vegetation types, and obtained estimated availability of graminoids in the moderately and intensively grazed rangelands. The mean graminoid biomass and asymmetric 95 % confidence intervals were calculated through Monte Carlo simulations (500 permutations; Krebs 1989).

In order to establish how the Trans-Himalaya compare with other ecosystems in terms of graminoid biomass, we compiled information on aboveground standing graminoid biomass from three different parts of the world – the polar desert and tundra, the temperate grasslands, and the tropical steppes and savannas.

To get an indication of the contribution of other life forms to aboveground biomass, especially shrubs (mainly *Caragana*), 30 plots of 20 x 20 cm were clipped. These *Caragana* plots were placed on bushes such that the entire plot had *Caragana* (100% cover), and the mean height recorded (an average of 10 height measurements). All above ground biomass within the plot was clipped, and leaves and woody material separated after clipping. A relationship was established between height and biomass for 100 % cover through a linear regression (Zar 1980). The model obtained (above ground biomass (g) = 343 x height (cm); $r^2 = 0.663, p < 0.00$) is used to provide rough estimates of aboveground biomass contributed by this life form.

In order to evaluate the productivity response of the moist sedge formations (*Carex infuscata-Kobresia royleana*) to different grazing intensities, we conducted a grazing simulation experiment. Five exclosures (9.5 m x 3.5 m) were constructed on five different patches of sedge vegetation, on homogenous stands of *C. infuscata*. These exclosures were designed to keep livestock or wild herbivores out. Within each exclosure, we established plots of 1 m x 1 m, buffered from each other, and from the fence, by at least 0.5 m. In 1998, in each of the exclosures, we selected 4 plots. One of these was designated the intensively grazed plot, in which we maintained the lawn at a height of 2 cm by regularly clipping through the growing season between May and August. The second plot was designated as moderately grazed, and maintained at a height of 5 cm. The other two plots were not clipped in that year. They represented relief from grazing in 1998. All clipped biomass was separately stored, dried and weighed, and the cumulative weight at the end of the growing season was used as a measure of production. The data from first and last clippings were removed from the analysis to make all plots comparable. Doing this ensured that our data represented

The standing biomass of graminoids was 857 kg/ha (95 % CL 724-970 kg/ ha; see Table 4.1) in a moderately grazed, very moist patch, declining dramatically to 13 kg/ha in very intensively grazed dry patches (Fig. 4.1*b*).

Clipping experiments revealed that in general, the *C. infuscata* vegetation had much higher production under intensive grazing as compared to moderate grazing under waterlogged conditions. This pattern was consistent across treatments, i.e., intensively grazed plots also tended to have higher production compared to moderately grazed ones in persistently grazed plots, as well as in plots which had a temporary relief from grazing (Figs. 4.2*a* and 4.2*b*; one of the exclosures got broken into by yaks, so the data not included). One-season relief from grazing tended to increase the total

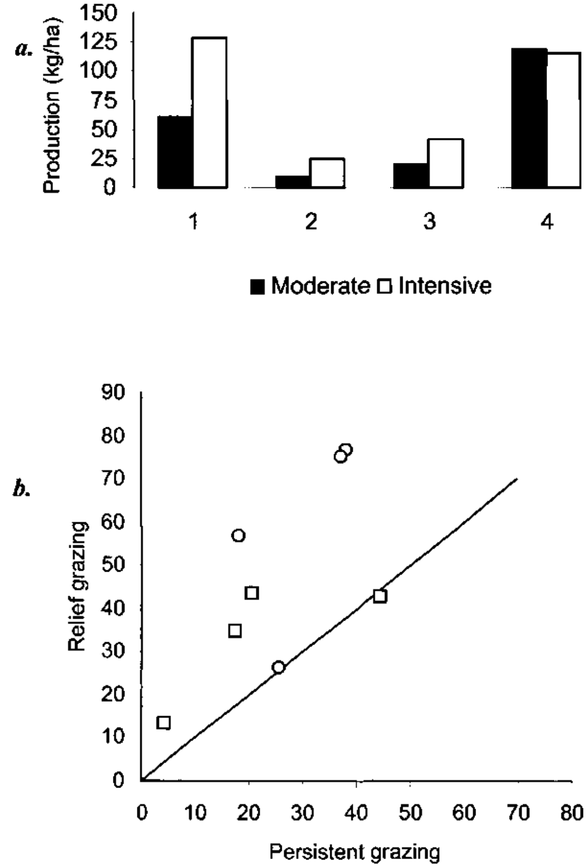

Fig. 4.2

a. Plant production in *Carex infuscata-Kobresia royleana* vegetation type under moderate and intensive grazing in 1998. The x-axis represents the different exclosures.

b. Plant production in 1999 under persistent grazing plotted against plant production under 1-year relief from grazing (pairs of plots from the same exclosures). The line hypothesizes no difference in production between persistent and relief treatments. (□ moderate grazing; ○ intensive grazing).

production under both intensive and moderate grazing by up to 68 % (average increase in production was 47 %).

II. Dwarf shrub vegetation (*Caragana versicolor*)

Caragana versicolor is a dominant species in terms of cover and its above ground biomass in the study area. Based on structure and species composition, several different types of dwarf shrub vegetation could be distinguished.

a. Closed *Caragana versicolor* type

Moderately grazed and less extracted (*Caragana* is harvested; see later, also see Chapter 2) for fuel as well as for lining the roof-tops) gentle E, W and N facing slopes above 4000 m often have well-developed dense vegetation with high cover and *Caragana* as dominant species (cover 30 % to a maximum of 70 %, total cover up to 90 %). Other shrub species that might be present are *Lonicera* sp. (locally dominant) and *Potentilla fruticosa* (scattered). Species such as *Lindelofia anchusoides, Nepeta discolor, Artemisia* spp. may be present. The abundant grass species are *Elymus longe-aristatus, Piptatherum munroi*, and *Poa lahulensis*. Graminoid cover can be up to 20 %. *Carex melanantha* can locally be abundant. The *Caragana* shrubs might form a mosaic with *Carex infuscata* patches, in which *C. infuscata* may cover up to 40 %. The graminoid biomass may vary from 58 to 205 kg/ ha. In general, this vegetation type achieves the maximum plant biomass with above ground *Caragana* biomass varying between 6,188 and 24,750 kg/ ha. This type was spread over 6.32 sq. km (23 %) of the study area.

b. Open *Caragana versicolor – Festuca olgae* type

This type occurs on moderately grazed gentle slopes and has open *Caragana* interspersed with tussocks of *Festuca olgae*. Locally, *Carex infuscata* patches may be

Table 4.1 Vegetation types in relation to grazing pressures and graminoid biomass in Spiti, Indian Trans-Himalaya. Parentheses indicate the formation and type number (see text). Area represents the percent covered by the vegetation type (of the total 27 km^2 vegetated area on the Kibber Plateau). The biomass values represent means, or a range of means (in cases where sampling was done at more than one place but the similarity in species-composition merited them to be put under the same type).

Vegetation type	Area (%)	Graminoid biomass (kg/ ha)
Moderate grazing		
Carex infuscata – Kobresia royleana (I)	6	217-857
Closed *Caragana versicolor* (II*a*)	23	58-205
Open *C. versicolor – Festuca olgae* (II*b*)	19	233-336
Poa lahulensis – Nepeta discolor (III*a*)	7	200
Potentilla nivea – Carex infuscata – Festuca olgae (II*f*)	3	1620
Intensive grazing		
C. infuscata – Lindelofia anchusoides (I)	3	13
Open *C. versicolor – Cousinia thomsoni* (IIc)	14	13-93
Very open *C. versicolor – Leymus secalinus* (II*d*)	12	177
Very open *C. versicolor – Oxytropis microphylla* (II*e*)	< 1	49
Stipa orientalis – Cousinia thomsoni (III*b*)	3	86
C. thomsoni – Heracleum thomsonii – L. secalinus (IIIc)	2	38
C. thomsoni – Arnebia euchroma (III*d*)	5	42
C. thomsoni – Astragalus grahamiana – Nepeta discolor (III*e*)	3	35

present on flat sites. Total plant cover varies between 30 to 75 %. *Elymus longe-aristatus* and *Potentilla bifurca* are always present. Scattered shrubs of *Lonicera* and/or *Potentilla arbuscula* may be present. Grass biomass may be as high as 233 to 336 kg /ha. Caragana biomass may vary between 8,044 and 13,406 kg/ ha. The total area covered by this vegetation type was 5.14 sq. km (19 %).

***c.* Open *Caragana versicolor – Cousinia thomsoni* type**

Heavily grazed areas with a possible history of *Caragana* harvest seem to be dessicated, and have relatively low shrubs with total plant cover varying between 20 to 50 %. *Cousinia thomsoni, Eurotia ceratoides, Nepeta discolor, Dracocephalum heterophyllum,* and *Lindelofia anchusoides* are often present with low cover. Grass cover comprises of *Elymus longe-aristatus*, the rhizome grass *Leymus secalinus* and sometimes *Stipa orientalis*, all with relatively low cover. Total graminoid cover usually does not exceed 30 %, and in terms of biomass, may be as low as 13 to 93 kg/ ha. The *Caragana* biomass is as low as 619 kg/ ha. This type was spread over 3.79 sq. km (14 %).

***d.* Very open *Caragana versicolor – Leymus secalinus* type**

Very similar to *c* but *Cousinia* is absent. Total cover varies, but does not usually exceed 40 %. *Leymus secalinus* is the dominant grass species with coverage upto 20 %. *Carex infuscata* may be present with variable coverage. This type occurs in areas with heavy grazing, and was spread over 3.42 sq. km (12 %). At peak growing season, the grass biomass may be high, estimated at 177 kg/ ha (95 % CL 133 to 225 kg/ ha) because *L. secalinus* is not grazed once the plants attain maturity. *Caragana* may have up to 2,063 kg/ ha as above ground biomass.

***e.* Very open *Caragana versicolor – Oxytropis microphylla* type**

A very open (20 to 30 % cover) vegetation type in which *Oxytropis microphylla* (10 – 20 % cover) is the dominant species. Other species are *Caragana, Eurotia ceratoides, and Dracocephalum.* Graminoid cover is low (5 to 7.5 %) and consists predominantly of *Stipa orientalis*. This type occurs locally on flat mountain-tops and is very limited in extent (0.13 sq. km; < 1 %). Graminoid biomass is low at 49 kg/ ha (95 % CL 27 - 72 kg/ ha). *Caragana* may attain a maximum biomass of 2,888 kg/ ha.

***f. Potentilla nivea – Carex infuscata – Festuca olgae* type**

One of the very few places where glacial melt has not been harvested, and consequently there is high soil moisture on the slope consisted of this type. This type is characterized by scattered tussocks of *Festuca olgae* and a relatively high cover of *Carex infuscata* and a high number of herb species. *Caragana* occurs with low cover (5 to 10 %). Total cover is 55 %; cover by rock is high (up to 30 %). Species richness was highest compared to any other type and many species not found in any other type are present here, such as *Potentilla nivea* var. *himalaica.* Similarly, the graminoid biomass, consisting of 8 species was the highest compared to any other vegetation type at 1620 kg/ ha (95 % CL 1106 to 2180 kg/ ha). This was despite moderate to high grazing pressures. Total area covered by this vegetation, occurring at higher altitudes (4800 m), was 0.9 sq. km (3 %).

III. Open steppe/desert vegetation

There are a number of vegetation types where *Caragana* or any other shrub species are virtually absent. There is variation between areas with moderate and heavy grazing. The most conspicuous species are low graminoids and/or forbs such as *Cousinia thomsoni, Arnebia euchroma, Heracleum thomsonii* or *Artemisia* spp.

***a. Poa lahulensis – Nepeta discolor* type**

Steppe vegetation that is blueish in appearance because of the abundance of *Poa lahulensis, Carex melanantha*, and *Elymus longe-aristatus*. Total plant cover of 20 to 30 % is predominantly contributed by graminoids, with an average height of 10 cm. This type occurs on S and SE facing slopes at high altitude (4600 m) in moderately grazed areas. The vegetation often has a 'wavy' appearance due to regular patterns formed by the graminoids. The grass biomass is relatively high at 200 kg/ ha (95 % CL 168 to 238 kg/ ha). This type has a total surface area of 2.04 sq. km (7 %).

***b. Stipa orientalis – Cousinia thomsoni* type**

Some of the relatively low altitude pastures (3800-4100 m) close to villages, which probably had high grazing pressure in the past are currently kept only for winter grazing. These areas have a very open (total cover 20 %) vegetation type with *Stipa orientalis* and *Piptatherum munroi* as the most important species. Other graminoids occurring here were *Festuca olgae, Elymus repens, E. longe-aristatus* and *E. semicostatus*, each never covering more than 2 %. *Artimisia maritima* is usually present, but always with low cover and height. This vegetation type is restricted (0.71 sq. km; 3 %). The graminoid biomass was 86 kg/ ha (95 % CL 67 to 106 kg/ ha).

***c. Cousinia thomsoni – Heracleum thomsonii – Leymus secalinus* type**

Heavily grazed areas may have an open vegetation (cover upto 30 %) characterized by the presence of several perennial herbs with *Cousinia* and *Heracleum* as the dominant species. Other frequent herbs are *Thalictrum foetidum, Nepeta discolor, Silene moorcroftii* and *Dracocephalum heterophyllum*. Grass cover is very poor and consists mainly of *Leymus secalinus*, and/or *Stipa orientalis* and *Elymus longe-aristatus*. Scattered shrubs of *Caragana versicolor* or *Potentilla arbuscula* may occur. This type occurs in areas with moderate slopes. Several of the species in this type are probably indicators for overgrazing. This vegetation occurred over 0.5 sq. km (2 %) in the study area. The graminoid biomass was very low at 38 kg/ ha (95 % CL 11 to 77 kg/ ha).

***d. Cousinia thomsoni – Arnebia euchroma* type**

Heavily grazed and degraded sites are often characterized by very low vegetation cover (10 to 15 %) and height, and a low number of species. *Cousinia* and/or *Arnebia euchroma* are most the conspicuous, while *Heracleum thomsonii* may be present. Grass cover is minimal and may consist of *Elymus longe-aristatus* and *Stipa orientalis*. This type was spread over 1.29 sq. km (5 %). Graminoid biomass was very low, estimated at 42 kg/ ha (95 % CL 32 to 51 kg/ ha).

***e. Cousinia thomsoni – Astragalus grahamiana – Nepeta discolor* type**

This type occurs in areas neighbouring *Caragana versicolor – Leymus secalinus* vegetation type. Vegetation cover varies considerably between 30 to 50 % (occasionally even higher). *Carex infuscata* may be interspersed with the other species or there is a mosaic with large patches of *C. infuscata* in which *Carex* cover is significant. Graminoid cover is generally low, except in the pure *Carex* patches. *Leymus secalinus* and *Elymus longe-aristatus* are the most common grass species. The type again characterizes heavily grazed areas. It was spread over 0.7 sq. km (3 %) and attained a very low graminoid biomass of 35 kg/ ha (95 % CL 24 to 47 kg/ ha).

Graminoid biomass: a global comparison

Information from 29 sites spread across three ecosystems, the polar desert and tundra, temperate grasslands and tropical steppes and savannas is presented in Appendix 4.2. Only a single site in the polar desert of former USSR had a lower mean graminoid biomass compared to the Trans-Himalayan system studied (Fig. 4.3). The lower limit of the range reported for tropical Senegal was also less than the Trans-Himalaya, though the reported upper limit was much higher (see Appendix 4.2).

Discussion

Dwarf shrub vegetation with *Caragana* as the dominant species has been recognized as an important formation in semi-arid high mountain regions of the Himalaya and adjacent areas (Schweinfurth 1957, Hartmann 1987, Zhang Jingwei 1982). Six variations (types) of this formation could be recognized in our study area, mostly under different stages of degradation. These covered over three fourths of total vegetated area in the rangelands. *C. versicolor* seems to facilitate the growth of several other species, especially graminoids, by affording protection from grazing and trampling, and perhaps also by increasing N availability through N-fixation. The species is hardly browsed upon by livestock (see Chapter 6). However, the villagers extract substantial amounts of *C. versicolor* every year, which is used for fuel, as well as for lining the rooftops of the mud houses for intercepting rain. Areas especially close to larger villages have lost many *C. versicolor* patches, causing loss of top soil through erosion. The villagers now have regulations on its extraction (see Chapter 2). Removal of the species may initially lead to an increase in graminoid cover if grazing pressures are low. However, continuous and intensive grazing results in very poor

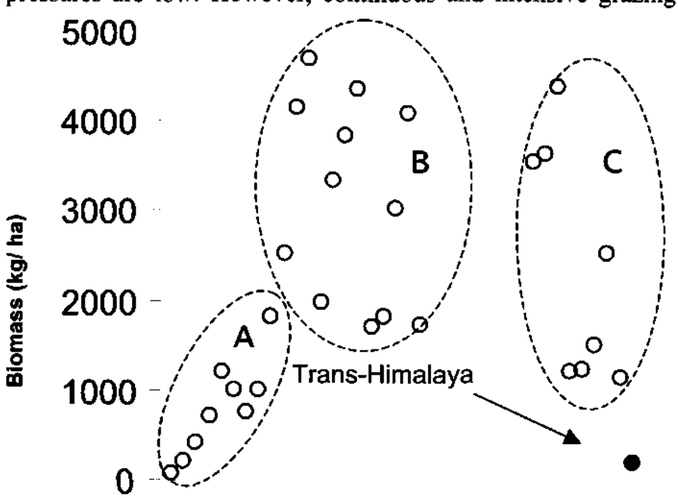

Fig. 4.3 Graminoid biomass in the Trans-Himalaya (•) and twenty nine other sites (o) across the world. It was not always clear if the reported aboveground biomass in literature was that contributed by graminoids alone, or if it included other species. We have presented data only from those systems where graminoids contribute over 50 % of the standing plant biomass in the ground layer. We have used mid-points in cases where ranges, rather than means, were reported. See Appendix 4.2 for details.

A: Polar desert and tundra, **B**: Temperate grasslands, and **C**: Tropical steppes and savannas graminoid/ plant cover and increase in species such as *Cousinia thomsoni* and *Leymus secalinus* (which is a less palatable graminoid) that are relatively graze resistant.

Agro-pastoralism is the predominant land use in the Spiti Region. The area is arid and wherever possible, water from springs, snowmelt, or glacial ponds is diverted to the crop-fields through channels dug along the contour lines (see Chapter 2). These channels are usually several kilometres long. This water harvest very likely has resulted in the loss of substantial patches of moist sedge vegetation (*Carex infuscata-Kobresia royleana*) over historical time. Sedges and other graminoid species form very important forage for livestock as well as wild herbivores (see Chapter 6). The remaining sedge patches face intensive grazing pressures, but seem quite resilient to grazing as long as there is sufficient soil moisture (water logging), as indicated by our clipping experiments. Nevertheless, loss of this vegetation has probably reduced the grazing potential of these rangelands over historical time. Similarly, water harvest has possibly also resulted in a substantial loss of vegetation types such as *Potentilla nivea – Carex infuscata – Festua olgae*, which have very high graminoid biomass and therefore were presumably important grazing patches for both livestock and wild herbivores. Although such lost grazing is at least partly compensated for in the case of livestock that are also fed forage raised in crop-fields (see Chapter 2), the effects of habitat loss were probably disproportionately high on wild herbivores.

Intensive grazing is correlated with a reduction in graminoid biomass (Table 4.1), which is to be expected considering that all the large herbivores in these rangelands feed predominantly on graminoids (Chapter 6). There are no areas where livestock grazing is completely absent. In fact, there are no such areas in the entire Spiti Valley, and perhaps in the entire Trans-Himalaya where the vegetation is free from grazing or other human impacts. The grazing pressures are generally quite high, and our studies have established that a majority of the rangelands in the Spiti Valley are overstocked (Mishra *et al.* in press). Thus, even though the human population of the study area is low (density of <1 person per km^2; Mishra 2000), human impacts on the vegetation are intensive and widespread.

Evaluating grazing impacts on the vegetation are difficult when grazing is pervasive and has a long history (Fleischner 1994), as is the case in Spiti. Given the absence of 'reference' sites, which could give some indication of how the rangeland vegetation would appear in the absence of human use, grazing impacts on the vegetation are difficult to interpret. The low number of species as well as the constancy of some species (present in almost all releves) perhaps indicate vegetation degradation. Most of the vegetation types that we have described may in fact be considered derivates of the more 'natural' vegetation. Establishing and monitoring areas free from livestock grazing could help give some indication of how the rangeland vegetation and associated wildlife would have appeared in the absence of human use.

Finally, the global comparison reveals that the Trans-Himalaya could be considered a low graminoid biomass ecosystem. This means that insofar as the large grazer assemblage in the Trans-Himalaya is concerned, as seen in Chapter 1, competition rather than facilitation, is expected to be the dominant form of interaction among species.

Acknowledgements

The Chief Wildlife Warden of Himachal Pradesh, on behalf of the Department of Forest Farming and Conservation, accorded permission to conduct fieldwork in Spiti. The research was made possible by grants to C. Mishra by the Netherlands Foundation for the Advancement of Tropical Research (WOTRO), a body residing under the Netherlands Organization for Scientific Research (NWO), and to P. Ketner by the NWO. L. Gyalson and T. Dorje made fieldwork easier and enjoyable. The staff at the Wildlife Institute of India made their resources accessible. We are grateful to all of them.

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Appendix 4.1 The plant species recorded during sampling on the Kibber Plateau in Spiti Valley, Indian Trans-Himalaya.

Gramineae:

1 *Agropyron repens*
2 *Agrostis cf. stolonifera*
3 *Elymus nutans*
4 *Elymus longe-aristatus*
5 *Elymus semi-costatus*
6 *Festuca cf. valesiaca*
7 *Festuca olgae*
8 *Leymus secalinus*
9 *Piptatherum munroi*
10 *Poa alpina*
11 *Poa lahulensis*
12 *Stipa jacquemontii*
13 *Stipa orientalis*

Cyperaceae:

1 *Carex infuscata*
2 *Carex melanantha* var. *moorcroftii*
3 *Carex orbicularis*
4 *Carex spec.*
5 *Kobresia royleana*
6 *Scirpus setaceus*

Others

1 *Allium carolinianum*
2 *Allium jacquemontii*
3 *Arabidopsis himalaica*
4 *Arabis tibetica*
5 *Arnebia euchroma*
6 *Artemisia maritime*
7 *Artemisia spec.*
8 *Artemisia tournefortiana*
9 *Asperula oppositifolia*
10 *Astragalus grahamiana*
11 *Astragalus rhizanthus*
12 *Caragana versicolor*
13 *Christolea crassifolia*
14 *Cousinia thomsoni*
15 *Draba altaica*
16 *Dracocephalum heterophyllum*
17 *Ephedra gerardiana*
18 *Eritrichium canum*
19 *Eritrichium cf. fruticulosum*
20 *Eurotia ceratoides*
21 *Gentiana tianchanica*
22 *Gentianella cf. tenella*
23 *Gentianella moorcroftiana*
24 *Geranium pratense*
25 *Heracleum thomsonii*
26 *Hippophae rhamnoides* spp. *turkestanica*
27 *Koelpinea linearis*
28 *Lactuca dissecta*
29 *Lactuca orientalis*
30 *Lactuca tartarica*
31 *Leontopodium himalayanum*
32 *Lindelophia anchusoides*
33 *Lonicera sp.*
34 *Microsisymbrium axillare*
35 *Nepeta discolor*
36 *Oxytropis cachmeriana*
37 *Oxytropis microphylla*
38 *Oxytropis mollis*
39 *Pedicularis cf. cheiranthifolia*
40 *Pedicularis longiflora*
41 *Polygonum aviculare*
42 *Polygonum paronychoides*
43 *Polygonum tortuosum*
44 *Potentilla arbuscula*
45 *Potentilla bifurca*
46 *Potentilla nivea* var. *himalaica*
47 *Potentilla sericea*
48 *Potentilla* sp.
49 *Psychrogeton andryaloides*
50 *Ranunculus pulchellum*
51 *Rosularia alpestris*
52 *Scorzenera virgata*
53 *Scrophularia dentata*
54 *Silene tenuis*
55 *Silene moorcroftiana*
56 *Sisymbrium brassiciforme*
57 *Thalictrum foetidum*
58 *Thesium multicaulum*
59 *Thymus linearis*
60 *Tragopogon pratensis*
61 *Trigonella emodii*
62 *Viola kunawarensis*

Appendix 4.2 Aboveground plant biomass (largely graminoid) of some graminoid dominated ecosystems in the world.

Region	Ecosystem	Biomass (kg/ ha)
Polar desert and tundra		
U.S.S.R.	Polar desert	60
Canada	Cold plateau	200
U.S.S.R.	Polar semi-desert	400
	Arctic tundra	710
	Arctic tundra moss-herb community	1190
	Moss *Dryas* –sedge tundra	1000
Canada	Sedge meadow	600-900
U.S.A.	Wet sedge meadow	1000
Finland	Sub-alpine heath	1820
Temperate grasslands, with different dominant grass species		
Czechoslovakia	*Festuca sulcata*	2520
	Alopecurus pratensis	4130
	Phalaris arundinacea	4690
Poland	*Carex fusca*	1960
	Alopecurus pratensis	3320
	Arrhenatherum elatius	3830
	Dactylis glomerata	4350
U.S.S.R.	*Puccinellia distans*	1700
	Festuca pseudovina	1800
Netherlands	*Juncus gerardii*	3020
	Puccinellia maritima	4070
Hungary	*Festuca vaginata/Koeleria glauca*	1720
Tropical steppes and savannas		
Ivory Coast	*Loudetia simplex* steppe	3540
	Transition to *Loudetia simplex* steppe	3620
	Andropogon schirensis steppe	4360
Senegal	*Aristida* spp. *Schoenefeldia gracilis* steppe	590 – 1800
	Tree and shrub savannas with different woody cover (graminoid biomass)	20 – 2410
Mauritania, Sahara zone	Herbaceous steppe with *Panicum* spp. and/or *Aristida* spp.	491 – 2500
Mali, Sahel-Sudan zone	Herbaceous steppe with *Loudetia togolensis*, *Schoenefeldia gracilis* and/or *Cenchrus biflorus*	1000 – 4000
	Steppe with annual Gramineae	250 – 2000

Chapter 5

Overstocking in the Trans-Himalayan rangelands of India

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Stocking rangelands with too many livestock can compromise livestock production, as well as undermine conservation efforts in areas where livestock and wildlife share the rangelands. The important question is, how many is too many? We analyse stocking densities in Spiti's rangelands, to establish whether or not they are overstocked.

Abstract

High livestock densities in rangelands can result in reduced animal production due either to overgrazing or to directly reduced per capita food availability, yet evidence for reduced animal production due to overstocking is scarce. Here, using simple animal production models, we establish the occurrence of overstocking in a traditional agro-pastoral system in the Spiti Valley of the Indian Trans-Himalaya. Empirical data showed that fecundity of adult female livestock was related to total livestock biomass density (S), and we modeled it as a negative linear function of S. We then modeled total herd production as a quadratic function of S, and thereby calculated an optimum livestock biomass density (S_{op}) at which total herd production would be maximized. A sample of 40 villages showed that over 83 % of Spiti's rangelands may be overstocked with values of $S > S_{op}$. Overstocking seems to be a classic case of the tragedy of the commons, as livestock is individually owned while the land is communally grazed. Recent socio-economic changes have probably contributed to high levels of overstocking. Even areas within wildlife reserves are overstocked. Conservation management needs to focus on creation of grazing free areas and management of livestock densities.

Introduction

Maximizing sustained livestock production is the central concern of most livestock production systems as well as of range ecology. Pastoralists often maintain herds at high stocking density in order to maximize production. However, stocking more animals than can be adequately fed in the rangelands can actually compromise herd production, lead to rangeland degradation, and undermine conservation efforts in areas where livestock and wildlife share the rangelands. The Trans-Himalayan regions of the Tibetan Plateau and the Tibetan Marginal Mountains, spanning over 2.6 million km^2, represent an ecosystem where most of the area has been subject to traditional pastoralism and agro-pastoralism for several millennia (Handa 1994, Schaller 1998). The region also harbours a unique assemblage of wild herbivores such as the wild yak (*Bos grunniens*), Tibetan antelope (*Pantholops hodgsoni*), Tibetan gazelle (*Procapra picticaudata*), Tibetan argali (*Ovis ammon*), ibex (*Capra ibex*), and bharal (*Pseudois nayaur*), and associated predators such as the snow leopard (*Uncia uncia*). In Spiti Valley of the Indian Trans-Himalaya, the entire catchment is grazed by livestock, and, consequently, wild herbivores and livestock share the rangelands. This paper examines livestock stocking densities in the rangelands of Spiti, which includes area within Spiti's wildlife reserves, with the ultimate aim of guiding conservation management in the Trans-Himalaya.

Before proceeding further, we introduce the scope of the paper in the context of the global debate on overgrazing, and distinguish between the terms overgrazing and overstocking as used in this paper. Overgrazing is a worldwide concern, has been a subject of much deliberation, and yet conclusive evidence for its occurrence has been remarkably difficult to find. Indeed, changes in vegetation composition, dominance of unpalatable species, and areas of accelerated erosion in rangelands are not difficult to find and have been abundantly reported (Prins 1989, Wilson and Macleod 1991). However, though strongly indicating overgrazing, by themselves these are not proof of overgrazing; they represent states of stable degradation (*sensu* Prins 1989; also see Rietkerk and Van de Koppel 1997 for a theoretical treatment of the subject). As defined by Prins (1989, p. 292) 'Overgrazing occurs when the consumption is at such a level that the amount of vegetation is reduced to that level where further reduction of the biomass causes a reduction both in production and harvest'. The question that has remained largely unanswered is whether or not such changes in vegetation cause a reduction in animal production. This has been expressed by Wilson and Macleod (1991, p. 474) ' ...(It is) surprising that there is not more concrete evidence available of the effects of overgrazing on animal production as opposed to the resource base'. In this paper our objective is to present evidence of reduced animal production resulting from high stocking densities in the little known montane agro-pastoral system in Spiti Valley. Since a reduction in animal production can be effected not just by decreased food production (overgrazing) but also by decreased per capita food availability (effected merely by high livestock numbers), we choose to call it overstocking rather than overgrazing. Are Spiti's rangelands overstocked? We address this question in the present discourse, using simple models that relate animal production and stocking density.

Study area

The 186,000 km^2 of the Indian Trans-Himalaya, the rain-shadow region of the Greater Himalaya, include parts of the Tibetan Plateau and the Tibetan Marginal Mountains. The Spiti Valley (31°35' to 33°0' N and 77°37' to 78°35' E; altitudinal range 3350 to 6700 m) in the Trans-Himalayan Lahaul and Spiti District spans an area of over 12000 km^2 in the catchment of the river Spiti. The Greater Himalaya in the South, Ladakh in the North and Tibet in the East' flank the region. The region is characterized by low precipitation, a short growing season, low primary productivity, and high stocking density (Mishra 2000). The livestock assemblage in Spiti includes domestic yaks (*Bos grunniens*), cattle, cattle-yak hybrids, horses, donkeys, sheep and goats. The present-day Sino-Tibetan speaking inhabitants are thought to have occupied the region around the beginning of the first millennium BC (Handa 1994). Buddhism was introduced in the region in the 8th century AD. The present local human population is entirely Buddhist. The local inhabitants are agro-pastoral, though in some villages the men also work as guides for trekking tourists and mountaineers. Livestock is owned by individual families whereas the grazing land is common to the village with equal access. The climate in Spiti is arid, with most of the precipitation in the form of snow. Temperatures range between 0 to 30 C in summer and –30 to 3 C in winter.

The steppe rangeland vegetation is characterized by the absence of tree layer. Shrub layer is largely formed by *Caragana*, and to a smaller extent by *Lonicera*, *Rosa* and *Potentilla* species. The vegetation cover is generally sparse and rarely exceeds a height of 1 m. Several species of herbs and graminoids such as *Festuca*, *Poa*, *Stipa* and sedges constitute the forage biomass. The extant large wild herbivores in Spiti are the bharal, ibex, and hare (*Lepus oiostolus*).

Modeling animal production

The assumption that overstocking can occur implies that (1) at the level of the individual animal, production should be a function of stocking density, and (2) at the level of the landscape, there should be an 'optimal' stocking density at which total herd production can be maximized. The first question to be answered then is whether or not animal production in Spiti's rangelands is related to stocking density. Animal production can be measured in different units such as weight gain per day, annual wool production etc. (Donnelly *et al.* 1983, 1985). In pastoral production systems in general, 75 % of the calories come from milk, and only 25 % from meat (Prins 1989). Since milk production is directly related to fecundity, the latter can also be used as a unit for measuring pastoral production.

We compared livestock performance between two adjoining rangelands differing in stocking density over three successive years (1998 to 2000). Each spring (early May), we conducted an age/ sex specific census of all the livestock grazing in these two rangelands, and obtained the stocking density (in terms of biomass) for each of them. In calculating the values of stocking density, we have considered all individuals of all livestock species grazing in these two respective rangelands. This was done because all species of livestock in Spiti largely utilize the same resource, graminoids (see Chapter 6). Using goat and sheep as samples (their higher population enabled statistical analysis), we then calculated the average proportion of adult females that were accompanied by kids or lambs. This ratio (kid or lambs: adult female) was used as an index of livestock performance (henceforth referred to as fecundity). Since most births in goat and sheep in the region are confined to winter months (especially February-March), we believe that the ratio gives a good approximation of the annual fecundity per female.

The second question that needs to be addressed now is whether or not one can estimate an "optimal" stocking density that would maximize herd production (fecundity) in these rangelands. The answer to this question depends upon the nature of the relationship between fecundity and stocking density. Both linear and non-linear curves have been reported for herbivores (see Crawley 1983). For simplicity, we assume that the relationship is linear. Using simple linear and quadratic models, we calculated the 'optimal' stocking density (Jones and Sandland 1974, Wilson and Macleod 1991).

Fecundity (F_i) of individual females can be represented by the linear equation (see Fig. 5.1):

$$F_i = F_{max} - mS \quad ....(1)$$

where

F_{max} = maximum annual fecundity per female

M = incremental change in fecundity with change in stocking density

S = biomass density of livestock

It now becomes possible to model the total production (fecundity) of the entire population at the landscape (rangeland) level (F_t). This can be done using the quadratic equation (see Fig. 5.2):

$$F_t = F_{max}S - mS^2 \quad ....(2)$$

where

F_t = population fecundity or herd production per sq. km of rangeland

The vertex of this curve represents the 'optimal' biomass density (S_{op}) at which F_t will be maximized, and can be calculated as $F_{max}/2m$ (Wilson and Macleod 1991). It is obvious, by virtue of the quadratic model (2) that F_t will decrease on either side of S_{op} (Fig. 5.2). In other words, F_t will be lower than its value at the optimal stocking density not only when $S > S_{op}$, but also when $S < S_{op}$. However, these represent two very different situations. In the former case the reduction in F_t can be ascribed to

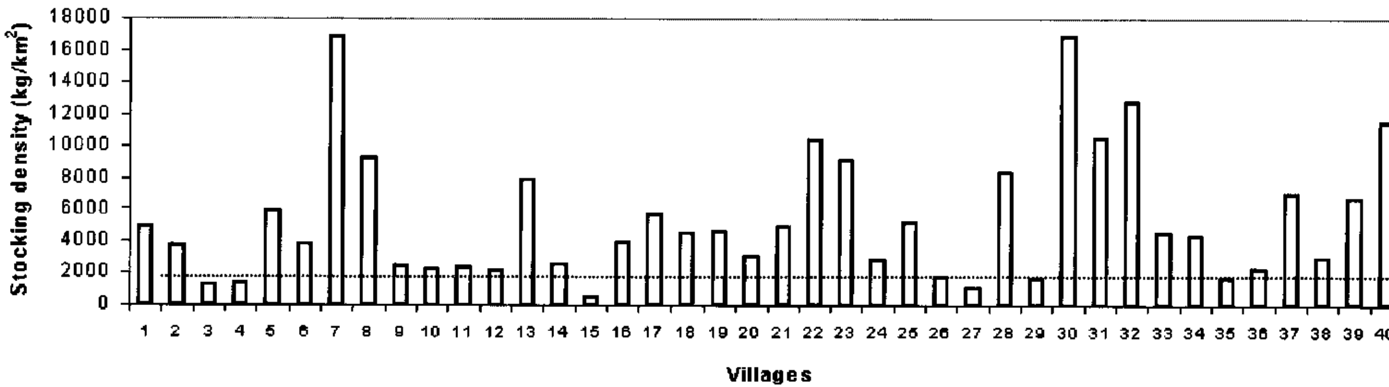

Fig. 5.3 Livestock biomass density in rangelands of 40 villages of Spiti, Indian Trans-Himalaya. The hatched line represents the optimal stocking density (S_{op}) at which herd production is maximized. Species that are free ranging for most of the year (horse and yak) are not included. Villages, corresponding to their numbers, are as follows: 1 Chichim; 2 Chichong; 3 Chidang; 4 Gete; 5 Guling; 6 Hal; 7 Hansa; 8 Hurling; 9 Kaa; 10 Kaza; 11 Kee; 12 Khar; 13 Khurik; 14 Kibber; 15 Kibri; 16 Kungri; 17 Kyomo; 18 Kyoto; 19 Langza; 20 Lara; 21 Lari; 22 Lidang; 23 Lossar; 24 Mane Kongma; 25 Mane Yongma; 26 Mikim; 27 Morang; 28 Mud; 29 Pangmo; 30 Phukchung; 31 Poh; 32 Quling; 33 Rangrik; 34 Sagnam; 35 Shego; 36 Sumling; 37 Tabo; 38 Tangti Kongma; 39 Tangti Yongma; 40 Teling

the examined villages had biomass densities lower than S_{op}, and only 11 that had biomass densities within 500 kg/km^2 of S_{op} (Fig. 5.3). The analysis therefore suggests that over 83% of Spiti's rangelands may be overstocked, i.e., grazed at intensities much higher than what is biologically optimal.

Discussion

Relationship between fecundity and stocking density

The relationship between fecundity and stocking density was described using a linear function in order to keep the analyses simple. Indeed, a consequence of doing so is that a stocking density of ca. 3750 kg/km^2 yields an F_i value of zero (and subsequently negative values) which is certainly not true (see Figs. 5.1 and 5.2). We realize that ideally, an asymptotic function would be a better representation of reality, but we chose a linear function out of a desire for simplicity. Furthermore, the regression model explains only 42% of the observed variation in fecundity. This is because other factors such as precipitation (snowfall) are also important determinants of plant production and consequently seem to cause annual variation in animal production in Spiti. Perhaps a significant proportion of the unexplained variation in animal production in our data could be explained by annual variation in snowfall. However, reliable climatic data are presently lacking for the region.

Causes of overstocking

It may be assumed that the local human communities know best how to manage their land, a knowledge that has been accumulated over generations of experience. Yet, why should Spitians maintain livestock holdings so large as to compromise their own production output as indicated in the present analysis? Socio-economic changes, especially in the late 1980s and early 1990s, have resulted in an escalation of livestock population, and seem to have contributed to the currently high levels of overstocking (Mishra 2000). However, the tendency to overstock is attributable to several other causes. Being an agro-pastoral system as against a purely pastoral one, maximizing milk or meat production is not the only objective of livestock rearing in Spiti. Livestock are also needed for ploughing fields (yak and *dzo*), as draught animals (donkey), and for producing dung used as manure and fuel (all species). Furthermore, high levels of livestock loss to wild predators (estimated at 12% annual loss of the livestock population in some villages; Mishra 1997) may mean that a relatively larger livestock holding is required to maintain herd constancy at the family level. It is also possible that with individual ownership of livestock holdings and communal ownership of the grazing land, Spiti is witnessing a classic case of the tragedy of the commons.

The implications

The entire Spiti Valley, including the area within its wildlife reserves, is grazed by livestock (Mishra, personal observation 1995-2000). Such a situation perhaps prevails over most of the Indian, as well as Tibetan, Trans-Himalaya (Rodgers and Panwar 1988; Schaller 1998). A majority of the rangelands in Spiti are overstocked, and wild herbivores (bharal *Pseudois nayaur* and ibex *Capra ibex*) and livestock seem to compete for forage; heavily stocked rangelands have reduced wild herbivore density (see Chapter 6). The data presented in Fig. 5.3 in fact include six of the 13 villages that use rangelands within Kibber Wildlife Sanctuary – rangelands belonging to four of them are overstocked. Conservation management in the Trans-Himalaya must address issues of livestock husbandry and regulation of stocking density. The density of bharal, the dominant wild herbivore, is presently about ten times lower than that of livestock in Kibber, a situation responsible for high levels of depredation of livestock by wild carnivores and their retaliatory persecution by the herders (Mishra 1997). We believe that creating wildlife reserves was only a first step towards wildlife conservation in the Trans-Himalaya. With almost the entire region being grazed at high livestock density, there are hardly any areas that could serve as a benchmark for how the pastures and associated wildlife would appear in the absence of human use. Creation of (even small) inviolate areas and managing livestock stocking density in others are urgently required as the next step. The present analysis provides for the first time, a guideline, albeit a rough one, for managing herbivore density in Trans-Himalayan rangelands.

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Chapter 6

Resource competition in a Trans-Himalayan herbivore assemblage: diet overlap and its demographic consequences

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In this chapter, we examine if bharal *Pseudois nayaur* (a female and kid seen in the left photograph) and livestock compete for forage in Spiti's rangelands.

Abstract

The impact of livestock grazing on native wildlife is a global conservation concern. The issue of competition between livestock and wild herbivores has remained contentious, and has been a subject of heated debates. In India, pastoralism is amongst the most common forms of land use within wildlife reserves, with three-fourths of them subject to livestock grazing. The Trans-Himalayan region in India has a long history of livestock grazing. The entire Spiti Valley in the Indian Trans-Himalaya, including its wildlife reserves, is grazed by livestock, resulting in complete spatial overlap in the areas used by livestock and wild herbivores. We studied the diets and population structures of Bharal *Pseudois nayaur*, the most abundant wild ungulate in the region, and all the seven species of livestock (Yak *Bos grunniens*, horse, cattle, yak-cattle hybrids called *dzomo*, donkey, sheep and goat) in Spiti Valley, to evaluate whether or not they compete for forage.

The seasonal diet spectrum (niche breadth) of herbivores was negatively correlated with the proportion of graminoid contribution in the diet, i.e., grazers tended to feed on fewer species compared to species with mixed diets in both summer and winter. Bharal, yaks, horses, cow and *dzomo* were grazers in summer, while donkey, sheep and goat were intermediate feeders. Bharal had the narrowest diet spectrum in summer compared to all the other species. In winter, bharal, together with yaks and horses, used rangelands that had been grazed by livestock through summer. Depleted graminoid availability caused all three species to expand their diet spectrum and turn from grazers to intermediate feeders in winter. On the other hand, sheep, goat donkey, cow and *dzomo* grazed in pastures maintained exclusively for winter use, and all of them were grazers in winter.

The similarity in diet composition of species seemed correlated with similarity in their body masses, especially in summer. The relationship tended to break down in winter. We found considerable diet overlap between species in both seasons. Diet of bharal in summer overlapped completely on (was a subset of) the diet of yak, donkey, and sheep. This overlap was less in winter because of bharal's expanded diet spectrum. In both seasons, all important forage species in bharal diet were consumed in substantial amounts by one to several species of livestock.

Comparison of graminoid availability (at the time when standing crop is maximum) between a heavily and moderately livestock grazed rangeland suggested that livestock grazing caused a significant reduction in the standing crop of forage. Graminoid availability per unit livestock biomass was three times greater in the moderately grazed rangeland compared to the intensively grazed one.

Comparison of population structures of herbivores between rangelands differing in livestock densities yielded evidence for resource competition. Moderately grazed rangelands had a higher density of bharal, and populations in these rangelands showed better performance (had greater young: adult female ratios; functions of fecundity and neonate mortality). Presence of livestock was estimated to cause an average of 33 % reduction in bharal performance in the intensively grazed rangeland compared to 8 % in the moderately grazed one. Goat and sheep showed qualitatively similar patterns. Variation in performance in goat and sheep was not correlated with variation in adult female body mass.

Introduction

Livestock grazing impacts on native wildlife are an important conservation concern globally (Prins 1992, Noss 1994, Fleischner 1994; Voeten 1999). India supports the world's largest livestock population (449 million) that is still increasing (6 % increase between 1984 and 1994; WRI 1996). Wildlife reserves cover less than 5 % of the India's area, and even these are not free from human and livestock impacts. More than three million people are estimated to live inside wildlife reserves in India with livestock grazing being one of the most widespread forms of land use (an estimated three fourths of Indian wildlife reserves support livestock populations; Kothari *et al.*

1989, 1995). There have been few attempts to evaluate livestock grazing impacts on native wildlife. Consequently, the raging debate on what kind of impacts does local human resource use have on native wildlife, and vice-versa, remains ill-informed. The question of whether local human use of wildlife reserves should be modified, curtailed or encouraged continues to be fuelled by activism rather than by ecology (see Mishra and Rawat 1998).

The arid Trans-Himalayan region is spread over 2.6 million square kilometres, covering the Tibetan plateau, and the Tibetan marginal mountains in the rain-shadow of the Greater Himalayan range. Most of the region has a pastoral history dating back to several millennia (e.g. Handa 1994, Schaller 1998). The region also supports a unique wildlife assemblage, including a diverse and endemic large wild herbivore assemblage. This includes globally threatened species such as the wild yak (*Bos grunniens*), chiru (*Panthalops hodgsoni*), and the Tibetan gazelle (*Procapra picticaudata*). 'Despite the extent and importance of these rangelands, few studies have been conducted by range ecologists, pastoral sociologists or wildlife biologists...' (Miller and Bedunah 1993, p. 618). Little is known about the diets of either livestock or wild herbivores. Thus, our understanding of the impacts of livestock on wild herbivores is very limited, and, consequently, so is our ability to effectively manage Trans-Himalayan wildlife reserves.

Spiti Valley in the Indian Trans-Himalaya spans an area of over 12000 km^2, and has a pastoral history of over 3 millennia (Handa 1994). Spiti presently has three species of wild herbivores (ibex *Capra ibex*, bharal *Pseudois nayaur*, and hare *Lepus oiostolus*), several species possibly having gone extinct in the past due to competition with livestock (see Chapter 7). All available rangelands are grazed by livestock in Spiti, and consequently, at the rangeland level, there is complete spatial overlap in areas used by livestock and wild herbivores. For instance, all our sightings of bharal in the 31 km^2 intensive study area have been in areas where we have also recorded livestock grazing. Over 83 % of the rangelands in Spiti are currently are overstocked (Mishra *et al.* in press). Given complete spatial overlap and a high level of overstocking, do the extant wild herbivores and livestock compete for food?

In this paper, we first analyse the diet composition of seven species of livestock and the bharal, which is the most abundant large wild herbivore in the area, in the Kibber Wildlife Sanctuary of Spiti. We also analyse diet overlap amongst these various species. Most studies of large herbivore communities have been criticized in falling short of actually demonstrating resource competition, and have been observed to 'merely describe patterns of resource use and partitioning among sympatric species' (Putman 1996, p.7, also see Prins 2000). After evaluating diet overlap, we attempt to move a step further and ask if this overlap actually translates to competition for food between wild herbivores and livestock. 'The best test for proving the existence of competition is to find out whether there is a negative influence of one species on the fitness of individuals of another species' (Prins and Olff 1998, p.468).

Density dependent decline in forage availability is known to affect the reproductive performance in ungulates (Clutton-Brock *et al.* 1982). Forage availability influences the body condition of females, and consequently their fecundity (Clutton-Brock *et al.* 1982, Skogland 1983, Leader-Williams 1988). Further, there is evidence for density dependent mortality in neonates and calves (Sæther 1997, Clutton-Brock *et al.* 1982). We analyzed the population structures of livestock and bharal in order to test whether or not they compete for food. Several testable predictions can be made if and when they compete: (1) The density of bharal will decrease with increasing livestock density (2) Bharal as well as livestock have reduced young: adult female ratios (henceforth called performance) in rangelands with high livestock density (3) The lowered reproductive performance is associated with a decreased body mass of adult females. In the present paper, we test these three predictions in order to ascertain whether livestock and wild grazers in Spiti's rangelands compete for food.

Study area

The 186,000 sq. km of the Indian Trans-Himalaya includes parts of both the Tibetan Plateau and the Tibetan Marginal Mountains, immediately north of the Greater Himalayan range. The Spiti region (33°35' to 33°0' N and 77°37' to 78°35' E) in the catchment of the River Spiti is a part of the Trans-Himalayan Lahaul and Spiti district of the Himachal Pradesh state. It is flanked by the Greater Himalaya in the south, Ladakh in the north, and Tibet in the east. Agro-pastoral communities have inhabited the region for over two to three millennia. Parts of Spiti are visited in summer by trans-humant pastoralists from Ladakh (for barter trade) and the Greater Himalaya (for grazing). The local livestock assemblage in Spiti includes yak (*Bos grunniens*), cattle, cattle-yak hybrids (males and females called *dzo* and *dzomo*, respectively), horse, donkey, sheep and goat. Livestock graze in the pastures during most of the year except in the extreme winter. Their diet is supplemented by stall feeding in winter. Large carnivores include snow leopard *Uncia uncia*, wolf *Canis lupus*, and red fox *Vulpes vulpes*. Agricultural and rangeland primary production is limited to the short growing season between May and September. Lying in the rain shadow of the main Himalayan Range, the region is cold and arid, with most of the precipitation in the form of snow. The tree layer is absent in these steppe rangelands. The shrub layer is formed by *Caragana* sp., and to a smaller extent by *Rosa, Potentilla,* and *Lonicera* sp. Plant cover is sparse, and the vegetation rarely exceeds a height of 1 m. Several species of herbs and graminoids such as *Stipa, Festuca,* and *Carex* grow interspersed with the shrubs, rarely exceeding 25-50 cm in height.

Methods

Field methods

Diet

The diet of livestock was recorded through direct observation. Livestock herds were followed to the pastures, and an animal of a given species was selected at random from the herd. This animal was followed continuously while feeding for fifteen minutes, and every 10 seconds, the plant species being fed upon was recorded. After the 15-minute sample (approximately 90 bites), we chose another animal of another species, and repeated the procedure. Observations were spread across each season (divided broadly into summer and winter) and across pastures. For bharal, direct observations were not possible, as the animals did not allow close approach. We searched for bharal herds, and after locating them, waited until the herd had fed and gradually moved away. We then visited the 'feeding station' and from feeding signs, recorded which species were fed upon heavily (forming more than 10% plant cover, with most individuals having been fed upon), and which ones were fed upon moderately (these were either plants that formed less than 10% cover with feeding

Table 6.1 Characteristics of rangelands used as treatments of varying livestock density in Spiti, Indian Trans-Himalaya. On the left are rangelands whose livestock populations were compared, and on the right are those whose bharal populations were compared.

Treatment	Livestock		Bharal (*Pseudois nayaur*)	
	Moderately grazed	**Intensively grazed**	**Moderately grazed**	**Intensively Grazed**
Name	Gete Village	Kibber village	Tabo	Kibber plateau
Altitudinal range (m)	4300-4600	4200-4600	3600-4300	4200-4900
Distance between compared rangelands	Adjoining		40 km	
Area of rangelands (sq.km)	5	15	14*	31
Biomass of livestock (kg) (1998 census)	6,637 (herded livestock)	38,510 (herded livestock)	33,432	95,851
Biomass density of livestock (kg/sq.km)	1,327	2,567	2157	3091

* Area available to both bharal and livestock. The latter had another 1.5 km available for grazing which was completely inaccessible to bharal.

signs, or those that were abundant but only a few plants had signs of feeding). These were given scores of 2 and 1, respectively.

Population structure

We identified two pairs of rangelands (ranging from 5 to 31 km^2; Table 6.1) as moderately and heavily grazed. Population structure of all species of livestock and bharal (as defined in Table 6.2) grazing within these rangelands were determined. This was done through field-surveys for bharal, and livestock census of all families grazing their livestock in these rangelands. In each year, data collection for all comparisons was done within the same month. In the case of bharal, care was taken to ensure that the heavily and moderately grazed (by livestock) areas were neither too far (to preclude habitat differences) nor too close (to ensure the distinct identities of the compared populations). The highly and moderately grazed rangelands whose livestock populations were compared were selected as close to each other as possible. The details of these rangelands are summarized in Table 6.1. Field surveys for bharal were conducted during periods of congregation – beginning of winter (November-December, 1998) and the end of winter (April-May 2000). Bharal were located from horseback, on foot, or from a terrain vehicle. They were then approached within 100 m on foot, counted and classified. All snow-free slopes were searched. Care was taken to avoid repeated counts of the same individuals.

Forage availability

We compared the graminoid biomass between the two rangelands whose livestock populations were compared, to find out if the difference in livestock density translated into a difference in forage availability. We clipped above-ground graminoid biomass from 123 plots covering a total of 1434 square meters spread across the dominant vegetation types in the intensively and moderately grazed rangeland. The plot sizes ranged from 0.0625 to 25 square meters depending upon the heterogeneity of vegetation and abundance of graminoids. In the case of tussock grasses (*Festuca* sp.), we derived a relationship between grass cover and standing biomass. Point intercept transects (50 to 250 points) were distributed across the vegetation to estimate tussock grass cover and the derived relationship used to calculate mean grass biomass. All clippings were done in July-August (2000), the months when vegetation is at its maximum standing biomass. With the aid of a Leica Vector rangefinder, we estimated the total area covered by each of the vegetation types, and obtained estimated availability of graminoids in the moderately and intensively grazed rangelands. The details of vegetation composition and biomass have been presented elsewhere (see Chapter 4). Here, we restrict our focus to providing an estimate of the graminoid biomass available to livestock in the moderately and intensively grazed rangelands.

Analytical methods

The number of plant species eaten per sample by different herbivores and across seasons was compared using ANOVA with unequal replication, and Tukey's honest significant difference tests were employed for within season post hoc comparisons of the number of species eaten (Zar 1984). The representative seasonal diet for each herbivore was obtained by averaging across replicate samples i.e., first the proportion that each plant species contributed in each sample was calculated, and then these proportions were averaged across all the samples for a given herbivore in a given season. For bharal we calculated the average diet in two ways. We first ignored the scores assigned to each plant species and used presence/ absence (if a species was eaten, it was recorded as 1 irrespective of how intensively it was fed upon) data for plant species across samples for a given season to calculate their contribution to the diet. We then repeated the exercise with the species scores (heavily eaten species being considered twice as important as moderately eaten ones). The average diet obtained from both the methods was highly correlated (Pearson's $R = 0.97$ in summer and 0.99 in winter; Zar 1984), and we have presented the latter one in this paper. Matrices of Bray-Curtis index were calculated to assess similarity in diet of different species (Bray and Curtis 1957). We chose this index because it is sensitive to the abundant species, with rare species adding very little to the value (Krebs 1989). These

Table 6.2 Summary of age-sex classes (in months) of herbivores as defined in this paper.

Species	Young	Sub-adult	Adult Female	Adult Male			
Goat	≤ 6	6-18	> 18	> 18			
Sheep	≤ 6	6-18	> 18	> 18			
Donkey	≤ 12	12-36	> 36	> 36			
Cow	≤ 12	12-36	> 36	> 36			
Dzomo	≤ 12	12-36	> 36	> 36			
Horse	≤ 12	12-36	> 36	> 36			
Yak	≤ 12	12-36	> 36	> 36			
Bharal		Yearling		Class IV	Class III	Class II	Class I
Pseudois nayaur	≤ 6	6-18	> 18	> 96	72-96	48-72	18-48

matrices were compared with matrices of similarity in body masses of these species. Similarity in body masses was expressed as the weight ratio, i.e., for each pair of species, the body mass of the smaller species was divided by that of the larger one. We tested if the similarity in diet was correlated with similarity in the body masses using Mantel tests (Manly 1994). Statistical significance of Mantel tests was assessed through 5000 random permutations. Individual species' niche breadth was assessed

Table 6.3 Diet profiles of herbivores in Spiti, Indian Trans Himalaya. The figures indicate % contribution of each plant species to the average diet of each herbivore (sample sizes used to derive the average diet in parantheses, each sample equals approximately 90 bites). The table is simplified in that only species contributing more than 3 % to the diet of any herbivore are mentioned. Those contributing less are clubbed into the others category (last row). Therefore, blank spaces imply either 0 or up to 3 % contribution.

	Yak	Horse	Dzomo	Cow	Donkey	Sheep	Goat	Bharal
SUMMER	(24)	(23)	(12)	(13)	(25)	(13)	(14)	(48)
Elymus longe-aristatus	16.3	17.9	21.3	23	13.8	11.9	8.6	20.7
Carex melanantha	10	12.6	13.9	18.2	6.3	9.6	5.3	
Stipa orientalis	5.6	5.8	.	8.8	8	6	7.5	24.1
Hieracleum thomsonii	.	.	6.5	4.5	.	4.8	.	.
C. infuscata	6.6	15.3	3.4	3.5	13.2	7.7	7.6	5.2
Eurotia ceratoides	.	.	.	3.3	7.2	.	.	3.4
Unidentified forb	.	.	.	3.2	.	.	.	.
Nepeta discolor	.	.	.	3.1	.	.	.	.
Carex sp.	9.6	5.2	.	.	7.6	5.3	5.1	6
Festuca olgae	16.9	.	8	.	.	.	3	17.2
Lindelophia anchusoides	.	.	.	.	.	5.7	10.2	.
Carex sp.	7.6	4.9	.	.	5.7	.	.	.
Alium	.	.	.	.	7.8	.	.	.
Leymus secalinus	13.5	13.9	25.6	9.5	.	9.7	15.7	5.2
Kobresia royaleana	5.1	3.5	.	.	.	.	.	.
Astragalus grahamiana	.	.	.	.	.	7.1	8.2	.
Potentilla spp.	.	.	.	.	.	3.9	6.6	.
Unidentified herb A	.	.	.	.	.	5.3	3.7	.
Unidentified herb B	.	.	.	.	.	3.7	.	.
Cousinia thomsonii	.	.	.	.	7	.	.	.
Others	8.9	20.9	21.4	22.9	23.4	19.4	18.3	19.1
WINTER	(15)	(15)	(6)	(4)	(7)	(32)	(29)	(24)
C. melanantha	24.5	9.8	24.6	4.4	9.6	11.7	10.6	.
E. longe-aristatus	19.8	17.5	39.1	26.1	40.3	35.2	29.2	19.8
C. thomsonii	13	14.4	.	.	13.8	7.9	5.3	3.7
L. anchusoides	7.6	3.7	4.4	3.3	.	.	.	.
Carex spp.	7	.	.	.	.	12.5	17.3	.
Heracleum	6.1	.	8.4	10.7	3.3	.	.	16
Eurotia	5.5	11.1	.	4.4	.	.	.	.
Cicer	5.4	.	.	.	.	.	.	.
L. secalinus	4.2	4.3	.	.	.	11.4	11.4	9.9
S. orientalis	.	20	7.7	27.6	12.4	6.1	3.8	18.5
A. grahamiana	.	8.5	.	.	.	.	.	.
Alium	.	3	.	.	.	6.9	10.2	.
C. infuscata	.	.	13.3	23.5	15.9	.	.	.
Caragana	.	.	.	.	.	.	4.2*	.
Festuca olgae	.	.	.	.	.	.	.	6.2
Scorzonera	.	.	.	.	.	.	.	4.9
Polygonum aviculare	.	.	.	.	.	.	.	4.9
Arnebia euchroma	.	.	.	.	.	.	.	3.7
Rosa webbiana	.	.	.	.	.	.	.	3.7
Others	6.9	8.1	2.3	0	4.9	8.4	8	8.7

using Levins measure (Levins 1968), standardized to a scale of 0-1 following Hurlbert (1978). The total number of species eaten at least once by at least one herbivore in a given season was used to calculate the index.

Overlap in diet of different pairs of species was assessed using the MacArthur and Levins (1967) index. This is an asymmetrical index, which, for any given pair of species, separately estimates the extent to which the diet of the first overlaps on the second and the second on the first. In fact, the widely used Pianka's (1973) index is a geometric mean of the two values of MacArthur and Levins index that characterize any given pair (Krebs 1989). For our purpose, we find this index superior since it takes into account the fact that if the diet of the first species of a pair of herbivores is a subset of the diet of the second, then from the point of view of the former, overlap is total, but only partial from that of the second. For each species, Wilcoxon's signed ranks tests were used to test for significant differences in the distribution of values of its diet overlap on other species, and of each of the others on the species itself (Zar 1984). The mean graminoid biomass and asymmetric 95 % confidence intervals were calculated through Monte Carlo simulations (500 permutations; Krebs 1989).

Results

Dietary profile

Yak: Yaks were recorded feeding on 19 species in summer and 13 species in winter. They were grazers in summer (90 % graminoids, 10 % herbs) with several species of graminoids contributing to the diet (Table 6.3). In winter, they became intermediate feeders (58 % graminoids, 36 % herbs, and 6 % shrubs), though graminoids *Carex melanantha* and *Elymus longe-aristatus* still formed the bulk of the diet.

Horse: Horses were recorded feeding on 29 species in summer and 14 species in winter. They were grazers in summer (81 % graminoids, 17 % herbs, and 2 % shrubs) with several species of graminoids contributing to the diet. In winter, like yaks, horses turned into intermediate feeders (54 % graminoids, 35 % herbs, and 11 % shrubs). While *E.longe-aristatus* was an important component of the diet in both seasons, the contribution of *S. orientalis* increased substantially in winter.

Dzomo: Dzomo fed on 23 species in summer and 7 in winter. They were predominantly grazers in both summer (80% graminoids, 18 % herbs, and 2 % shrubs) and winter (84 % graminoids, 13 % herbs, and 3 % shrubs). *Leymus secalinus* and *E. longe-aristatus* together were contributed substantially to dzomo diet in summer, while in winter, *E.longe-aristatus* alone formed the bulk of the diet (Table 6.3). The importance of *C. melanantha* in the diet increased in winter.

Cow: Cows were recorded feeding on 26 species in summer and 7 species in winter. Among these, *E. longe-aristatus* contributed highly to the diet both in summer and winter. The contribution of *Stipa orientalis* and *Carex* spp. in the diet increased markedly in winter. Cows were predominantly grazers, graminoids contributing 75 % of the diet in summer, and 80 % in winter (herbs and shrubs respectively contributed 21 % and 3 % in summer, and 15 % and 5 % in winter).

Donkey: Donkeys fed on 31 species in summer and 8 in winter. They were relatively intermediate feeders in summer (61 % graminoids, 30 % herbs and 9 % shrubs). The diet was mixed at the species level as well with several species contributing to the

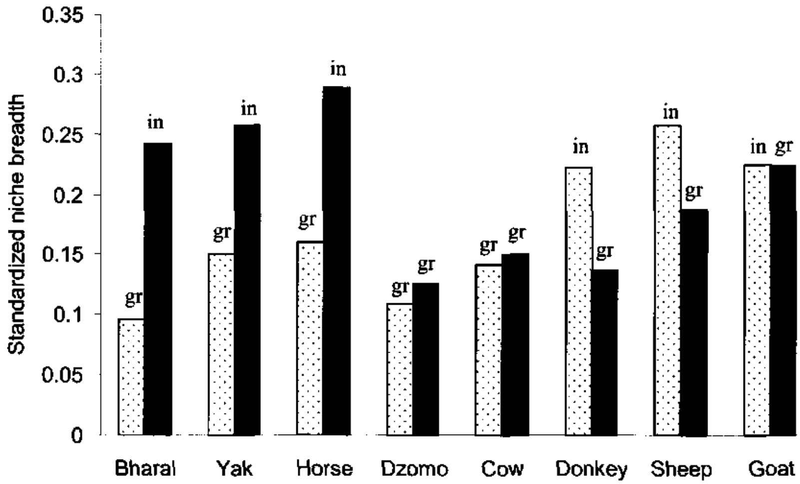

Fig. 6.1 Seasonal diet spectrum of herbivores in Spiti, Indian Trans-Himalaya, represented by Levin's (1968) niche breadth index, standardized to a scale of 0-1 following Hulbert (1978). Hatched and black columns represent summer and winter, respectively (in = intermediate feeder, gr = grazer).

Levin's Niche breadth $B = 1/\Sigma p_i^2$

Where p_i = proportion of diet contributed by plant species i

Standardized Niche breadth $B_s = (B—1) / (n—1)$

Where n = total number of plant species

diet. In winter however, donkeys turned grazers (86 % graminoids, 14 % herbs, and no shrubs), with *E. longe-aristatus* alone contributing more than 40 % to the diet.

Sheep: Sheep were recorded feeding on 32 species in summer and 12 species in winter. They were intermediate feeders in summer (51 % graminoids, 48 % herbs, and 1 % shrubs). Several species contributed to the summer diet, but none of them forming the bulk of the diet. In winter, however, sheep turned grazers with *E.longe-aristatus* forming the bulk of the diet (82 % graminoids, 18 % herbs). Sheep, together with goats, had the widest diet breadth in summer (Fig. 6.1).

Goat: Goats were recorded feeding on 26 species in summer and 14 species in winter. Their diet was similar to sheep in that they were intermediate feeders in summer (55 % graminoids, 42 % herbs, and 3 % shrubs) with no single species forming the bulk of the diet (Table 6.3). They turned grazers in winter (75 % graminoids, 20 % herbs, and 5 % shrubs) with *E. longe-aristatus* forming the bulk of the diet.

Bharal: Bharal were recorded feeding on 22 species in summer and 16 species in winter. They were predominantly grazers in summer (80 % graminoids, 16 % herbs, and 4 % shrubs). Bulk of the summer diet was constituted by *S.orientalis*, *E.longe-aristatus*, and *F. olgae* (Table 6.3). Bharal turned intermediate feeders in winter (56 % graminoids, 38 % herbs, and 6 % shrubs), though *S. orientalis* and *E. longe-aristatus* retained their importance in the diet. Bharal increased their consumption of *Hieracleum thomsonii* substantially in winter. Of all the species of herbivores, they had the narrowest diet breadth in summer, though in winter their diet breadth was substantially wider (Fig. 6.1).

Comparison of diets

ANOVA (with unequal N) with number of plant species eaten per sample as the dependent variable and animal species as well as seasons (summer and winter) as fixed factors revealed only a few differences between animal species (df = 7, F = 3.6, $p < 0.00$) as well as season (df = 1, F = 36.5, $p < 0.00$). Bharal fed on significantly fewer species than cow, goat and sheep in summer, while there was no detectable difference in winter. The only other detectable difference was between sheep and cow in summer, with the former consuming more species (Tukey's honest significant difference test for unequal N, $p < 0.05$).

There was a significant positive correlation between similarity in the summer diet of herbivores, and their similarity in body masses (Mantel tests, R = 0.589, $p = 0.014$ for the livestock assemblage, and R = 0.581, $p = 0.0036$ after including bharal; see Fig. 6.2). This relationship tended to break down in winter (R = 0.384, $p = 0.11$ for the livestock assemblage, and R = 0.384, $p = .109$ after including bharal).

The Levins (1968) standardized niche breadth showed a strong negative correlation with proportional graminoid contribution in the diet, declining from mixed feeders to

Table 6.4 Diet overlap in the herbivore assemblage in Spiti, Indian Trans-Himalaya (MacArthur and Levins' (1967) overlap index). Note that these are asymmetrical matrices. The rows represent overlap indices of the diet of a given species (corresponding to the first column) on every other species of herbivore (corresponding to the first row).

MacArthur and Levins' overlap index $O_{jk} = \Sigma p_{ij} p_{ik} / \Sigma p^2_{ij}$

Where O_{jk}= Niche overlap of species k on species j

p_{ij} and p_{ik}= Proportion that plant species i contributes to the diet of herbivore species j and k

	Yak	Horse	Dzomo	Cow	Donkey	Sheep	Goat	Bharal
Summer								
Yak	.	0.85	0.72	0.76	0.81	0.93	0.84	0.61
Horse	0.81	.	0.7	0.82	0.98	1	0.9	0.48
Dzomo	0.95	0.98	.	0.95	0.76	1	1	0.49
Cow	0.8	0.91	0.75	.	0.9	1	0.85	0.56
Donkey	0.57	0.73	0.4	0.6	.	0.8	0.66	0.43
Sheep	0.57	0.83	0.52	0.65	0.7	.	0.84	0.4
Goat	0.58	0.66	0.54	0.56	0.65	0.96	.	0.38
Bharal	0.91	0.74	0.55	0.79	0.9	0.96	0.8	.
Winter								
Yak	.	0.76	0.61	0.39	0.56	0.7	0.72	0.52
Horse	0.69	.	0.47	0.53	0.55	0.59	0.58	0.69
Dzomo	1	0.91	.	0.82	0.92	0.96	0.93	0.88
Cow	0.61	0.92	0.72	.	0.79	0.66	0.61	0.93
Donkey	0.93	1	0.87	0.85	.	0.97	0.92	0.96
Sheep	0.91	0.86	0.71	0.56	0.76	.	1	0.83
Goat	0.81	0.72	0.59	0.44	0.62	0.9	.	0.7
Bharal	0.55	0.81	0.52	0.63	0.61	0.68	0.65	.

grazers (Pearson's R = -0.85, df = 15, p = 0.000; see Fig. 6.1). Donkey, goat, and sheep showed a decline in diet breadth from summer to winter (they were mixed feeders in summer and grazers in winter), while bharal, yak, and horses showed an increase in niche breadth from summer to winter. There was only a marginal increase in niche breadth of cow and dzomo from summer to winter (they were grazers in both seasons).

The values of MacArthur and Levins (1967) diet overlap index are presented in Table 6.4. Considering that the values can range from 0 (no overlap) to 1 (complete

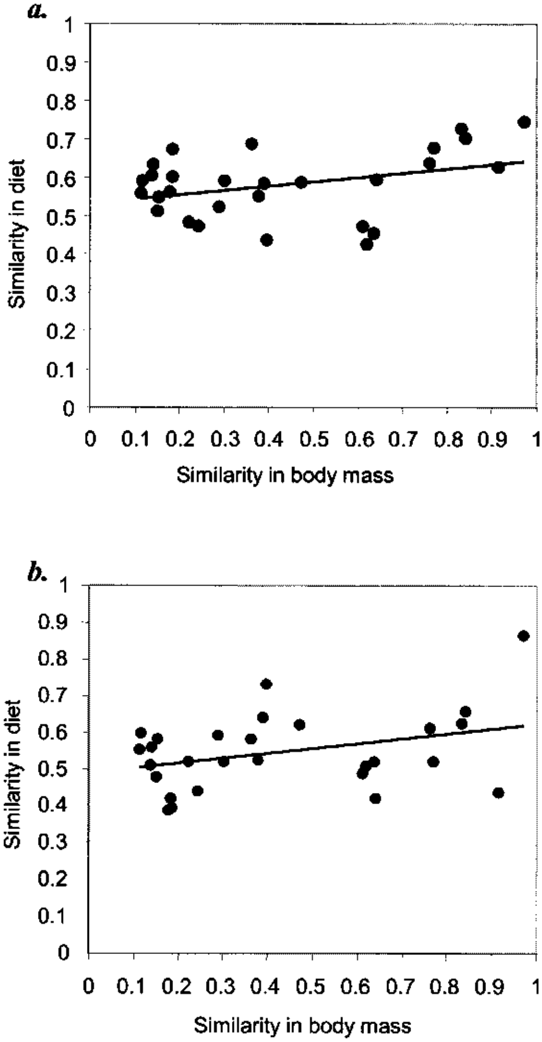

Fig. 6.2 Relationship between similarity in body masses and similarity in diets of eight species of large herbivores in Spiti, Indian Trans-Himalaya. The correlation was especially strong in summer (a) than in winter (b) as indicated by Mantel tests (R = 0.581, p = 0.014 in summer, and R = 0.384, p = 0.109 in winter).

overlap), the diet overlap between members of this herbivore assemblage was considerably high. In summer, the overlap of diets of dzomo and bharal on other species was significantly higher than overlap of others on them (Wilcoxon's signed ranks tests, $z = -2.197$, $p = 0.028$ for dzomo and $z = -0.237$, $p = 0.018$ for bharal), i.e, their diets tended to be subsets of the diet of other herbivores but not vice versa. This is also partly reflected in the fact that these species had amongst the narrowest diet breadth in summer (Fig. 6.1). On the other hand, the diets of sheep and goat showed significantly lower overlap on others compared to overlap of others on them ($z = 2.028$, $p = 0.043$ for goat and $z = 2.366$, $p = 0.018$ for sheep). Sheep and goat had amongst the widest diet breadth in summer (Fig. 6.1). In addition to dzomo, the diets of yaks, horses, and donkeys also became subsets of the diets of other species in winter. Overlap of their diets on other species became significantly higher than that of other species on them ($z = -2.366$, $p = 0.018$ for dzomo, $z = -2.208$, $p = 0.043$ for yak and $z = -2.366$, $p = 0.018$ for horse, $z = -2.197$, $p = 0.028$ for donkeys).

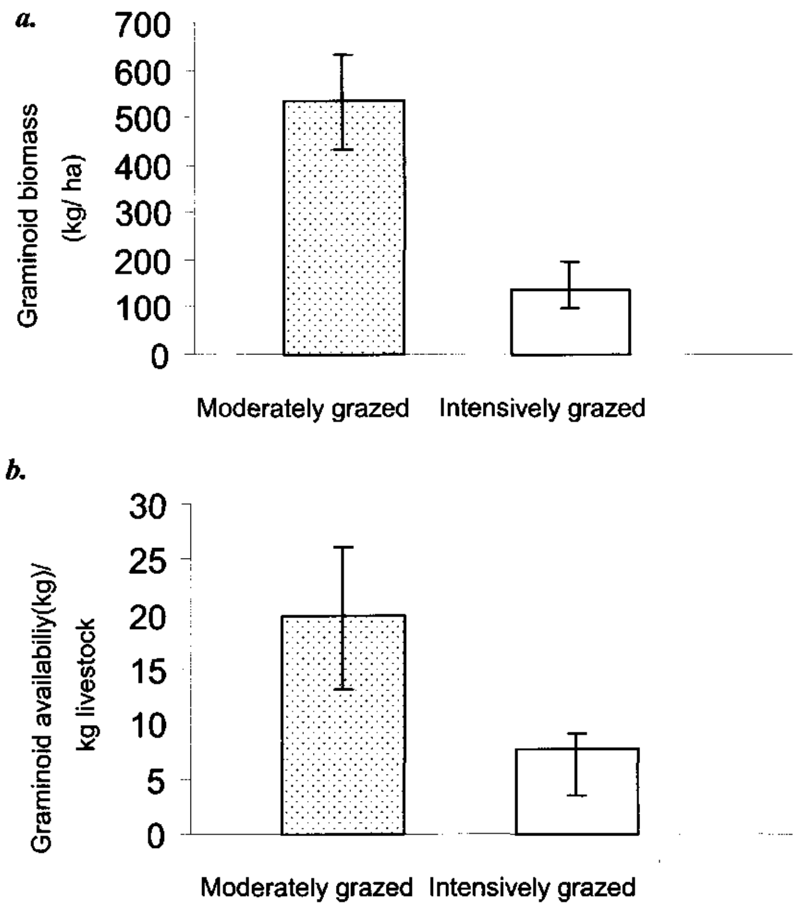

Fig. 6.3 Graminoid biomass in moderately and intensively grazed rangelands in Spiti, Indian Trans-Himalaya. Error bars represent asymmetric 95 % confidence limits.

a. Graminoid biomass in kg/ ha

b. Graminoid biomass (in kg) per unit livestock biomass (kg).

continued

	1988		1999		2000	
	Moderately grazed	Intensively grazed	Moderately grazed	Intensively grazed	Moderately grazed	Intensively grazed
Adult Female	11	64	9	53	9	56
Subadult Male	0	0	0	0	0	1
Subadult Female	0	1	0	0	0	1
Young male	0	0	0	0	0	2
Young female	0	1	0	0	0	1
Young/100 females	0	2	0	0	0	2
Horse						
Total	6	47	6	38	6	32
Adult Male	0	7	1	5	2	2
Adult Female	6	29	2	31	3	24
Subadult Male	0	4	1	1	1	1
Subadult Female	0	7	1	1	0	3
Young male	0	0	0	0	0	1
Young female	0	0	1	0	0	1
Young/100 females	0	0	50	0	0	8
Yak						
Total	15	105	14	99	14	93
Adult Male	4	45	4	49	4	47
Adult Female	5	30	8	32	8	26
Subadult Male	1	8	0	5	1	10
Subadult Female	2	11	0	4	0	7
Young male	1	3	2	2	0	1
Young female	2	8	0	7	1	2
Young/100 females	60	37	25	28	13	12
Bharal						
Total	98	71	.	.	102	91
Male Cl IV	3	4	.	.	1	6
Male Cl III	11	6	.	.	4	6
Male Cl II	5	8	.	.	3	14
Male Cl I	6	5	.	.	3	2
Adult Female	31	24	.	.	16	35
Yearlings	20	12	.	.	10	7
Young	22	12	.	.	15	21
Unclassified	0	0	.	.	50	0
Kids/100 females	71	50	.	.	94	60

The mean body mass ± SD (sample size in parentheses) of adult female sheep was 32.7 ± 4.9 kg (n = 45) in the moderately grazed rangeland compared to 30.2 ± 5.2 kg (n = 34) in the heavily grazed one. The difference, though marginal, was statistically significant (t = 2.183, df = 78, p = 0.032). No difference could be detected in the mean body mass of adult female goats, which was 28.9 ± 4.6 kg (n = 22) in the moderately grazed rangeland and 28.3 ± 4.1 kg (n = 18) in the heavily grazed one.

The rangelands whose bharal populations were compared varied by 30 % in livestock biomass density (Table 6.1). There was a three-fold difference in the average (± SD) density of bharal between the moderately grazed rangeland (7.1 ± 0.2 per sq. km) and the heavily grazed one (2.6 ± 0.46 per sq. km) (Fig. 6.4). In terms of performance, again, bharal fitted the predicted pattern; 55 (± 7.1) kids per 100 females in the heavily grazed rangeland compared to 82.5 (± 16.3) kids per 100 females in the moderately grazed one (Table 6.5).

Discussion

Why grazers become intermediate feeders and vice vesa

The growing season for vegetation in the Trans-Himalaya is restricted to the few summer months. Summer is therefore the time of relatively higher forage availability. In winter, the leaves die off, and an estimated 90 % of the area in Kibber becomes inaccessible for herbivores due to snow cover. Therefore, as against summer diet where herbivores probably exercise some choice in what they eat, winter diets are expected to be largely constrained by what is available. Proceeding with this assumption, it becomes easier to see why yaks and horses, which are grazers in summer, turn into mixed feeders in winter.

The grazing practice in Kibber is such that yaks and horses largely range free in distant pastures for most of the year except during extreme winter when they are herded back and stall-fed. The pastures that yaks and horses use in winter have been used right through summer as well. As a result, as winter approaches, the plant biomass, especially graminoid biomass, in these pastures gets depleted, and these species are forced to include more herbs and some shrub in their diet. This is probably true for bharal as well, since they also largely grazed in the few snow-free pastures that had been used by livestock right through summer. We studied bharal diet only in a rangeland intensively grazed by livestock. We predict that in areas of lower livestock density and consequently higher graminoid biomass, bharal continue to remain grazers in winter. Future research should focus on comparing diets of bharal between areas of intensive and moderate livestock grazing.

In contrast, cows and dzomo continue to remain grazers in winter, since (together with other herded livestock donkey, sheep and goats) they graze in pastures that are not used in summer but exclusively kept for winter grazing. These pastures have greater graminoid availability compared to those used by yaks and horses. Why the summer mixed feeders, donkey, sheep and goats, which use the same winter pastures as cow and dzomo, should also turn grazers in winter is not very clear. It is most probably related to greater graminoid biomass availability compared to herbaceous biomass during winter, though we do not have data to establish that conclusively.

Diet and body mass

In a theoretical exploration presented elsewhere, we deduced that up to four species of wild herbivores might have been driven to extinction in Spiti over the last three millennia due to competitive exclusion by livestock (see Chapter 7). This analysis was partly based on the assumption that body masses of herbivores are important determinants of their forage consumption; larger species are able to handle relatively coarser forage compared to smaller ones, and smaller species have a greater energy requirement (Prins and Olff 1998). Does this mean that species that are similar in body masses also select their diet (composition) in a similar manner? Indeed, in summer, when herbivores exercised choice over what they ate, there was a significant positive correlation between similarity in diets and similarity in body masses (Fig. 6.2). The correlation tended to break down in winter, when diets were constrained by what was available, and availability differed for different herbivore species.

Diet overlap and forage availability

Data on graminoid biomass in the rangelands indicate that even during summer, the time of peak vegetation production, the areas with intensive livestock grazing supported a lower graminoid biomass compared to areas with moderate livestock grazing. Further, during this period, bharal were grazers with a very narrow diet breadth, and their diet overlapped almost completely on that of at least three species of livestock. All these three species, on the other hand, had much wider diet breadths as compared to the bharal. The MacArthur and Levins' (1967) overlap index we used is believed to indicate competitive interactions when the overlap value exceeds 0.544 (also see Putman 1996). As seen in Table 6.4, with the exception of *dzomo* in winter, the diet overlap of bharal on all other species in both seasons exceeded this value. Given this high overlap, together with the fact that livestock at high densities seem to actually cause reduced forage availability in the pastures, there seems to be forage competition between livestock and bharal even in summer. In winter, though there is less overlap in the diet, it is because bharal (together with yaks and horses) seem to subsist on what little forage is available in the pastures that have been intensively grazed by livestock right through summer. Compared to bharal, livestock seem to fare slightly better in winter due to access to better rangelands (not grazed in summer), and/ or supplementary feed provided by the owners.

Demographic consequences of competition

Data on population structure of livestock suggests that reduced forage availability causes reduced performance in at least goats and sheep. However, this variation in performance was not significantly correlated with variation in body masses of adult females. This is probably because goat and sheep in these herds are a mix of several breeds, some inherently larger than others. Thus, it is likely that any forage-related variation in body masses is probably being masked by the inherent variation caused by heterogeneity in livestock breeds.

From the data on bharal population structure, it is apparent that competition for forage with livestock results in reduced density and performance of bharal (Fig. 6.4, Table 6.5). As predicted, bharal showed lowered performance in the intensively grazed rangeland, though the magnitude of difference was much smaller than in the livestock species examined. This may be explained by the fact that the maximum annual fecundity (which influences performance) per female in bharal is only 1 (Schaller 1998) compared to 2 in goat and sheep.

Yet, the observed values of bharal performance in the two rangelands may be functions not only of livestock density but also partly of bharal density itself. What proportion of the reduced performance could then be attributed to livestock density alone? We try to evaluate this by ignoring neonate mortality and assuming that performance is related entirely to fecundity. In the absence of livestock, bharal fecundity could be assumed to be a linear function of bharal biomass density (Mishra *et al.* in press), described by the equation:

$F_b = F_{max} - mS_b$..............(1)

where

F_b	=	annual fecundity per adult female bharal in the absence of livestock
F_{max}	=	maximum annual fecundity per adult female bharal
m	=	incremental change in fecundity with change in bharal biomass density
S_b	=	bharal biomass density

As mentioned before, F_{max} for bharal is 1. The values of S_b for the two rangelands were calculated using the 1998 age-sex structures (Table 6.5); 261 kg km^{-2} (moderately grazed rangeland) and 97 kg km^{-2} (intensively grazed rangeland). In goat and sheep from the same region, the value of m, the incremental change in fecundity with change in livestock biomass density, has been earlier calculated as 4.0 X 10^{-4} (Mishra *et al.* in press). Assuming that the value of m for bharal is the same as that for domestic sheep and goat, the values of F_b can now be calculated for both the rangelands using (1); 0.89 for the moderately grazed rangeland and 0.95 for the intensively grazed one. However, this is assuming the absence of livestock (*sic.*). When livestock are present, bharal fecundity gets reduced, and can now be modeled by the equation:

$\bar{F}_b = F_{max} - mS_b - f(S_{li})$..............(2)

where

$\bar{F}_b$	=	annual fecundity per adult female bharal in the presence of livestock
S_{li}	=	livestock biomass density
$f(S_{li})$	=	function describing the reduction in bharal fecundity effected by the presence of livestock alone.

The values of $\bar{F}_b$ represent the observed bharal performance in the two rangelands (Table 6.5). Clearly, subtracting (2) from (1), the value ($F_b - \bar{F}_b$) equals $f(S_{li})$, the reduction in bharal fecundity caused by the presence of livestock; it was 0.07 in the moderately grazed rangeland and 0.41 in the intensively grazed rangeland. Thus, the presence of livestock alone is responsible for an estimated 33 % reduction in bharal fecundity in the intensively grazed rangeland compared to 8 % in the moderately grazed one. This is apparently due to the difference in the degree of competition.

Having focussed on fecundity, it is important to consider that amongst the younger age classes, '...the difference between the number of young and yearlings (in bharal) provides a rough estimate of mortality' (Schaller 1998, p. 105). Considering this, there seems to be slightly greater mortality in the younger age classes of bharal in the intensively grazed rangeland (year 2000 survey). Thus, the variation in performance in bharal seems to be brought about by resource-dependent variation in both fecundity as well as neonate mortality.

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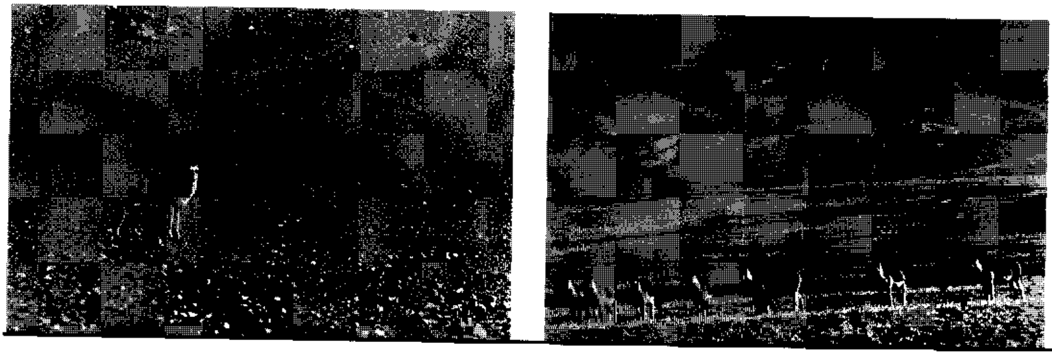

Several wild large herbivores such as the Tibetan gazelle *Procapra picticaudata* (left) and kiang *Equus kiang* (right) are 'missing' from Spiti Valley. We explore if this low species diversity of wild herbivores could be a consequence of competitive exclusion by livestock.

Abstract

Understanding livestock grazing impacts on native wildlife is difficult when grazing is pervasive and has a long history. Spiti Valley in the Indian Trans-Himalaya is characterized by overstocking of rangelands and a grazing history of over 3 millennia. An intriguing aspect of the wild large herbivore assemblage in Spiti is its low diversity. In the present theoretical exploration, we analyze the wild and domestic herbivore assemblages of the Trans-Himalaya against the backdrop of competition theory, and ask if this low diversity of wild herbivores in Spiti could be a consequence of the high diversity of introduced livestock. The analysis suggests that competitive interactions might have played an important role in structuring the Trans-Himalayan wild herbivore assemblage. This is reflected in a proportional regularity in species body masses, with each species being a constant proportion larger than the nearest smaller one. Such a proportional regularity is absent in the livestock assemblage. The theoretical analysis makes a case for the competitive exclusion of at least four wild grazers in Spiti over the last three millennia. The present grazer assemblage conforms reasonably to the theoretical predictions – these four species are among the six wild herbivores presently missing from Spiti. The implications of the present analysis for conservation management in the Trans-Himalaya are discussed.

Introduction

We owe the title of this chapter to a paper published a decade ago that asked how harmonious the co-existence between pastoralism and wildlife was in East Africa, and if there was resource competition between livestock and wild herbivores (Prins 1992). Using data on livestock, human, and wild herbivore densities, Prins had outlined a scheme whereby wild herbivores could be driven to extinction due to increasing human and livestock populations, coupled with land use change. This was called *the pastoral road to extinction*.

Long histories of livestock grazing can make the evaluation of grazing impacts on native wildlife and landscape difficult, since the impacts are often pervasive and therefore go unnoticed (Fleischner 1994). The Spiti Valley in the Indian Trans-Himalaya has a long history of livestock grazing, the present day agro-pastoral community believed to have inhabited the area over three millennia ago (Handa 1994). The entire catchment is grazed by livestock, and presently most of the rangelands are overstocked (Mishra *et al.* in press). An intriguing aspect of the large wild herbivore assemblage in Spiti is its low diversity when compared to the neighboring Trans-Himalayan areas of Tibet and Ladakh (Schaller 1998, pers. observ.). This low diversity in Spiti has been observed in the past (e.g. Bhatnagar 1997, p. 24) but the possible causes of rarity have not been explored. Why are there so few species of wild large herbivores in Spiti? In this paper, we revisit *the pastoral road to extinction*, and taking recourse to recent theoretical advances in herbivore community ecology, ask if this low diversity of wild herbivores could be a consequence of the high diversity of introduced livestock.

Study area

The Spiti Valley (31°35' to 33°0' N and 77°37' to 78°35' E; altitudinal range 3350 to 6700 m) spans an area of over 12200 sq. km, and is flanked by Greater Himalaya in the south, Ladakh in the north and Tibet in the east. The climate in Spiti is arid, with most of the precipitation in the form of snow. Its vegetation has been described as dry alpine steppe (Champion and Seth 1968). The region is inhabited by a sedentary agro-pastoral Buddhist community. Low primary productivity, high stocking rates, and a diversity of livestock species characterize the region's livestock production system (Mishra 1997). Livestock reared includes yak, cattle, *dzo* and *dzomo* (male and female hybrids respectively of yak and cattle), horse, donkey, sheep and goat. Only three species of wild herbivores, namely the ibex *Capra ibex*, bharal *Pseudois nayaur*, and the Tibetan woolly hare *Lepus oiostolus*, presently occur in Spiti, while the neighbouring parts of the Trans-Himalaya have six more species in addition to these (Table 7.1).

Methods

Sources and data

We collected information on body masses of wild herbivores from literature. We then averaged the reported adult body masses for each sex and again between the sexes to obtain species body mass. For livestock up to 100 kg, several live adults were weighed. In addition, we weighed six adult yaks, three *dzomo*, and one *dzo* after they were killed by the local villagers for meat. For four of these individuals, two to three observers independently estimated the body masses prior to slaughtering. The mean of these estimates ranged between 0 to 7.3 % of the actual body mass. The same observers estimated the body masses of adult cows and horses that were not slaughtered.

Theoretical framework and statistical analyses

We began the analysis by assuming that the six species of wild herbivores that are present in the neighbouring regions, but absent in Spiti, were actually present in Spiti and have gone extinct from the region in historical times. We gathered evidence for the past occurrence of these species in Spiti Valley from literature, as well as by asking local people and gathering anecdotal information during fieldwork between 1996-2000. For simplicity, in the present analysis we ignored the herbivorous bird Tibetan snowcock *Tetraogallus tibetanus* that occurs in Spiti as well as in its neighbouring Trans-Himalayan region. (In any case, for the following analysis, only species of a single guild are important, namely, those that feed substantially on graminoids. The Tibetan snowcock is known to have a catholic diet, feeding on roots, tubers, grass, and leaves and fruits of shrubs; Ali and Ripley 1987). We also ignored the Ladakh urial *Ovis orientalis* that has a very restricted distribution in Ladakh and is missing from these neighbouring parts of Spiti (Mallon 1983). Thus, our starting assumption was that six species of wild herbivores have gone extinct in Spiti in historical time, while they have persisted in the neighbouring regions of Tibet and Ladakh. The assemblage of nine species that occurs in the neighbouring areas was considered as an 'intact' assemblage representative of this part of the Trans-Himalaya.

The role of competition in structuring wild large herbivore assemblages

As a first step, we evaluated whether or not competition has played a role in structuring the 'intact' Trans-Himalayan wild herbivore assemblage. Almost a century ago, experiments by A. G. Tansley (1917) had recorded that the presence or absence of a species in a given area could be determined by interspecific competition. Subsequently, Gause (1934) demonstrated that the joint placement of pairs of similar species that compete for the same resource could cause extinctions as a result of resource competition. Competition has since been considered a major force in structuring species composition in ecological communities. In a recent paper, Prins and Olff (1998) explored patterns in species richness of grazer assemblages in Africa as a function of resource competition and facilitation. Their theoretical analysis predicted an 'optimum' difference in body mass between co-existing members of any natural grazer assemblage, a pattern expected to be effected by the long-term balance between competition and facilitation. Empirical data corroborated this prediction; species in African grazer assemblages indeed show a constant weight ratio, with each grazer species on average being a constant proportion larger than the nearest smaller one. Such morphological relationships (a constant weight ratio) between the members of a guild are believed to be brought about by character displacement (a co-evolutionary response) and species sorting (an ecological response), both being consequences of competition (Dayan and Simberloff 1998).

If the species in an assemblage are ranked in the order of increasing body mass, with the smallest species having a rank of zero, and if the assemblage represents a random selection from a uniform distribution of body masses, the natural log-transformed (ln) body mass is a non-linear function of species rank (see Appendix 7.1). Therefore, in case an assemblage is characterized by a strong linear relationship, it is evident that the species are not a random selection from a uniform distribution. Instead, each member is a constant proportion bigger than the nearest smaller species, and this weight ratio can be calculated as e^{slope} (May 1973, Prins and Olff 1998).

We performed a least squares regression to assess the linearity of the relationship between ln transformed body masses of species in the 'intact' Trans-Himalayan wild herbivore assemblage and their species ranks. The hypothesis tested was whether these body masses were simply a random selection from a uniform distribution, or whether they did show certain regularity as predicted by competition theory. Further, since an *a priori* relationship is to be expected between body masses and species ranks, we compared the coefficient of determination (r^2) of this regression with those of random assemblages. In this null model approach, we first drew at random nine body masses (integers) from the range defined by the 'intact' Trans-Himalayan assemblage, ranked them and performed a regression between ln transformed body masses and species ranks. We repeated this exercise up to 100 times and compared the r^2 values of these random assemblages with that of the 'intact' assemblage.

Species introductions into an 'intact' assemblage: can livestock drive wild herbivores to extinction?

We consider a wild multi-species herbivore assemblage in a large area, with its competition-facilitation interactions, and in equilibrium with the vegetation. We also assume that this 'intact' assemblage, at equilibrium, represents the 'optimum' weight ratio and species packing for that ecosystem. Herbivore introductions in such an ecosystem will reduce the weight ratio. If the population of the introduced species builds up to the extent that it can have a significant influence on graminoid biomass, new competition-facilitation interactions begin to develop. Left to itself, the system is likely to experience changes in relative abundance of species, which, in some cases, may cause species extinctions.

What happens if the reproductive performance of the introduced species were enhanced through mediation of the negative competitive or climatic effects it would have otherwise faced, such that it is maintained at an 'inflated' density? In the Guindy National Park of Southern India, chital *Axis axis* was introduced about 50 years back.

Table 7.1 Large wild herbivores presently occurring in parts of Trans-Himalaya bordering Spiti, their body mass, evidence of their historical and contemporary presence in Spiti, their respective habitats that occur in Spiti, and the reported graminoid contribution in their diets.

Species	Body mass (kg)	Habitats used that are present in Spiti	Historical/ contemporary presence in Spiti	Reported graminoid contribution to diet
Tibetan woolly hare *Lepus oiostolus*		Alpine steppe, mountain slopes, river valleys and alluvial fans (*pers. observ.*)	Present	36.1 % (Schaller 1998)
Himalayan marmot *Marmota himalayana*	6	Alpine steppe, mountain slopes, river valleys and alluvial fans (*pers. observ.*)	Last record ca. 7 years back (Chhering Gara, Kibber, *pers. comm.*.)	Unknown, reported to feed on roots, leaves grasses and seeds (Prater 1971)
Tibetan gazelle *Procapra picticaudata*	14	Alpine steppe, hills and mountains (Schaller 1998)	Unknown	3.1 to 16.4 % (Schaller 1998)
Chiru *Pantholops hodgsoni*	32	Alpine steppe and similar semi-arid areas. High rounded hills (Schaller 1998)	Unknown	32.2 to 71 % (Schaller 1998)
Bharal *Pseudois nayaur*	55	Alpine steppe, rolling slopes bordering steep cliffs (*pers. observ.*)	Present	Feeds predominantly on graminoids (Mishra *unpublished data*)
Ibex *Capra ibex*	76	Alpine steppe, steep mountain slopes (Bhatnagar 1997)	Present	Feeds predominantly on graminoids, only occasionally on shrubs (Heptener *et al.* 1966, Schaller 1977)
Tibetan argali *Ovis ammon hodgsoni*	87	Alpine steppe, high rolling hills and plateaux, gentle mountain slopes (Schaller 1998)	Last (photographic) record in 1991 (Lama Kalu, Kibber, *pers. comm*)	23.6 to 87.9 % (Schaller 1998)
Kiang *Equus kiang*	275	Alpine steppe, broad valleys and hills (Schaller 1998)	Unknown	84.3 to 100 % (Schaller 1998)
Wild yak *Bos grunniens*	413	Alpine steppe, high mountains (Prater 1971, Schaller 1998)	Reported at least until 1940s (Prater 1971)	44.1 to 96.3 % (Schaller 1998)

Supplementary feeding by the park management, which benefited only chital, inter alia, caused a drastic decline of the native blackbuck *Antilope cervicapra* population as a result of competitive effects of the former (Raman *et al.* 1995). Supplementary-fed livestock introduced into an area that already has a wild grazer assemblage can effect a similar situation. If the livestock population is overstocked, one can expect reductions in the population, and eventual extinction of some or many of the original inhabitant species. Thus, introduced species such as supplementary-fed livestock, at high density, can effect the extinction of wild herbivores. One can therefore expect a decrease in weight ratio when livestock is introduced, followed by a reversed trend with the weight ratio increasing at the expense of wild herbivores. At exceptionally high density, supplementary fed livestock could drive all wild grazers to extinction. Theoretically, however, there should be a temporal sequence to these extinctions, with species of wild grazers most similar in body mass to livestock most likely to go extinct first (Prins and Olff 1998).

Against this theoretical framework, we explored the relationship between the livestock assemblage in Spiti and the rarity of wild grazers in its rangelands. We calculated pair-wise weight ratios of body masses between each of the seven livestock and nine wild herbivore species by dividing the heavier species in each pair with the lighter one, and examined the smallest weight ratios.

Results

The body masses of wild herbivores and livestock are summarized in Tables 7.1 and 7.2, respectively. Table 7.1 also gives some indication of availability of potential habitat in Spiti for the wild herbivore assemblage. We could get evidence that at least 3 of the six missing large herbivores were once present in Spiti Valley. Thus, our assumption of the past presence of all the species in Spiti is not entirely unfounded. We have also summarized from literature, the percent graminoid contribution in the diet of all these wild herbivores (Table 7.1).

Has competition structured the Trans-Himalayan wild large herbivore assemblage?

If competitive interactions have indeed structured the 'intact' wild large herbivore assemblage, the species body masses in this assemblage should exhibit conformity, characterised by a certain weight ratio. Fig. 7.1*a* depicts the relationship between ln transformed body mass and species ranks of the 'intact' Trans-Himalayan wild grazer assemblage (see Table 7.1). The high coefficient of determination (r^2 = 0.9768) suggests conformity in body masses, yielding a weight ratio of 1.812, i.e., in this assemblage, each species, on the average, is ca. 81 % heavier than the next smaller one.

Ten random draws of nine body masses from the range defined by the 'intact' Trans-Himalayan grazer assemblage (3 to 413 kg; Table 7.1) yielded a mean coefficient of determination of 0.779 (± 0.138 SD), suggesting that the high r^2 of the 'intact' assemblage is indeed an expression of a real proportional regularity. Furthermore, out of 100 random draws, none yielded an r^2 value that was greater than or equal to the observed value, thereby suggesting that the probability of getting such an assemblage of body masses as exists in the 'intact' assemblage by chance alone is very remote ($p < 0.00$; range 0.246 to 0.966). Thus, the analysis suggests that competitive interactions have played an important role in structuring the Trans-Himalayan wild grazer assemblage. Furthermore, for the observed maximum difference of 4.925, the weight ratio of 81 % represents 'optimal' species packing for the wild grazer assemblage of the Trans-Himalaya.

Could the introduction of livestock have driven several wild herbivores to extinction?

As mentioned earlier, the livestock production system in Spiti includes as many as seven species (including a hybrid) maintained at fairly high densities. In fact, the livestock density in an intensively monitored region of Spiti (Kibber pastures) is presently 10 times the density of bharal, the most common wild ungulate in the region (Mishra 1997). We now examine whether the introduction of this diverse livestock assemblage, presumably in the first millennium BC (Handa 1994), could have caused the competitive exclusion of six species of wild herbivores in Spiti. It is clear that for this to be true, the extinct grazers should be the ones most similar in body mass to livestock.

When as many as seven species of livestock, as are present in Spiti, are introduced

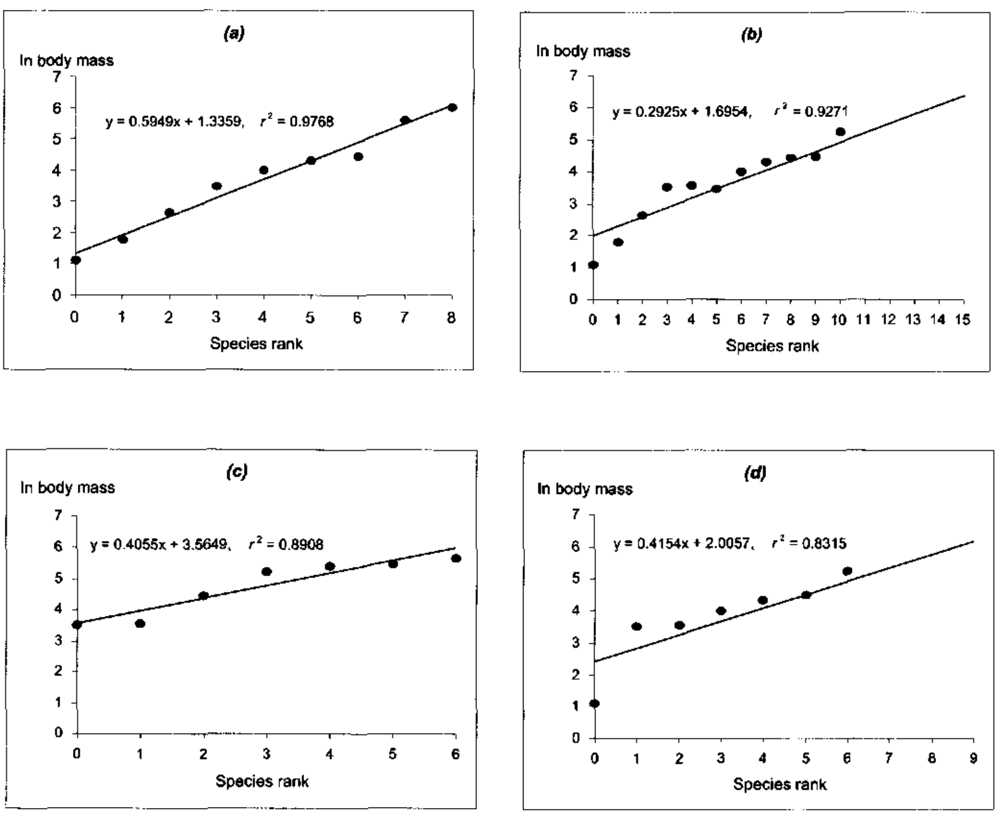

Fig. 7.1 Relationships between natural log-transformed body mass and species rank in the large herbivore assemblage of the Trans-Himalaya.

a. The 'intact' wild grazer assemblage in parts of the Trans-Himalaya bordering Spiti

b. The hypothesized grazer assemblage when as many as seven livestock species are introduced into the 'intact' assemblage

c. The present livestock assemblage in Spiti

d. The present grazer assemblage in Spiti including three wild and seven domestic grazers.

into the 'intact' assemblage, the weight ratio declines to 1.339 (Fig. 7.1*b*). All these seven species feed substantially on graminoids (> 50 % contribution in the diet), though some are intermediate feeders (see Chapter 6). Since this new assemblage is human-modified, and is not structured entirely by long-term competitive interactions, one expects a decline in the proportional regularity of body masses. This is reflected in a decline in the coefficient of determination ($r^2 = 0.9271$). This r^2 value is not significantly different from an assemblage where body masses are a random selection from a uniform distribution ($p = 0.15$). In fact, the r^2 decreases to 0.8908 if only livestock are considered, suggesting that although representing a wide range of body masses, there is no proportional regularity in this introduced assemblage (Fig. 7.1*c*). The weight ratio of the present grazer assemblage in Spiti, including the three extant

Table 7.2 Mean adult body mass (in kg) of the livestock assemblage in Spiti (± SD and sample size in parentheses).

Species	Male	Female	Species
Goat	35 (± 2.5, 4)	33 (± 4.1, 4)	34
Sheep	35 (± 2.7, 5)	34 (± 5.4, 6)	35
Donkey	83 (± 15.5, 5)	97 (± 2.1, 2)	90
Cow	*	191 (± 9.6, 5)**	191
Dzo/ Dzomo	239 (n = 1)	214 (± 2.0, 3)	227
Horse	*	248 (± 10.5, 3)	248
Domestic yak	368 (± 44.9, 4)	228 (± 21.9, 2)	298

* Adult cow and horse populations are largely devoid of males. Usually only a single adult male cow is kept in a village, while male horses are sold off as soon as they attain maturity.

** An adult cow that was subsequently slaughtered weighed 193 kg, indicating the reliability of estimated weights in the case of cows and horses.

Table 7.3 Pair-wise weight ratios for most similar pairs (smallest ratios) of wild and domestic grazers in the Trans-Himalaya.

	Species pairs	Weight ratio
1	Tibetan argali - Donkey	1.03
2	Chiru - Goat	1.06
3	Kiang - Domestic yak	1.08
4	Chiru - Sheep	1.09
5	Kiang - Horse	1.11
6	Ibex - Donkey	1.18
7	Yak - Domestic yak	1.39
8	Kiang - Cow	1.44
9	Bharal - Sheep	1.57
10	Bharal - Goat	1.62
11	Bharal - Donkey	1.64
12	Yak - Horse	1.67
13	Yak - *Dzomo*	1.82
14	Yak - Cow	2.16

wild species and livestock, is 1.514 though the low coefficient of determination negates any proportional regularity ($r^2 = 0.8315$, $p = 0.44$; Fig. 7.1*d*).

So far, we have seen that the 'intact' Trans-Himalayan wild grazer assemblage is likely to have been structured by long-term competitive interactions, and that the present assemblage in Spiti is far from being 'intact'. However, until now it is only assumed that livestock has effected the competitive exclusion of wild grazers in Spiti. Keeping in mind the high livestock density and the relatively low primary productivity of the region, the evidence now required to support this assumption would be that the presumably extinct species were the ones most similar in body mass to the introduced livestock.

Pair-wise weight ratios between each of the seven livestock and nine wild herbivore species yielded 63 values, of which the first 14 (smallest weight ratios) are presented in Table 7.3. Since the livestock assemblage includes seven species, we examined the first seven weight ratios. As is evident from Table 7.3, these include five wild herbivores, of which four are actually missing in Spiti, i.e., species we earlier assumed had gone extinct. Furthermore, for all the nine wild herbivores, we listed the nearest respective species in body mass (including both wild herbivores and livestock), and asked if these presumably extinct wild ungulates preferentially had livestock as the most similar species. As seen in Table 7.4, all these four species indeed have livestock as the most similar species. Thus, the analysis suggests that wild yak, kiang, Tibetan argali, and chiru may have presumably been driven to extinction in Spiti due to competitive exclusion by livestock.

Discussion

The absence of two species in Spiti, the Tibetan gazelle and the Himalayan marmot remains unexplained by competition theory. At least in the case of the former, little information available seems to suggest that the animal is a browser (Table 7.1), and therefore, it is unlikely to have been competitively excluded by grazer species. Reanalysis of the data after removing the Tibetan gazelle did not affect the conclusions derived earlier qualitatively, only the weight ratio of the 'intact' Trans-Himalayan assemblage increased to 1.969 ($r^2 = 0.9438$), i.e. instead of 81 %, each species becomes *ca.* 97 % heavier than the next smaller one.

One of the wild species that figured in the first seven weight ratios in Table 7.3, the ibex, persists in Spiti, though much restricted in distribution as well as density when compared to bharal (Bhatnagar 1997, pers. observ.). In fact, if we expand this list up to a weight ratio of approximately 2.0 (the average weight ratio in the 'intact' assemblage), even bharal gets included in the list of wild species most similar to the introduced livestock (Table 7.3). It is perhaps not surprising that we have found evidence for competition between livestock and bharal – bharal have reduced density in areas of high livestock density (see Chapter 6).

In the light of the present analysis, it becomes important to briefly consider Bhatnagar's (1997, p. 111) statement that '...there is likely to be no adverse impact of resident livestock on ibex'. He qualifies that 'This statement has to be taken with caution as the primary reason for this is the more or less stable resident livestock population in Pin Valley (his study area in Spiti) and the manner in which people restrict usage by their livestock to near their settlements.... With extra fodder being made available, there is a likelihood that the livestock holding may grow and cause adverse impact on ibex usage.'

Table 7.4 Pair-wise weight ratios of each of the Trans-Himalayan wild herbivore and its closest (in body mass) livestock and wild species.

	Livestock	**Wild herbivore**
Hare	11.33 (goat)	2.00 (marmot)
Marmot	5.66 (goat)	2.00 (hare)
Tibetan gazelle	2.42 (goat)	2.28 (gazelle)
Chiru	1.06 (goat)	1.70 (bharal)
Bharal	1.57 (sheep)	1.38 (ibex)
Ibex	1.18 (donkey)	1.14 (Tibetan argali)
Tibetan argali	1.03 (donkey)	1.14 (ibex)
Kiang	1.08 (domestic yak)	1.50 (wild yak)
Wild yak	1.38 (domestic yak)	1.50 (kiang)

Bhatnagar's findings on habitat segregation between livestock and ibex should be seen against the light of the fact that his observations are restricted to *c.* 30 km^2 area within Pin Valley National Park, where livestock are present at much lower densities (Y. V. Bhatnagar, *pers. comm.*). Further, the migratory livestock in Spiti, which comprises of goat, sheep and horses, is restricted to a few areas in summer. The competitive exclusion of wild herbivores analysed in this paper has most likely been effected by resident livestock, which is not only more diverse, but also geographically and temporally much more widespread. Migratory livestock then locally accentuate grazing pressures that are already quite high in Spiti (Mishra *et al.* in press). The issue of competition between livestock and ibex in Spiti needs be studied.

One important question remains unanswered and is beyond the scope of the present exercise; what has allowed these species to persist in the neighbouring Trans-Himalayan areas? Lower livestock stocking rates, differences in the livestock production system, and larger area with source populations for recolonization could be among the causes, and a detailed comparative study between Spiti and other regions of the Indian Trans-Himalaya could provide the answer. Another general conclusion can be drawn about the wild herbivore assemblage in this part of the Trans-Himalaya. In general, the species richness is low. The wild grazer assemblage of the Serengeti Ecosystem in Africa, which is about twice the size of Spiti (i.e. the size of Spiti together with neighbouring parts of the Changtang), shows an average increment in body mass of *ca.* 12 % (Prins and Olff 1998). Keeping in mind the low primary productivity in Spiti, this conforms to the theoretical prediction that grazer species-richness is low in areas of extremely high or low productivity (*ibid.*).

Caveats and conclusions

The present analysis has several important limitations. Given that no historical distribution information was available, and that we found evidence for the past occurrence of only three of the six missing species in Spiti, our starting assumption that all six species were once present in Spiti remains only partly substantiated.

Further, owing again to the lack of historical information, we have focused only on body mass and completely ignored the past densities of livestock that have presumably driven these competitive exclusions. While we now have evidence that the rangelands in Spiti are overstocked, and that bharal compete with the livestock for forage, the underlying assumption throughout this analysis has been that the livestock densities in the past also were high enough to limit availability of forage for wild herbivores. Our inability to substantiate this assumption remains an important drawback of this analysis. Finally, we have ignored the possible role played by differences in species habitat selection patterns in mediating competitive interactions. These differences might play an important role in structuring the wild herbivore assemblage. However, given the ubiquitous presence of livestock across habitats in Spiti, they are less likely to cause variation in the competitive effects of livestock on wild herbivore species.

Despite these limitations, the analysis, we believe, has important implications. The Trans-Himalaya have traditionally been viewed as a low productive ecosystem, where 'Wild animals occur in low densities and need larger areas to maintain their viable populations...' (Chundawat and Rawat 1994, p.3; also see Rawat *et al.* 1990, Johnsingh *et al.* 1999). There is little doubt that the primary production in the region is relatively poor, and that wild herbivores are likely to occur at lower density and diversity compared to many other ecosystems. However, a worrying fallout of this traditional view has been that even the possibility that other important factors (such as high livestock density) could be limiting large herbivore diversity and density in many parts of the Trans-Himalaya has not been considered. These instead have inadvertently been accepted as being consequences of the naturally low primary production. Further, the fact that most of the area is grazed by livestock at high density (and has historically also been subject to other extractive uses such as fuel and fodder collection) has meant that 'ecological benchmarks' showing how the vegetation and associated wildlife would appear in the absence of livestock grazing are completely missing. This could be another reason why the need for considering factors other than low primary production in explaining herbivore diversity has not been felt. Notwithstanding the caveats, the present analysis suggests that livestock grazing might have actually driven several wild herbivores to extinction locally in parts of the Trans-Himalaya. We therefore propose that if these several endangered (many of them globally) wild herbivores are to be conserved in the Trans-Himalaya, this traditional view needs to be re-examined if not discarded. Managing livestock densities and creating grazing-free areas (which at the moment are lacking even inside wildlife reserves) should become the top priority for wildlife management. Research needs to urgently focus on exploring the causes of variation in wild herbivore diversity and density in different parts of the Trans-Himalaya.

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Appendix 7.1

In an assemblage where body masses follow a uniform distribution, i.e., every body mass within a given range has an equal probability of being present, the expected difference in body mass between any two adjacent species can be described as (Prins and Olff 1998):

$$W_{i+1} - W_i = (W_{max} - W_{min}) / (n - 1) \quad \text{.........................(1)}$$

where

W_{max} = Maximum body mass in the assemblage

W_{min} = Minimum body mass in the assemblage

n = species richness

The expected body mass of the *i*-th species in such an assemblage can be described as:

$$W_i = [W_{min} + R_i - 1] * [(W_{max} - W_{min}) / (n - 1)] \quad \text{.............(2)}$$

where

R_i = species rank

or, following ln-transformation,

$$\ln(W_i) = \ln\{[W_{min} + R_i - 1] * [(W_{max} - W_{min}) / (n - 1)]\} \quad \text{......(3)}$$

From equation (3), it is evident that in an assemblage where body masses follow a uniform distribution, the natural ln-transformed body mass is a non-linear function of species rank.

In assemblages where each species on average is a constant proportion larger than the next smaller one (i.e., assemblages that show a constant weight ratio), the expected body mass of the *i*-th species can be described as (May 1973, Prins and Olff 1998):

$$\ln(W_i) = a R_i + b \quad \text{...(4)}$$

where

e^a = weight ratio

e^b = interpolated lowest body mass in the assemblage

In assemblages that follow a constant weight ratio (equation 4), the ln-transformed body mass is a linear function of species rank.

Chapter 8

Pastoralism and wildlife conservation: a synthesis

Introduction

'But the great age of mammals in the Himalaya need not to be over unless we permit it to be. For epochs to come the peaks will still pierce the lonely vistas, but when the last snow leopard has stalked among the crags and the last markhor has stood on a promontory, his ruff waving in the breeze, a spark of life will have gone, turning the mountains into stones of silence.'

George Schaller (1979)

This thesis is a collection of studies conducted in the high altitudes of the Trans-Himalaya that have attempted to address the question of *how harmonious the co-existence between pastoralism and wildlife is?* Conservation managers and conservation policies in many parts of the world continue to remain ill informed on how local pastoral communities use rangeland resources, and the impacts of such resource use on wildlife. Raging debates on whether pastoral use of lands inside wildlife reserves should be allowed, encouraged, modified, or curtailed continue to generate more heat than light, fuelled by activism rather than by ecology (see Noss 1994, Mishra and Rawat 1998). We therefore decided to study a traditional pastoral system and its impacts on wildlife, with the ultimate aim of guiding conservation management and policy. Focussing on an agro-pastoral system that has probably existed for over three millennia in the Trans-Himalaya, we tried to understand the production system and its relationships with wildlife. We specifically focussed on understanding the impacts of livestock grazing on the wild herbivore assemblage of the Trans-Himalaya. The bulk of this thesis tried to evaluate whether livestock and wild herbivores compete for resources. In this chapter, I condense the important findings of the work, and establish the coherence among chapters. I then explore how the ideas of harmonious co-existence between pastoralism and wildlife have generally come to prevail, and discuss the lessons learnt from the present thesis in a broader scientific and conservation context. In this light, I outline the possible road ahead to wildlife conservation in an ecosystem with pervasive human use, in the hope that *the great age of mammals in the Himalaya need not be over*. I finally discuss the limitations of the present thesis, which might perhaps be the best starting point for future work.

The findings

In the first section of the thesis (Chapters 2 and 3) we tried to understand the agro-pastoral system in Spiti Valley of the Indian Trans-Himalaya where this study was conducted. Observing and interviewing villagers, we soon realized that this 'traditional system' was no static entity; it was temporally and spatially very diverse and dynamic. The diversity of practices employed for agriculture as well as livestock grazing seemed to change between villages and over time, making it difficult to describe the production system. However, following recent anthropological literature (MacDonald 1998, Bishop 1998), we realized that the diversity could be meaningfully interpreted in the context of its role in mediating environmental risk. This was done in Chapter 2, the main aim of the chapter being to provide insights into the society and its agricultural and livestock grazing practices. Perhaps the single most important message from the chapter is that from the viewpoint of the individual family (which is the basic unit of production), the agro-pastoral system in Spiti Valley represents a repertoire of locally appropriate practices that attempt to maximise agro-pastoral production while mediating environmental risk. This is especially relevant because we subsequently see that at the rangeland level, the agro-pastoral system does not achieve the objective of maximizing livestock production (Chapter 5).

Continuing the focus on the agro-pastoral society, Chapter 3 established that the co-existence between pastoralism and wildlife is far from harmonious. The villagers lose a significant proportion of their livestock annually to snow leopard *Uncia uncia* and wolf *Canis lupus*. This translates to high financial losses, and in retaliation, the carnivores, especially the wolves, have been regularly eliminated. Recent escalation of this conflict seems related to an increase in livestock numbers between the late 1980s and early 1990s.

Having set a social context for the thesis (Chapters 2 and 3), I moved on to the issue of resource competition between livestock and wild herbivores. The first step was to describe the resource in question, the rangeland vegetation. In chapter 4, we described the rangeland vegetation in terms of the different types and their extent, species composition and forage biomass. We also presented preliminary observations on changes in rangeland vegetation due to livestock grazing and water harvest for agriculture. Agriculture, livestock and wild herbivores seem to indirectly compete for water; water harvest has probably caused the loss of important grazing patches for livestock and wild herbivores. Comparisons with other ecosystems such as the polar desert and tundra, temperate grasslands, and tropical savannas showed that the Trans-Himalaya fall at the low end in terms of graminoid biomass.

In Chapter 5, I explored the issue of resource limitation. Using empirical data on livestock production together with animal production models, we estimated an optimal stocking density for these rangelands (the point of resource limitation for large herbivores) and analysed the stocking densities in rangelands belonging to 40 of the approximately 60 villages in the Valley. The results strongly suggested resource limitation, with four-fifths of the rangelands in Spiti currently being overstocked. Thus, while the livestock grazing practices in Spiti may be appropriate from the viewpoint of the individual family as seen in Chapter 2, at the level of the rangeland, total herd production is significantly compromised.

Considering that a majority of the rangelands were overstocked beyond points of resource limitation (Chapter 5), the possibility of competition between livestock and wild herbivores became apparent. In Chapter 6, we asked if bharal *Pseudois nayaur*, the most abundant of the three wild herbivores presently occurring in Spiti, and livestock compete for resources? We first studied the diets of bharal and all the seven species of livestock to estimate the extent of resource overlap, which we found to be considerable. All eight species predominantly fed on graminoids in both summer and winter. We also found that livestock at current densities are able to significantly reduce the standing biomass of graminoids (resource availability) in the rangelands. We then analysed the population structures of these species and tested several predictions related to competition. The results showed that bharal density was a negative function of livestock density, strongly suggesting resource competition. This resource-dependent variation in bharal density seems to be brought about by variation in fecundity and neonate mortality.

Thus, chapters 5 and 6 established that there is resource limitation for large herbivores in Spiti valley, and that bharal are out-competed by livestock (Chapter 6). In Chapter 7, we theoretically explored whether the low species richness of wild herbivores in Spiti Valley could actually be a case of herbivore impoverishment due to competition with livestock? We first analysed in terms of species body masses, the complete large herbivore assemblage (nine species) characteristic of this part of the Trans-Himalaya. The analysis revealed – in line with theoretical predictions – that this assemblage seems to have been structured by long-term competitive-facilitative interactions. This was reflected in a constant weight ratio, i.e., every species in this assemblage seems to be a constant proportion larger than the next smaller one. Assuming that the entire complement of species was once present in Spiti, the analysis made a case for competitive exclusion of at least four wild herbivores in the valley over the last three millennia. The present herbivore assemblage conforms to the theoretical predictions, thus suggesting that Spiti might have seen the competitive exclusion of several wild herbivores by livestock in historical times.

The co-existence between pastoralism and wildlife then does not seem very harmonious in Spiti.

On harmonious coexistence between pastoralism and wildlife

'The impression has thus arisen that there can be harmony between wildlife and pastoral exploitation...' (Prins 1992) was the opening sentence of this thesis. Several subsequent chapters established that the coexistence between *wildlife and pastoral exploitation* in the Trans-Himalayan Spiti Valley is far from harmonious. While there is no denying that there might be areas in the world where the objectives of pastoral production and wildlife conservation are achieved simultaneously on the same piece of land, harmonious coexistence seems to be more often assumed than it is demonstrated. The *impression* of harmonious coexistence seems to arise time and again, especially when traditional pastoral systems are in question. Why does this idea come about, and why is it so appealing?

The presence of pastoral people and large wildlife together has often been considered as proof of compatibility between pastoral production and wildlife conservation, even in recent and otherwise well-informed texts. For example, in an authoritative anthropological work on the pastoralists of Trans-Himalayan Tibet, Goldstein and Beall (1989, p. 179) write, '...Additional data also suggest that the balance of livestock, people, and pasture in Pala is not degrading or overgrazing the pastureland. First, there are an abundance and diversity of wild ungulates such as antelope, wild asses, gazelles, and blue sheep. We always encountered herds of the first three when travelling between camps...'. Saberwal's (1996, p. 747) compelling political ecology treatise on pastoralists of western Himalaya goes even a step further, '...I saw no native ungulates and only two Himalayan brown bears, including one shot by a herder...Unfortunately, the absence of sightings has often been taken as an indication of a small or nonexistent population. My talks with hunters suggest the possible presence of a healthy large mammal community, despite the presence of approximately 50,000 to 75,000 goats and sheep in the region.' The presence of livestock and large wildlife together has often been confused with successful multiple-use of rangelands, giving an impression of harmonious coexistence.

Romanticized notions of people and wildlife living in harmony have perhaps also been promoted by the fact that many traditional pastoral communities indeed employ range conservation measures, or at least measures that reduce the risk of pasture degradation (e.g. MacDonald 1998). Again, there perhaps are areas where this has allowed wildlife conservation to proceed alongside pastoral production in rangelands. However, in all cases, a distinction needs to be made between the objectives and the output. Are such conservation objectives and practices always able to prevent pasture degradation and/ or allow conservation of rangeland wildlife? As seen in Chapter 2, many of the practices employed in the agro-pastoral system of Spiti reflect range conservation objectives. This, together with strong Buddhist values of non-violence and tolerance towards all forms of life is bound to invoke thoughts of harmonious coexistence between pastoralism and wildlife. Yet, as seen in all subsequent chapters, these practices and values have not necessarily been able to prevent pasture degradation, or for that matter allow large mammal conservation. That they certainly must have contributed to delay the degradation process, as well as allow at least some wildlife to persist till the present day is a tribute to the Spitian people, but a different issue altogether.

Our ignorance of local pastoral systems and their resource use has probably played a role too. For instance, the analysis presented in Chapter 3, to my knowledge, was the first attempt in the Indian Trans-Himalaya to quantify one of the most serious conservation issues in this region, livestock depredation by large carnivores and their retaliatory killing by herders. To spread the notion of harmonious coexistence when families are suffering substantial losses due to large carnivores would be a rather serious disservice to the Spitians. Similarly, to say that the local pastoral system is compatible with wildlife conservation because the snow leopards, the wolves, and the bharal are still present in the rangelands would be, I think, somewhat misplaced in the light of the present study.

Finally, the fact that the alternative option is less romantic and more difficult to accept has probably played a role in making this belief so appealing and widespread. To recognize that both local people and wildlife might be suffering at each other's hands, and that the problems need to be addressed, poses numerous moral, social, political and economic challenges. With limited knowledge of traditional land use systems and their impacts on wildlife (and vice versa), a belief in harmonious coexistence has perhaps been the easier option to live with.

On resource management and conflicts with wildlife

Are Spitians not managing their rangeland resources optimally? Why is there such a serious conflict between pastoral production and wildlife conservation? Based on the findings of this study, I try to address these issues briefly in the present section.

There are several factors responsible for the conflict between pastoral production and wildlife conservation in Spiti. To start with, it needs to be kept in mind that the primary production in the Trans-Himalaya is relatively low compared to many other ecosystems due to low temperatures and high aridity (Chapters 2 and 4). This sets the limits to how many livestock and wild herbivores can be supported in Trans-Himalayan rangelands. As we estimated in Chapter 5, large herbivore production seems to be maximum at a biomass density of ca. 1900 kg km^{-2} in the rangelands. At higher density, both livestock as well as wild herbivore populations can be expected to be resource-limited. Yet, Spitians graze their rangelands at much higher livestock densities. One of the important causes of overstocking in Spiti is that the livestock is owned by individual families, while the grazing land is communally owned. Considering that livestock are needed for many products and services (e.g. ploughing, manure, meat, milk, trade etc., Chapter 2), and that a significant number is lost to wild carnivores (Chapter 3), a livestock holding of 10-12 animals, at the level of the individual family, is perhaps rather small. Yet, when the livestock of all individual families is added up, and their biomasses rather than numbers are considered, overstocking becomes apparent. Overstocking in Spiti then is not a result of either ignorance or faulty management; it is a constraint imposed by the land tenure system, coupled with agro-pastoral needs.

How are livestock herds maintained under conditions of overstocking in the rangelands? The agricultural system in Spiti, with inputs of nutrients (in the form of dung and human waste), and water (diverted from the rangelands; see Chapters 2 and 4), is able to produce substantial amounts of supplementary forage for livestock (Fig. 8.1). This is in the form of black pea, grown especially for fodder, and all other agricultural by-products (from barley and green pea plants, and weeds). As discussed in Chapter 1, supplementary feeding offsets the effects of density-dependent resource limitation in the rangelands. Agriculture coupled with pastoralism then seems to be able to make it possible for the rangelands to be overstocked. Overstocking in purely pastoral systems, that do not have means of supplemental feeding, is less likely to happen.

As seen in Chapter 1, coupled dynamics of consumer populations and resource availability predict that when there is resource overlap between wild herbivores and livestock and when livestock are supplementary-fed, overstocking will cause wild herbivores to get out-competed. It is evident from subsequent chapters (2, 5, 6 and 7) that all these conditions are indeed met with and that wild herbivores are getting out-competed in these Trans-Himalayan rangelands. Further, as discussed in Chapter 4, water harvest for agriculture has also resulted in a reduction of forage production in the rangelands, again disproportionately affecting wild herbivores.

Any interface between livestock and large wild carnivores invariably results in at least some livestock getting killed (Madhusudan and Mishra *in press*). Ever since wild herbivores were domesticated 10,000 years ago, decreased risk of predation in a human-mediated environment has resulted in a lowered ability to detect predators,

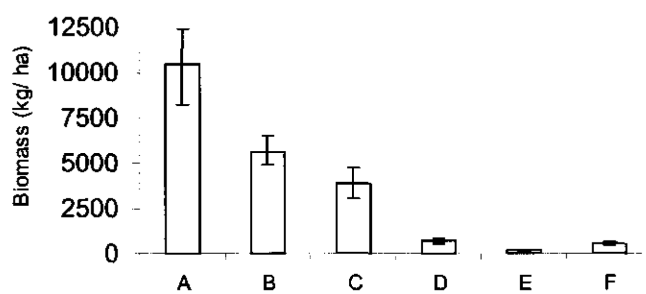

Fig. 8.1 A comparison of above ground plant biomass between crop fields (A to D) and rangelands (E and F) in Spiti, Indian Trans-Himalaya. The entire biomass of black pea is used as forage, as is the plant material collected while weeding barley and green pea fields. After the pods of green pea and ears of barley are harvested, all the remaining biomass is used as fodder.

A: Biomass of green pea plants, B: Biomass of black pea plants, C: Biomass of barley plants, D: biomass of weeds growing in green pea and barley fields, E: Forage (graminoid) biomass in a heavily grazed rangeland, F: Graminoid biomass in a moderately grazed rangeland.

The columns represent means and error bars represent asymmetric 95 % confidence limits.

reduced agility to escape from them, and, in many cases, a breakdown of their protective camouflage colouration (Zohary *et al.* 1998). This, coupled with the fact that hunting success (the proportion of hunts that result in successful kills) of wild predators on wild prey is rather low, makes livestock especially vulnerable to wild carnivore predation when an opportunity is present (Madhusudan and Mishra *in press*). In Spiti's rangelands, out-competition of wild herbivores has further meant that livestock greatly outnumber wild prey of the snow leopard and the wolf. All these factors, together with inadequate anti-predatory livestock management, are responsible for the high levels of livestock depredation in Spiti's rangelands, and the intensifying conflict between pastoralism and wildlife (Chapter 3).

On resource limitation and competition in a broader context

Competition between species populations has been generally difficult to measure, and, consequently, development of theory has long surpassed empiricism. While field studies are still struggling with the issue of whether or not competition occurs (Goldberg and Barton 1992), a substantial body of theory addressing how competition influences community structure and the evolution of competitive ability already existed two decades ago (Roughgarden 1979). Measuring competition in large herbivore assemblages has been especially difficult. This is due partly to the logistic difficulty in manipulating populations, and partly because research has traditionally focussed on the role of predation in limiting large herbivore populations, pushing the role of resource limitation and competition to the back seat (Kie *et al.* 1991, Sæther 1997). Recent reviews have shown a remarkable worldwide scarcity of studies demonstrating competition between wild herbivores or livestock (Putman 1996, Prins 2000).

Against this background, I briefly touch upon the main contributions of the present thesis. As mentioned earlier, we find that supplementary feeding in agro-pastoral systems may allow livestock densities to be maintained beyond points of resource limitation (overstocking). So far, there has been little empirical evidence of overstocking in rangelands; even though the important global debate on overgrazing is founded on the assumption that overstocking does occur (Wilson and Macleod 1991). Chapter 5 is a small contribution in this direction. Chapter 6 established that wild herbivores could indeed get out-competed by livestock in overstocked rangelands. Our results should serve as a wake up call since this might also be taking place in other areas where forage biomass is limited (as is the case in the Trans-Himalaya, Chapter 4). Finally, we find that wild herbivores may even be driven to extinction when rangelands are overstocked (Chapter 7). Specifically in the context of the Trans-Himalaya, our analysis, though entirely theoretical, challenges the traditional view that has ascribed the low diversity and density of wild herbivores entirely to the naturally low levels of primary production. We have argued that such views can come to prevail especially when human use is pervasive, and 'bench mark' areas (that could show how the vegetation and associated wildlife would appear in the absence of livestock grazing) are missing. This again is perhaps a lesson not just for the Trans-Himalaya, but also for all other areas that have a long history of pervasive livestock grazing or other human impacts.

Having highlighted some of the implications of this thesis for other areas, it might be worthwhile to briefly consider the grazing systems in sub-Saharan Africa, which, unlike the Trans-Himalaya, have drawn considerable global attention. The African savanna is amongst the best-understood multi-species grazing systems, and the present work benefited immensely from the current understanding of these tropical semi-arid areas. At first glance, this may seem odd, considering the many fundamental climatic and landscape differences between the two systems. For instance, the highest altitude that savanna systems can be found is 1600 m, which is 2-3 vertical kilometres lower than the Trans-Himalayan system studied (Solbrig 1996). Similarly, the minimum average annual temperature reported for savannas is 19°C, while in the Trans-Himalaya, it is close to freezing point. There are other differences as well, such as the absence of fires, trees, and megaherbivores in the Trans-Himalayan rangelands, and, unlike the African semi-arid rangelands, a low abundance of annuals even in intensively grazed, degraded sites (Rietkerk *et al.* 1996, Van de Koppel and Prins 1998, Van de Vijver 1999).

Yet, the findings of the present thesis, as well as impressions gathered during the work, point to strong similarities between the Trans-Himalayan and African semi-arid grazing systems. As in the Trans-Himalaya, pastoralism is an important aspect of land use and economy in many parts of Africa (Prins 1992). In both areas, graminoids form the most important forage for a majority of large herbivores and the wild herbivore assemblages in both areas seem structured by competitive interactions (Prins and Olff 1998). We have noticed that Trans-Himalayan rangelands show regular vegetation patterns on moderate slopes as well as collapse of vegetation under intensive grazing, characteristics that have so far been reported from tropical semi-arid rangelands (Rietkerk 1998, Klausmeier 1999, Rietkerk and Ketner 2001).

A principal underlying cause of similarity with African semi-arid systems is perhaps the important role soil moisture seems to play in limiting rangeland production in the Trans-Himalaya, where potential evapotranspiration arguably exceeds annual precipitation. The difference is in the source of soil moisture, which is largely snowfall in the Trans-Himalaya, and rainfall in the savanna (Prins and Loth 1988). Yet, the cold Trans-Himalayan steppes seem to functionally behave much like the warm tropical semi-arid systems. This has immense implications, as it suggests that recent catastrophic models developed in the context of semi-arid grazing systems in Africa (see Rietkerk 1998) could help us understand rangeland dynamics in the Trans-Himalaya. Further, the Trans-Himalaya may provide the venue to test the general applicability of concepts developed in tropical arid and semi-arid systems and vice-versa. This underscores the need and scope for collaborative work between the two regions.

On conservation management in the Trans-Himalaya: the road ahead

In the light of the present study, it is no longer difficult to recognize that there are serious conflicts of interest between wildlife conservation and agro-pastoral land use in Spiti, and perhaps in most of the Trans-Himalaya. More difficult is the question of how conservation management could be made more effective and these conflicts resolved. Conservation management is an exercise that extends much beyond ecology, into several fields– *economics*, the costs and benefits of conservation and conflict management strategies; *society*, the social and administrative institutions required to oversee conservation strategies; *politics*, the political will to deliver proposals into reality, and many more. All these subjects are beyond the scope of the present thesis. Our studies have only enabled a recognition and ecological understanding of some of the serious conservation issues in the Trans-Himalaya. Additionally, the studies did provide us an opportunity to understand an agro-pastoral way of life that is perhaps still characteristic of many parts of the Trans-Himalaya. These insights into the society are important, since conservation objectives and strategies have to be developed in the context of existing social frameworks, have to fall in line with the rights of self-determination, and, as articulated by the 'Malawi Principles' (as endorsed by the Conference of Parties of the Convention on Biological Diversity; http://inbada.iven.org), have to be a matter of societal choice.

Bearing these points in mind, I draw upon the findings of the present study to briefly highlight some management needs and approaches for the Trans-Himalaya. I will concentrate on those issues that are specific to the Trans-Himalaya. This is not to imply that other steps such as conservation education, means of strengthening local economies, streamlining the functioning of different government and non-governmental departments (whose actions are often conflicting with each others' and with those of conservation management) etc. are not important. These certainly need to be addressed, just like they need to be addressed in most other wildlife habitats in India. I will not discuss these any further. Another point of general applicability, which I will actually return to later, is that most of the associated costs of having wildlife, albeit in an impoverished state, are currently being borne almost entirely by the indigenous Trans-Himalayan people. Further, they are deriving negligible benefits from the wildlife they share their resources with. Conservation efforts need to ensure that the rest of the society, which shares *in absentia* benefits of conservation, can start sharing the associated costs (see Prins 1992), while the indigenous communities can start deriving some benefits from wildlife conservation.

We decided to conduct this study in the Trans-Himalaya partly because livestock grazing is pervasive in this ecosystem, and because of a lack of understanding of its impacts on Trans-Himalayan wildlife. Our studies have established that this conservation concern was, after all, not misplaced. Livestock grazing is currently the most serious conservation issue in the Trans-Himalaya. That it is also the most important form of land use does not make wildlife conservation any easier.

As mentioned in Chapters 4, 5 and 7, establishing 'bench-mark' areas free from livestock grazing and other human use, and monitoring the response of wildlife to them, has to become the top priority for conservation management in the Trans-Himalaya. While setting aside large areas for wildlife would be desirable, it will not always be feasible, given the local dependence on rangeland resources. However, it is certainly possible, and reasonably effective, to achieve this at a smaller scale. This is best demonstrated by way of an example.

As we saw in Chapter 2, the traditional decision-making system of the village councils, which own most of the rangelands, is still very robust in the Trans-Himalaya. Further, many village councils have traditionally been leasing out parts of their distant grazing land to nomadic graziers from other parts of the Himalaya (Chapter 2). Recognizing the ability of the village councils to arrive at and implement collective decisions, and the precedence of leasing out grazing land, we have made efforts to free an area from livestock grazing and other human use at an experimental scale. An agreement was arrived at two years back between the village council of Kibber and the Nature Conservation Foundation (NCF), a science and conservation institution (with whom I work in India), to set aside a small rangeland area (5 km^2) free from human and livestock use for a period of five years. This is also an example

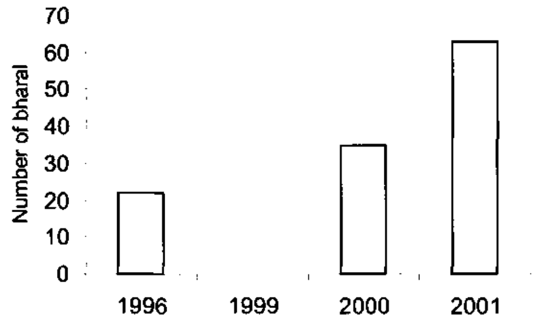

Fig. 8.2 Maximum number of bharal sighted in a day in a 5 km^2 area freed from livestock grazing and human use since 1999. No bharal were seen in 1999, while no sampling was done in 1998. There is indication that bharal use of the area may have increased following the removal of disturbance. We have also seen signs of snow leopard use of the area.

of how the society could pay for *in absentia* benefits of conservation. The costs of implementation and compensation for lost grazing are being met with by a grant from the Van Tienhoven Foundation in the Netherlands. Guards are employed from the village who prevent free-ranging animals from entering the area, while the village council ensures that herded livestock are not taken in. The project is being implemented in co-operation with the village council by scientists of the NCF and the Wageningen University voluntarily. Two years of total protection is already pointing towards some wildlife recovery, as indicated by a possible increase in the use of the area by bharal (Fig. 8.2). The International Snow Leopard Trust has recently joined hands with the programme. These institutions, in addition to scientific research and monitoring, are now working with the village council to evolve programmes (locally managed wildlife tourism and livestock insurance schemes, value addition to local handicrafts, and conservation education) designed to offset the costs of living with wildlife, make wildlife conservation beneficial to the villagers, and make the protected area self-sustaining by the end of five years.

Initiatives like this are feasible and are urgently required at a larger scale. However, by themselves, they do not address the issue of overstocked rangelands. Reduction in stocking densities is important in most areas for preventing further degradation of the rangelands and associated wildlife. Our understanding of the agro-pastoral system suggests that this might be possible to achieve without imposing restrictions on the way people have lived. As we saw in Chapter 2, the agro-pastoral system is characterized by continuous innovation and experimentation. Such experimentation has resulted in some villages developing fruit orchards over the last two decades. These villages have themselves reduced their stocking densities because of a reduction in the production of supplemental forage, and because of the damage that livestock cause to the plantations. Encouragement and assistance to such indigenous initiatives can benefit both the people and wildlife, and will be well within the concerns of self-determination.

Conservation management also needs to accept that the interface between livestock and wild carnivores will continue in the Trans-Himalaya, and that some livestock will invariably be lost as long as this interface exists (Madhusudan and Mishra *in press*). This conflict cannot be solved, though it certainly needs to be addressed. As discussed in Chapter 3, an important step in this direction is to develop self-managed (by the village councils) livestock insurance schemes. As part of our initiative in Kibber, we are working with the village council to set up such a scheme where the villagers will be paying a premium, while the corpus will be strengthened by grants from conservation agencies. Such schemes need to be coupled with better anti-predatory livestock management.

Efforts like this need to be replicated as much as possible. This, however, will only be a beginning towards better conservation management in Trans-Himalayan rangelands. As more information is generated, innovative ideas will constantly need to be evolved and tried out.

Caveats and future avenues

This thesis will have met its goal if some of the findings could contribute to better conservation management in the Trans-Himalaya. However, there are many important issues related to pastoralism and wildlife conservation that are completely ignored (such as potential disease transfers), there are other issues that we have failed to understand, and there are assumptions made that we have been unable to fully validate. A brief overview of the limitations of this work, I think, might perhaps be the best starting point for future work. This is the objective of the present section, and once again, I tackle it chapter-wise.

In Chapter 2, it was suggested that livestock holdings are generally constrained by the ability to supplement-feed animals in winter. What sets the limits to that ability? Available manpower (family size) and extent of agricultural land (where most of the supplementary feed is produced) are perhaps the co-limiting factors; this remains to be investigated. Further, from the daily records we maintained of pasture use (not presented in the thesis) and from interviewing herders, we were unable to understand the basis on which herders decide which pasture is to be grazed on a given day, especially in summer. It was apparent that the herders discontinue the use of a pasture after a few days as the forage biomass declines, or if there is a case of livestock depredation by carnivores. However, it is not clear to us how the decision on which pasture to graze next is made. Perhaps factors such as the distance between the village and pasture, accessibility, landscape characteristics of the pasture that make herding easier, personal motives of the herder (such as availability of *Alium* flowers or dung or mushrooms for collection), etc. affect this decision. Whether the decision indeed based on a set of rules, or is made in an *ad hoc* manner remains unclear.

In Chapter 3, I estimated that approximately 12 % of the livestock is lost to wild carnivores annually. This is an overestimate, since cases of depredation often tend to get exaggerated, both intentionally and unintentionally. I was unable to establish exact livestock losses to wild carnivores. Closer monitoring of depredation cases and simultaneous analysis of wild carnivore diet in areas differing in the relative abundances of livestock and wild prey could throw light on their proportional dependence on each of these groups of herbivores.

The main aim of Chapter 4 was to describe the resource for which the large herbivores potentially compete, the rangeland vegetation. Additionally, we made some attempt to also speculate on possible changes in rangeland vegetation due to

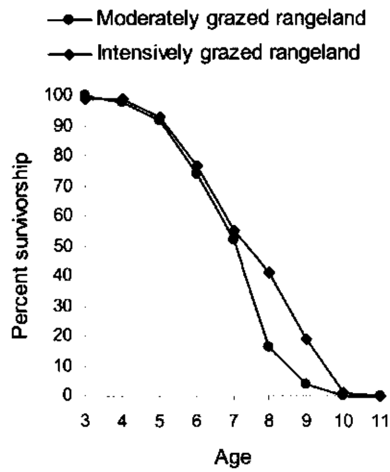

Fig 8.3 Bharal (adult males) survivorship curves in moderately and intensively livestock grazed rangelands in Spiti, Indian-Trans Himalaya. Horn lengths of adult male bharal were measured from skulls found in the rangelands or those collected nearby by the local people. A relationship was established between horn length and age (age in years = 0.162 times the horn length in cm; r^2 = 0.981, p ≤ 0.000, n = 17), and thus the age of mortality of all male bharal whose horns were found could be derived.

human use. However, the chapter largely described the different discernible vegetation types as they currently exist in a small area. The lack of understanding of vegetation dynamics in relation to factors such as climatic variation, soil types, and grazing pressures is perhaps the biggest lacuna not just in this thesis, but also in our general understanding of the Trans-Himalayan ecosystem. The seriousness of the issue is self evident considering that the area in question, over 2 million km^2 of rangelands, is dominated by a pastoral economy, and is also home to a unique wildlife assemblage. Further, the entire area has been subject to human use for several thousand years, and with hardly any 'benchmarks' available, it is difficult to establish the nature of rangeland vegetation in the absence of livestock grazing. Our ability to predict future changes in vegetation under varying grazing and geo-climatic regimes, and to reconstruct past vegetation, will be the critical determinants of how effectively we can manage these rangelands for pastoral production or wildlife conservation.

The animal production modelling in Chapter 5 provided us valuable insights into resource limitation for large herbivores in the rangelands. The parameter values were derived based on data from two rangelands that differed in stocking density, and whose livestock production we followed for three years. Animal production data from other rangelands, especially those with values of stocking densities in between the two rangelands we studied, would make the estimates more robust. These would also enable us to confirm if indeed animal production and stocking density follow a linear relationship as we assumed, or if there are threshold effects. Furthermore, effects of previous year's precipitation on current year's secondary production need to be estimated to increase the applied value of these models.

Chapters 2, 4, and 5 together established that overstocking of rangelands becomes possible in agro-pastoral systems due production of supplemental feed. We also saw that water harvest for agriculture seems to have resulted in a significant reduction in forage production in the rangelands. Irrigation experiments could confirm this. It appears that, other factors kept constant, purely pastoral systems without supplemental feeding or water harvest might then be more compatible with wildlife conservation compared to agro-pastoral ones, and this needs to be investigated in future work.

In chapter 6, we found that bharal were grazers in summer but intermediate feeders in winter. Due to difficult field conditions, our observations on bharal diet were restricted to a single area that had an overall high livestock density. We predict that in areas with lower livestock density (and consequently greater graminoid availability), bharal are likely to be grazers throughout the year, and this needs to be ascertained. Further, we found that resource competition between bharal and livestock largely operates through variation in fecundity and neonate mortality. However, the composite index of population performance we used (offspring: adult female ratios) is not able to tease out the amount of variation in bharal density explained by each of these factors independently. In fact, we also ignored adult mortality. This perhaps is not a serious concern, since most resource dependent mortality in large herbivores is reported in very young age classes (Clutton-Brock et al. 1982, Sæther 1997). Our unpublished observations on mortality patterns in adult male bharal do not indicate any resource dependence either (Fig 8.3). These issues could be pursued in detail in future work.

Chapter 7 was based entirely on theoretical analyses that were founded on several assumptions. We have been unable to fully validate most of them, including the starting assumption that all the 'missing species' were once present in Spiti. Further, our assumption that suitable habitat for the missing species is present in Spiti should be seen against the light of the fact that it is based on very little and sketchy information available in literature. This also goes for the assumption that most of the concerned species are grazers, since observations on diet in literature are mostly anecdotal. Future research needs to focus on understanding habitat selection and diets of these several wild herbivores. From the analyses, we predict that like bharal, ibex too is out-competed in these rangelands by livestock. This is contrary to what existing literature suggests (Bhatnagar 1997) and needs to be carefully investigated. Lastly, in the analyses, we chose not to invoke biogeographic factors that might affect the presence or absence of species in any area. Nevertheless, even though it remains unable to make a conclusive statement about actual competitive exclusions in Spiti, the chapter strongly points to potential species extinctions. It suggests that low density and diversity of wild herbivores in the Trans-Himalaya need not be passive consequences of the naturally low primary production. Even if it can serve as a wake up call that large herbivore species extinctions are a real possibility in overstocked rangelands, the chapter has met its goal. However, a better understanding of the causes of variation in wild herbivore species diversity in the Trans-Himalaya remains a challenge for future work.

Finally

This thesis, I hope, has contributed to a better understanding of the important subject of resource competition between livestock and wild herbivores, and the issue of *harmonious coexistence between pastoralism and wildlife.* Yet, I realize that some questions remain only partly answered, and many additional ones have been generated. These can direct the future course of work in the Trans-Himalaya. I conclude with the hope that the present thesis will be able to contribute towards better conservation management in India and other neighbouring countries such as Pakistan and the Autonomous Region of Tibet that share the Trans-Himalayan landscape.

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Summary

Livestock grazing impacts on native wildlife are a global conservation concern, and India is no exception. Three fourths of Indian wildlife reserves are grazed by livestock. There have been repeated calls over the last two decades for a better understanding of pastoralism and its impacts on wildlife in India, and this thesis is a response to them. Focussing on the high altitude steppe rangelands of the Indian Trans-Himalaya, I address the broad question of how harmonious the coexistence between pastoralism and wildlife is. Specifically, I try to understand a traditional agro-pastoral system in Spiti Valley (12,000 km^2) and evaluate if livestock and wild herbivores compete for resources.

The agro-pastoral system in Spiti Valley has probably existed for over three millennia. The present local population of over 10,000 people belongs to one of the three Buddhist sects (*Gelukpa, Ningmapa* or *Shakyapa*), is related by blood, and shares a common Tibetan dialect. Family is the basic unit of production, though families are highly dependent on the community to meet production goals. A democratically functioning village council is responsible for village administration, and ensures equal access of families to common resources (such as rangeland vegetation), as well as equitable distribution of responsibilities among them. The system seems to attempt at maximizing agro-pastoral production while mediating environmental risk. At the level of the family, the system comes forth as suitably adapted to the risk-prone mountainous environment, the risks being climatic, geological, and those posed by wildlife.

Despite risk mediating practices, the villagers lose an estimated 12 % of their livestock annually to wild carnivores, the snow leopard *Uncia uncia* and the wolf *Canis lupus*. They suffer substantial financial losses, and in retaliation, persecute the carnivores, both of which are globally threatened. The escalation of the conflict in the last decade is probably related to an estimated 38 % increase in livestock numbers between 1987 and 1996, with livestock currently outnumbering bharal *Pseudois nayaur*, a mountain ungulate and the most important natural prey of these carnivores, by nearly an order of magnitude.

The steppe rangeland vegetation shared by livestock and wild herbivores is dominated in terms of biomass by a single species of shrub. Three main vegetation formations were identified in the study area, and their variations (types) are described in terms of structure and species composition. Most of the vegetation appears to be under different stages of degradation due to intensive and pervasive human use. Graminoids have a generally low abundance, though they are the most important in terms of forage. The long history of livestock grazing and water harvest for agriculture have caused changes in vegetation composition and a reduction of graminoid biomass in the rangelands. A global comparison reveals that in terms of aboveground graminoid biomass, the Trans-Himalaya fall at the low end of the range.

The point of resource limitation for large herbivores was estimated using empirical data on livestock production together with animal production models. The resource limitation point corresponds to the 'optimal' stocking density that would maximize livestock production. A sample of 40 villages showed that over four-fifths of the rangelands in Spiti Valley might be currently overstocked beyond the point of resource limitation.

Studies on diet of all seven species of livestock and bharal revealed substantial resource overlap, with graminoids contributing predominantly to the diet of most herbivores. There was some indication that the similarity in diet composition of herbivores might be correlated with similarity in their body masses. Comparison of graminoid biomass between rangelands differing in livestock density showed that livestock at current densities are able to significantly reduce available forage in the rangelands, again pointing towards resource limitation. Resource overlap with livestock, together with resource limitation, results in bharal getting out-competed. Comparison of bharal populations between rangelands differing in livestock density showed that bharal density gets reduced as the livestock density increases. Variation in bharal density seems correlated with resource-dependent variation in fecundity and neonate mortality.

Theoretical analyses revealed a consistent morphological pattern in the multi-species Trans-Himalayan wild herbivore assemblage, with each species, on average, being a constant proportion heavier than the immediately smaller species. This pattern is arguably brought about by the long-term interplay of competitive and facilitative interactions among species. The analyses further make the case for competitive exclusion of four wild herbivores from Spiti Valley over the last three millennia out of the nine species that could potentially occur here. The present herbivore assemblage conforms reasonably to the theoretical predictions – these four wild herbivores are amongst the six species that presently do not occur in Spiti Valley, but are present in neighbouring parts of the Trans-Himalaya.

The coexistence between pastoralism and wildlife then is far from harmonious. The thesis has implications for pastoral and conservation management in the Trans-Himalaya.

Samenvatting

Negatieve effecten van begrazing door vee op de oorspronkelijke wilde fauna vormen een wereldwijd probleem en India vormt hierop geen uitzondering. Driekwart van de Indiase natuurreservaten wordt begraasd door gedomesticeerde hoefdieren. Het onderzoek gepresenteerd in dit proefschrift is een antwoord op de toenemende vraag naar onderzoek over de gevolgen van begrazing door vee op het wild. Ik concentreer mij op de brede vraagstelling in welke mate pastoralisten momenteel in harmonie leven met de wilde fauna. Het onderzoek is uitgevoerd op de steppe in het hooggebergte van de Indiase Trans-Himalaya. In de 12000 km^2 grootte Spiti Vallei is een agro-pastoraal systeem onderzocht en is bekeken of er voedselconcurrentie plaatsvindt tussen wild en vee.

Het onderzochte agro-pastoraal systeem bestaat waarschijnlijk al meer dan drieduizend jaar. De huidige lokale bevolking is sterk verwant, behoort tot drie verschillende boeddistische sektes *(Gelukpa, Ningmapa,* en *Shakyapa)* en spreekt hetzelfde Tibetaanse dialect. De basiseenheid voor economische productie wordt gevormd door het gezin dat hierbij echter wel afhankelijk is van de dorpsgemeenschap om aan alle productiedoeleinden te kunnen voldoen. Een democratisch functionerende dorpsraad is verantwoordelijk voor de dorpsadminstratie en zorgt ervoor dat alle families in gelijke mate toegang hebben tot alle hulpbronnen zoals bijvoorbeeld de weilanden rond het dorp. Het dorpsbestuur is ook verantwoordelijk voor een gelijkmatige verdeling van alle taken binnen de gemeenschap. Het systeem lijkt er op gericht te zijn de agrarische productie te maximaliseren zonder al te veel risico te nemen. Het systeem geeft de indruk goed aangepast te zijn aan het risicovolle leven in het hooggebergte. De grootste risico's voor de lokale bevolking worden gevormd door de geologische gesteldheid, natuurrampen en het wild.

Ondanks alle door de dorpsbewoners genomen voorzorgsmaatregelen wordt per jaar ongeveer 12% van hun vee gedood door wolven (*Canis lupus*) en sneeuwluipaarden (*Uncia uncia*). Dit heeft een substantieel financieel verlies tot gevolg en als wraak wordt er op beide, wereldwijd bedreigde, roofdieren gejaagd. Dit conflict is de afgelopen jaren geëscaleerd doordat de hoeveelheid vee tussen 1987 en 1996 met 38% is toegenomen. Het gevolg is dat er op dit moment meer vee is dan de van oorsprong voorkomende blauwschapen, de bharal *(Pseudois nayaur*), onder natuurlijke omstandigheden verreweg de belangrijkste prooi van genoemde roofdieren.

De graslandvegetatie van de steppe die wordt begraasd door zowel het vee als de wilde herbivoren wordt in termen van biomassa gedomineerd door één soort struik. In het onderzoeksgebied werd de variatie in structuur en soortensamenstelling van drie verschillende vegetatietypes beschreven. Grasachtigen komen relatief weinig voor maar vormen wel de belangrijkste voedselbron voor de herbivoren. De lange geschiedenis van begrazing door vee en wateronttrekking voor de landbouw hebben ervoor gezorgd dat de samenstelling van de vegetatie is veranderd en de grasproductie is verminderd. In vergelijking met andere gebieden in de wereld is de biomassaproductie van de graslanden in de Trans-Himalaya zeer laag.

Het punt waarop voedsellimitatie optreedt voor grote herbivoren werd geschat met behulp van empirische data over vee en dierlijke productiemodellen. Het voedsellimitatiepunt correspondeert met de optimale veebezetting waarbij de productie wordt gemaximaliseerd. Een onderzoek onder 40 dorpen toonde aan dat op

dit moment in viervijfde van het gebied de veedichtheid hoger is dan het punt waarop voedsellimitatie optreedt.

Een studie naar het dieet van alle zeven soorten vee en blauwschapen toonde aan dat er een grote voedseloverlap is tussen de herbivoren. Grassen vormen bijna altijd de belangrijkste voedselbron. Er is enige aanwijzing dat een overeenkomst in dieet gerelateerd is aan een overeenkomst in lichaamsgewicht. Een vergelijking van de bovengrondse grasbiomassa in gebieden met verschillende veedichtheden toonde aan dat het vee de hoeveelheid beschikbaar voedsel voor wilde herbivoren significant kan verminderen, een ander teken van voedsellimitatie. Een grote voedseloverlap met vee, tesamen met voedsellimiatie, heeft tot gevolg dat de blauwschapen worden weggeconcurreerd. De dichtheid aan blauwschapen is hoger in gebieden met weinig vee dan wanneer de veedichtheid hoog is. De variatie in de blauwschapendichtheid lijkt gecorreleerd aan een, aan de voedselbeschikbaarheid gekoppelde, variatie in vruchtbaarheid en neonatale sterfte.

Een theoretische analyse toonde aan dat er een consistent patroon is in de soortensamenstelling van de wilde herbivoren in de Trans-Himalaya. Hierbij is elke soort een constant percentage lichter dan de daaropvolgende iets zwaardere soort. Dit patroon is waarschijnlijk veroorzaakt door een zeer langdurig samenspel van competitieve en faciliterende interacties tussen de verschillende soorten. De analyse geeft verder aan dat in de afgelopen 3000 jaar waarschijnlijk vier van de potentieel negen soorten wilde herbivoren door competitieve uitsluiting uit de Spiti Vallei zijn verdwenen. Het momenteel aanwezige soortenpalet van herbivoren komt redelijk overeen met de theoretische voorspellingen. De vier verdwenen soorten horen bij de zes soorten die op dit moment niet voorkomen in de Spiti Vallei terwijl deze soorten wel aanwezig zijn in de aangrenzende gebieden in de Trans-Himalaya.

Het is duidelijk dat op dit moment de pastoralisten en de wilde fauna niet in harmonie met elkaar leven. De resultaten van dit proefschrift kunnen worden gebruikt voor zowel het natuurbeheer als voor het beheer van de pastorale systemen in de Trans-Himalaya.

Curriculum vitae

Charudutt Mishra was born in Delhi, India, on 1st February 1971. He completed his higher secondary education in 1988, and thereafter studied Zoology for a B. Sc. degree at the University of Delhi (1988-1991). He then joined an M. Sc. course in wildlife sciences at the Wildlife Institute of India, and graduated with distinction in 1993. For his graduation thesis, he worked with Dr. A. J. T. Johnsingh, and studied habitat selection by the goral *Nemorhaedus goral* in the Himalaya. To gain more experience in field-ecology and conservation, he conducted several surveys and research projects after his M. Sc. (1993-1996) that included status surveys of endangered mountain ungulates and primates, a study of revegetation patterns in abandoned mines, and organizing a workshop on illegal wildlife trade in India. In 1996, he conducted a preliminary study of livestock-wildlife interactions in the Indian Trans-Himalaya, which set the future course of his Ph. D. work. Since 1997, he has worked as a Ph. D. candidate with Professor H. H. T. Prins at the Tropical Nature Conservation and Vertebrate Ecology Group, Wageningen University, The Netherlands. He is one of the founder trustees of the Nature Conservation Foundation that was established in 1996 to promote the use of science for wildlife conservation in India. Charu has also been supervising a conservation project that has involved collaborating with the villagers in his study area to set up an area exclusively for wildlife, and garnering a long-term conservation commitment from the villagers. Over the last two years (1999-2001), Charu was also involved in developing the curriculum and structure of an M. Sc. course in Wildlife Ecology and Conservation to be started in India shortly. He is now working with the International Snow Leopard Trust to develop a science and conservation program for the Indian Himalaya.

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