DETERMINANTS OF OCCURRENCE OF SNOW LEOPARD AND ITS PREY SPECIES IN THE INDIAN GREATER AND TRANS HIMALAYA

A THESIS
submitted by

ABHISHEK GHOSHAL

for the award of the Degree of

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IN

WILDLIFE SCIENCE

Under the guidance of

BIVASH PANDAV

&

Co-guidance of

YASH VEER BHATNAGAR

Wildlife Institute of India
Dehradun - 248001

Saurashtra University
Rajkot - 360005

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Declaration

I hereby declare that the thesis titled **"Determinants of occurrence of snow leopard and its prey species in the Indian Greater and Trans Himalaya"** submitted in partial fulfilment of the requirements for the degree of Ph.D. in the subject of Wildlife Science, Faculty of Science, Saurashtra University, Rajkot, is a work carried out by me under the guidance of Dr. Bivash Pandav, Wildlife Institute of India, Dehradun, and co-guidance of Dr. Yash Veer Bhatnagar, Nature Conservation Foundation, Mysore. It is hereby certified that no part of the research presented in this thesis has been submitted for any other academic degree or diploma. The research presented in this thesis is true to the best of my knowledge.

Place: Dehradun

Date:

Abhishek Ghoshal
Doctoral Scholar
Wildlife Institute of India
Nature Conservation Foundation

Certificate

This is to certify that the research presented in the thesis titled **“Determinants of occurrence of snow leopard and its prey species in the Indian Greater and Trans Himalaya”** was carried out by Shri. Abhishek Ghoshal, Doctoral Scholar, Wildlife Institute of India, Dehradun, and Nature Conservation Foundation, Mysore, under our guidance. The thesis represents original research conducted by the candidate in partial fulfilment of the requirements for his PhD in Wildlife Science, Saurashtra University, Rajkot. The work has not been submitted for the award of any other academic degree or diploma.

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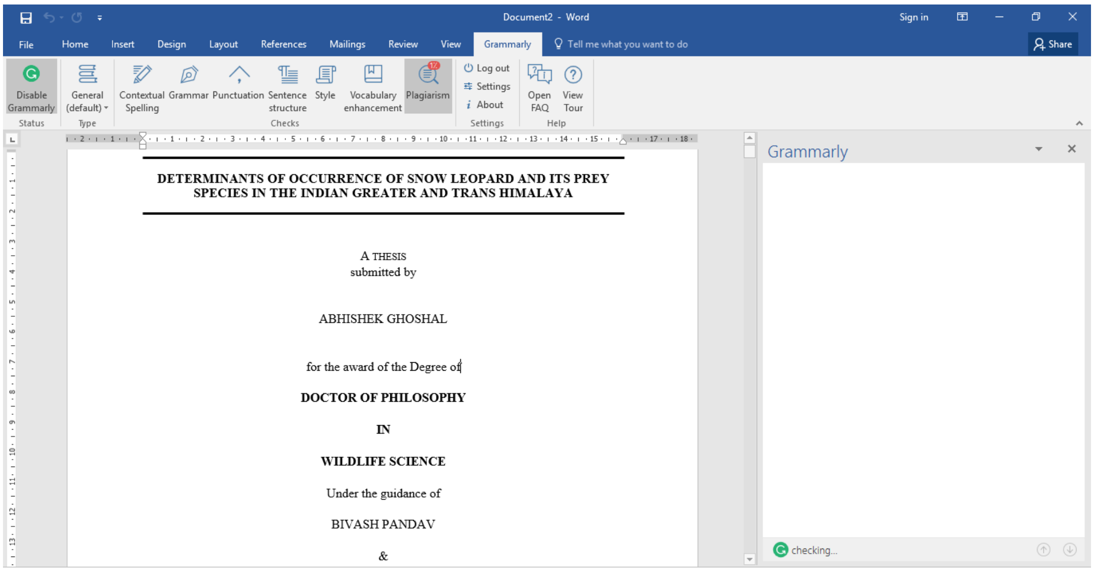

…to my grandparents, Ma-Baba, Ma-Bua and Sanga

&

to my teachers

I will be ever indebted to you for your teachings and support

Thesis abstract

Understanding patterns of species occurrences and how their distribution and abundance are affected by abiotic and biotic factors have been a major theme of ecological research. The range and changes in the distribution of a species are important parameters to assess conservation status. Robust assessment of factors affecting species distribution and abundance contribute to the identification of conservation issues, appropriate scale(s) for species conservation and key stakeholders.

Through this thesis, I have attempted to understand how distribution and abundance of a large-ranging and difficult-to-sample carnivore and its primary wild-prey species are affected by topographic, vegetation and land-use variables, at wide and fine spatial scales. I have focused on the snow leopard (*Panthera uncia*), the elusive, rare and endangered apex predator of the Central and South Asian mountain systems, and its main prey, blue sheep or bharal (*Pseudois nayaur*) and Asiatic ibex (*Capra sibirica*) for the work. I have utilized tools from quantitative ecology and social sciences through the thesis.

The presumed snow leopard, blue sheep and ibex habitats are cliff- and pasture-dominated areas between 3,200m-5,200m amsl in the Indian Himalaya and Trans-Himalaya. However, robust estimation of snow leopard and prey distribution across vast areas has rarely been attempted and hence remain poorly understood. The Himalayas also support resident and transhumant or migratory livestock grazing. Owing to limited arable lands and modern livelihood options in the rugged and remote mountainous terrain, livestock grazing has been a major livelihood. Although considered 'traditional',

resident and migratory livestock grazing practices have been evolving in response to environmental, socio-economic and geo-political changes. The rangelands or pastures grazed by livestock are often overstocked, compromising livestock productivity, forage availability and wild-ungulate densities. This, in turn, impacts snow leopard densities, since snow leopard density is directly related to prey abundance.

The results based on occupancy surveys across an area of 14,616 km^2 of potential snow leopard habitat suggest snow leopard and wild-prey were widespread, not restricted to protected areas. A considerable proportion (25%) of surveyed area was not likely to be used by snow leopards. Blue sheep and ibex had distinct distributions within the study area. Snow leopard and wild-prey (blue sheep and ibex combined) site-use were best explained by altitude and ruggedness. Blue sheep was likely to occur in areas without migratory livestock grazing, while ibex occurred in areas with intensive migratory livestock grazing. At a finer scale, effects of migratory livestock grazing on vegetation cover and biomass, and ibex population density and young:adult female ratios were tested in a grazed and ungrazed area across spring, summer and autumn seasons of 2015 and 2016. Graminoid and herb biomass were significantly lowered by migratory livestock grazing owing to humongous forage removal by livestock during two months of peak summer. Palatable species biomass was 2.25 times lower in grazed than that of ungrazed area. Ibex population density was 1.8-7 times lower in grazed than that of ungrazed area across two years, with six times lower yearling:adult female ratios in grazed area during peak summer. Significantly reduced forage availability led to exploitative competition between ibex and migratory livestock. Given the severe impacts of migratory livestock grazing on vegetation and wild-prey, the changes in migratory livestock grazing practice over the past decade were assessed. Additionally, perceptions of migratory herder and local communities on effects of grazing on pasture quality were examined. Herd size nearly doubled over the past decade, along with precipitous rise in prices of goat, sheep and wool. Pasture quality was perceived to be degrading by migratory herder and local communities and availability of palatable forage declining as a result of pasture degradation.

This work contributes to empirical understanding of snow leopard and wild-prey distributions across a vast landscape of the Indian Greater and Trans-Himalaya. It points to the importance of landscape-scale science-based participatory conservation planning for effective snow leopard and wild-prey conservation in the Indian Himalaya, rather than a protected area-centric approach. At a finer scale, this work establishes prevalence of exploitative competition between ibex and migratory livestock owing to palatable forage depletion by livestock. The findings on palatable forage reduction by migratory livestock grazing in Trans-Himalayan rangelands is in line with perceptions of the key stakeholders, providing a platform to engage with migratory herder community. The results provide insights for conservation management of the Indian snow leopard habitat and Himalayan rangelands at regional and local scales.

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Image 1: Snow leopard, the apex predator of the Central and South Asian mountains, is one of the main study species in this thesis.

Chapter 1

Introduction to species occurrence: importance of pattern and implication

Patterns of species occurrences have interested naturalists for centuries. An interesting aspect of observing species occurrences is that not all species occur everywhere. Although apparently, a simple fact, understanding what determines occurrence of a species at a place can be as theoretically interesting as it can be challenging.

While examining patterns of species occurrences, legendary naturalists and theorists, such as Charles Robert Darwin and Alfred Russell Wallace, began to address the challenges by describing the evolutionary and biogeographic processes underlying species occurrences. Our understanding on species occurrences improved as Darwin and Wallace explained why there were different species in the first place (natural selection, speciation and adaptive radiation) (Wallace, 1865, 1869; Darwin, 1897; Darwin & Keynes, 2001). Gradually, our understanding of patterns of species occurrences further improved, as 'ecology' (the term first used by Ernest Haeckel in 1869) emerged as a scientific discipline and evolved through the late nineteenth and twentieth centuries (Odum, 1977). Several generations of eminent ecologists such as, G. F. Gause, E. Mayr, E. O. Wilson, R. H. MacArthur and E. Pianka among many others, explained the species concept (Mayr, 2000), how similar species with similar requirement can exist in one place (niche and habitat partitioning; Gause, 1934, 1935; Pianka, 1981), why different sizes of isolated areas (islands) had different composition of species and why the diversity of species on 'islands' nearer and farther away from a 'mainland' differ as a function of distance from the 'mainland' (Island Biogeography Theory, MacArthur & Wilson, 1967).

The theory of island biogeography formed a landmark in the course of ecology as it contributed to our quantitative understanding of species distribution and extinction in relation to distance-dependent colonization and area-dependent extinction. In the wake of unprecedented habitat fragmentation and degradation and in turn, species extinction through the twentieth century (Pimm & Raven, 2000; Ceballos, García & Ehrlich, 2010), increasingly ecologists focused on protecting populations of species and landscapes of ecological importance (Soulé & Wilcox, 1980; Margules, Nicholls & Pressey, 1988). This led to the emergence of conservation biology, a discipline, as Soulé (1986) put it, 'the science of scarcity and diversity'. Through this discipline ecologists and conservationists adopted 'priorities' for conservation, be it at the species level (Simberloff, 1998) and / or across landscape or region or 'hotspot' (Myers *et al.*, 2000; Lovejoy, 2006). However, ecologists and conservationists continue to face two significant challenges in conservation of biodiversity, 'what to protect?' and at what 'scale' (Vane-Wright, Humphries, & Williams, 1991; Schneider 2001; Henle *et al.*, 2014).

Why large mammals?

Mammalian species are known to have lost an average of 68% of their range globally (Ceballos & Ehrlich, 2002). Range loss of mammals has been exceptionally high (83% range lost) in Southeast Asia, including India (Ceballos & Ehrlich, 2002). Within mammals, large mammals (> 3 kg) are particularly prone to the risk of extinction due to both environmental factors and intrinsic traits, such as, large body size, relatively low population density, slow reproduction rate and small litter size, and large home range size (Cardillo *et al.*, 2005; Davidson *et al.*, 2009). Owing to these intrinsic life-history traits of large mammals, their rate and risk of extinction are predicted to be much higher than smaller mammals (Cardillo *et al.*, 2005; Davidson *et al.*, 2009). Again, these very traits of large mammals, especially charismatic large carnivores, make them the focus for conservation at the landscape or ecosystem scale as 'flagship' species (Simberloff, 1988).

Why snow leopard?

Snow leopard *Panthera uncia* is an important ecological and cultural symbol of the Central and South Asian mountain ecosystem (SLWS, 2013; SLN, 2014). This elusive 'big cat' along with its co-predators, such as wolf *Canis lupus*, Eurasian lynx *lynx*, Palla's cat *Otocolobus manul* and wild mountain ungulates, such as blue sheep *Pseudois nayaur* and Asiatic ibex *Capra sibirica*, represent one of the least known assemblages of large mammals globally. As the top-predator, snow leopard habitat use and density depend on the abundance of wild-ungulates, especially blue sheep and ibex (Lyngdoh *et al.*, 2014; SLN, 2014; Sharma, Bhatnagar & Mishra, 2015). Snow leopards require large home range size (mean home range size 207 km^2; Johansson *et al.*, 2016), thus viable populations can only be secured across large contiguous landscapes. Therefore, the snow leopard represents the ideal 'flagship' and 'umbrella' species for the mountainous ecosystem of Asia (PSL, 2008; SLWS, 2013; SLN, 2014).

Additionally, the highlands of Central and South Asia provide invaluable ecosystem services in the forms of grazing lands for local communities, carbon sequestration in its extensive rangelands and serve as the source of major rivers of Asia supporting about one-third of the world's human population (SLWS, 2013; SLN, 2014). In India, the Himalayan and Trans-Himalayan ecosystem supporting snow leopard provide ecosystem services worth about US$ 4 billion per year (SLWS, 2013).

Snow leopard and prey distribution: existing knowledge and challenges in the Indian context

Snow leopard occurs across 12 countries in Central and South Asia: Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan and Uzbekistan (SLWS, 2013; SLN, 2014). The endangered snow leopard is the top-predator and 'flagship' for the conservation of the Indian Himalaya (SLWS, 2013; SLN, 2014; Bhatnagar *et al.*, 2016). The Indian Greater and Trans-Himalaya form the southern limit of global snow leopard distribution range and constitute *ca.* 6% of the estimated global snow leopard range. India has rich natural history records from snow leopard range spanning over a century (Bhatnagar *et al.*, 2016), but systematic surveys only began in the 1980's in parts of the Western Himalaya, such as Ladakh (Mallon, 1991; Fox *et al.*, 1991, Chundawat, 1992; Chundawat & Qureshi, 1999), Himachal Pradesh (Vinod & Sathyakumar, 1999; Bhatnagar *et al.*, 2008), Uttarakhand (Maheshwari & Sharma, 2010) and more recently in parts of Sikkim (Sathyakumar *et al.*, 2014) and Arunachal Pradesh (Mishra *et al.*, 2006). Ecological studies in Ladakh (Chundawat & Rawat, 1994), Spiti (Bhatnagar, 1997; Mishra, 1997; Mishra *et al.*, 2004; Suryawanshi *et al.*, 2013) and Uttarakhand (Kandpal & Sathyakumar, 2010; Bhattacharya *et al.*, 2012) have added to our understanding of snow leopard and prey ecology, such as impact of livestock grazing on snow leopard and prey populations, predation ecology of snow leopard and interactions between people and wildlife.

Despite on-going research and conservation efforts on snow leopard for nearly three decades, distribution and conservation status of snow leopard and its primary prey, blue sheep and Asiatic ibex, remain poorly understood beyond certain pockets of relatively small areas (e.g. Hemis National Park in Ladakh, Spiti in Himachal Pradesh, Prek Chu catchment in Kanchendzonga Biosphere Reserve, Sikkim). Such areas cover only about 4% of the potential habitat of snow leopard in India (Bhatnagar *et al.*, 2016). A third of the Indian snow leopard range has not yet received research attention (Bhatnagar *et al.*, 2016). About half of the potential snow leopard habitat is data deficient on even occurrence of snow leopard and prey. This brings us back to the issue of 'scale'. The snow leopard is a large ranging species (home range > 200 km^2), not restricted to protected areas. National and global snow leopard conservation agencies repeatedly suggested scaling up of research and conservation efforts for snow leopard habitat (Bhatnagar, Mathur & McCarthy, 2002; PSL, 2008; SLWS, 2013; SLN, 2014).

Conceptual framework

Understanding occurrences and distribution of species are fundamental to macroecology (Brown, 1995). Since the extent of range that a species occupy is an important criterion for assessing conservation status, determining species occurrences and the threats they face is a fundamental step towards conservation (Margoluis & Salafsky, 2001; MacKenzie *et al.*, 2006; Karanth *et al.* 2009). The distribution and habitats of several species have been severely affected by human activities and developmental pressures globally (Sanderson *et al.* 2003; Loehle & Eschenbach, 2012). The affected species are now facing large-scale range contraction and extinctions (Cardillo *et al.* 2005; Davidson *et al.*, 2009). As mentioned above, large mammals are often considered to be 'umbrella' or 'flagship' species for conservation (Simberloff, 1998). Large home range size and habitat specificity make large mammals vulnerable to drastic range contraction and extinction (Ceballos *et al.* 2005; Michalski & Peres, 2005).

India has an exceptionally rich and highly diversified flora and fauna, exhibiting complex composition, character and affinities (Mani, 1974). Over the past century, the country has seen rapid economic and human population growth, which has severely affected mammal species and their habitats (Das *et al.* 2006; Singh & Bagchi, 2013). Madhusudan & Mishra (2003) suggests that 20% of Indian large mammals face extinction while many others have lost over 90% of their historical range.

Recognizing the need for baseline knowledge on current distribution of large mammals, and on ecological and socio-cultural determinants of their persistence, Karanth *et al.* (2009) studied the geographical range and associated environmental, social and cultural covariates explaining distribution patterns of 20 large mammal species in India using occupancy modelling. Pillay *et al.* (2011) carried out a similar study on large mammals in the Western Ghats landscape. These studies reported restricted ranges and range shrinkage of certain common large mammals at broad spatial scales. However, in comparison to the large mammals of the Indian peninsula, the occurrences, distribution and conservation status of the high altitude large mammalian assemblage are still poorly understood. Reliable basic information on historical and current distribution range is lacking even for charismatic and endangered species such as the snow leopard and its primary prey species such as the blue sheep and Asiatic ibex (SLN, 2014).

The abundance of snow leopard in India relies predominantly on the density of blue sheep and Asiatic ibex (Schaller, 1977; Lyngdoh *et al.*, 2014; Sharma *et al.*, 2015). The snow leopard habitat in India faces extensive livestock grazing (PSL, 2008; SLN, 2014; Bhatnagar *et al.*, 2016). Decline in wild-prey populations due to rangeland degradation by livestock grazing is a serious conservation concern to snow leopards (Mishra *et al.*, 2004; Bagchi *et al.*, 2012). Livestock grazing affects rangeland quality by lowering availability of palatable forage and reduces density and population performance (young : adult female ratios) of wild-prey through interference and exploitative competition (Bagchi *et al.*, 2004; Mishra *et al.*, 2004; Suryawanshi *et al.*, 2010).

In the arid tracts of the Indian Trans-Himalaya, socio-economic shifts have reduced resident livestock populations (due to an emphasis on cash-crop and other employment), which are being replaced by larger, non-resident livestock herds of migratory peoples (USL, 2011). Owing to characteristic seasonal movement patterns, the transhumant or migratory herder community are not constrained by winter-forage availability. They descend to the Himalayan foothills during winter (November – April). They can afford to maintain much higher livestock densities than those traditionally held by resident herders. For example, in 2008, the resident livestock population in the Upper Spiti Valley in Himachal Pradesh was about 20,000, while over 40,000 migratory livestock were grazed in just two areas of Spiti (USL, 2011). Livestock populations in key migratory herder strongholds have increased by 25% between 1997 and 2007 (Livestock Census, 1997, 2007). Today about half of the available snow leopard habitat in Himachal Pradesh is under migratory livestock grazing, with 40% facing intense grazing (roughly 90 livestock/km^2) (Ghoshal *et al.*, in review). Migratory herders are now increasingly penetrating new areas and driving deeper into the heart of prime snow leopard habitat in the drier, and possibly less resilient pastures. They are striking pacts with local village-administration to use unused pastures, thus escalating the threats to wildlife, especially in areas where such threats were absent earlier.

Additionally, migratory livestock grazing in snow leopard habitat is linked to local, regional and national markets catering to demands for wool, milk and meat (Axelby, 2007; Bhasin, 2011; Bhatnagar & Singh, 2011). This linkage has contributed to economic demand for larger herd sizes. Studies across Central Asian grazing systems have shown that trade-driven livestock grazing is an important factor that has decimated natural prey-base of snow leopard (Bhatnagar & Singh, 2011; Berger *et al.*, 2013). Further, the issue of migratory livestock grazing has been socio-politically contentious, being more often dealt through activism rather than science-based ecological evidence (Saberwal, 1996; Mishra & Rawat, 1998).

With this background, understanding the mechanisms by which migratory grazing affects rangeland quality and wild-prey population of snow leopard is imperative. There is an urgent need for ecologists, conservationists and wildlife managers to engage with migratory herder community and other stakeholders associated directly or indirectly with the livestock production system to assess their role and means of engagement with snow leopard conservation.

Through this thesis, I have tried to understand snow leopard and wild-prey occurrences in relation to conservation threats at broad and fine spatial scales. I also attempt to understand the mechanism through which a key conservation threat, migratory livestock grazing, is affecting the snow leopard habitat and one of its primary prey, Asiatic ibex, at a fine spatial scale. I describe the underlying dynamics of migratory livestock grazing practice that leads to the observed impacts on snow leopard habitat.

Outline of thesis

The thesis consists of five chapters, a chapter on introduction, three data chapters and a synthesis (Illustration 1). In the first data chapter (Chapter 2) patterns of distribution changes of snow leopard and wild-prey have been explored in relation to relevant topographic and land-cover variables and conservation threats. Based on this chapter, migratory livestock grazing was identified as one of the most widespread and intense threats in the snow leopard habitat. In the second data chapter (Chapter 3) ecological impacts of migratory livestock grazing on rangeland vegetation and a primary wild-prey of snow leopard, Asiatic ibex, have been examined. Having looked into the ecological impacts of migratory livestock grazing on snow leopard habitat, the third data chapter (Chapter 4) assessed changes in migratory livestock grazing practice and its implication on the long-standing pastoral system, snow leopard and wild-ungulate conservation. In the final chapter (Chapter 5) I synthesize the findings of chapters 2-4, identify future research priorities, suggest short- and long-term participatory interventions for the conservation of snow leopard habitat and discuss limitations of the work.

Illustration 1: An illustration of the outline of the thesis.

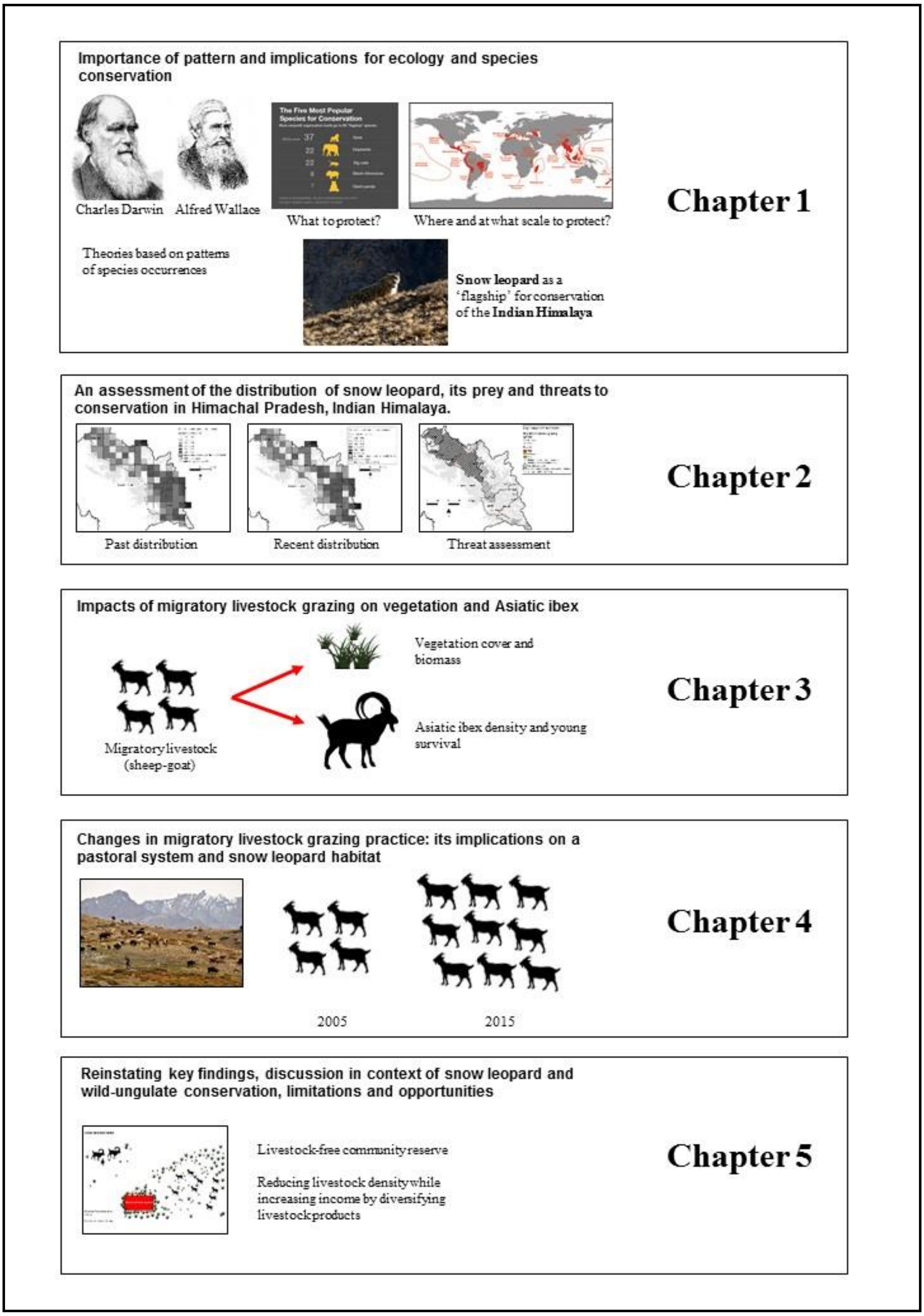

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Image 2: Majority of the study area is arid with 'steppe' vegetation, dotted by villages with agricultural fields. Nako and Malling villages, Hangrang Valley, Upper Kinnaur, Himachal Pradesh.

Image 3: The south-eastern and western parts of the study area had moister climate and forested areas. The Bhaba Valley, lower Kinnaur, has densely wooded tracts at lower altitudes, while alpine pastures above 3,000m altitude.

Image 4: Blue sheep is an important prey of snow leopard. Blue sheep use rolling pastures for foraging and use cliffs as escape terrain.

Image 5: Asiatic ibex is another primary prey of snow leopard. Ibex use rugged and steep areas and forage on pastures with cliffs in multiple directions. Ibex is more cliff-bound than blue sheep.

Image 6: Resident and migratory livestock grazing are important and widespread livelihood practice in the Greater and Trans-Himalaya. Here, livestock of a *Kinnaura* migratory shepherd is seen in Pin Valley National Park, Lahaul & Spiti, Himachal Pradesh.

Chapter 2

An assessment of the distribution of snow leopard, its prey and threats to conservation in Himachal Pradesh, Indian Himalaya

Abstract

Understanding species distributions, patterns of change and threats can form the basis for assessing conservation status of elusive, hard to sample species. Snow leopard (*Panthera uncia*) is the top-predator of the Central and South Asian mountains. Knowledge of distribution and status of this elusive Felid and its wild-prey is limited. Using recall-based key-informant interviews, site-use of snow leopards and their primary wild-prey, blue sheep (*Pseudois nayaur*) and Asiatic ibex (*Capra sibirica*) was estimated across two time periods (past: 1985-1992; recent: 2008-2012) in the state of Himachal Pradesh, India. A threats assessment for the recent period was also conducted. The probability of site-use was similar across the two time periods for snow leopard, blue sheep and ibex, while wild-prey (blue sheep and ibex combined) showed 8% contraction. Although the surveys were conducted in areas within the presumed distribution range of snow leopard, snow leopard was found to use only 75% of the area (14,616 km^2). Blue sheep and ibex had distinct distribution ranges. Snow leopard and wild-prey were not restricted to protected areas which covered only 17% of their distributions within the study area. Migratory livestock grazing was pervasive across ibex distribution range and was the most widespread and serious conservation threat. Depredation by free-ranging dog, along with illegal hunting and wildlife trade were the other severe threats. The results underscore the importance of community-based, landscape-scale conservation approaches and caution against reliance on geophysical and opinion-based distribution maps that have been used to estimate national and global snow leopard ranges.

Introduction

Distribution and habitats of several species have been severely affected by human activities and developmental pressures globally (Sanderson *et al.*, 2003). Large mammals, especially apex carnivores, are often considered to be 'umbrella' or 'flagship' species for ecosystem conservation (Simberloff, 1998). Large home ranges and habitat specificity tend to make large mammals vulnerable to drastic range contraction and extinction (Ceballos *et al.*, 2005; Michalski & Peres, 2005). Understanding threats to large mammals and determining their occurrences and changes in distribution are thus essential for conservation planning at large spatial scales (MacKenzie *et al.*, 2006; Karanth *et al.*, 2009; Taubmann *et al.*, 2016).

India experienced 194% increase in human population over the past six decades alongside rapid economic growth that have negatively affected mammal species and their habitats (Madhusudan & Mishra, 2003; Das *et al.* 2006; Singh & Bagchi, 2013). Studies at national and regional levels have reported declines in distribution ranges of certain common large mammalian species (Karanth *et al.*, 2009; Pillay *et al.*, 2011). In comparison to the large mammals of the Indian peninsula, the distribution and conservation status of the high altitude large mammalian assemblage have received little scientific attention (Gaston, Garson & Hunter, 1983; Mishra, Madhusudan & Datta, 2006). Reliable baseline information on distribution range is lacking even for charismatic and endangered species such as the snow leopard *Panthera uncia* and its primary prey blue sheep (*Pseudois nayaur*) and Asiatic ibex (*Capra sibirica*) in India (Lyngdoh *et al.*, 2014; Snow Leopard Network, 2014; Lovari *et al.*, 2013).

The endangered snow leopard is the top-predator and 'flagship' for conservation of the Indian Himalaya (SLN, 2014; Bhatnagar *et al.*, 2016). The Indian Greater and Trans-Himalaya form the southern limit of global snow leopard distribution range and constitute *ca.* 6% of the estimated global snow leopard range (SLWS, 2013). Amongst the five Indian states with snow leopards, Himachal Pradesh (HP) supports about one-fifth of the potential snow leopard habitat (area between 3,200m-5,200m altitude; PSL, 2008; SLN, 2014), corresponding to *ca.* 20,000 km^2. Within HP, a large, contiguous patch of potential snow leopard habitat is constituted by the four regions of Kinnaur (4,454 km^2 of area between 3,200m – 5,200m), Lahaul (4,653 km^2), Spiti (4,328 km^2) and Pangi (1,181 km^2). This region (14,616 km^2) constitutes 73% of the potential snow leopard habitat in HP. Since the 1980s, considerable socio-economic changes have occurred in these four regions owing to the advent and spread of cash crops (e.g. green pea in Spiti and Lahaul; apple in Kinnaur and Spiti) (Mishra, 2001; Rana *et al.*, 2011; Basannagari & Kala, 2013). Increased road connectivity along international borders led to a rise in infrastructure projects and unregulated tourism, especially since 1992 when Kinnaur and Spiti were opened to Indian and foreign tourists (SLN, 2014).

An updated threats assessment was conducted along with evaluating changes in the distribution of snow leopard, blue sheep and ibex in these regions over the past two decades. Multi-season occupancy modelling (MacKenzie *et al.*, 2006) was used on detection / non-detection data collected by interviewing local people and corrected for imperfect detection across two time periods (Karanth *et al.*, 2009; Pillay *et al.*, 2011; Taubmann *et al.*, 2016), past (1985-1992) and recent (2008-2012). This method allows collection of data from past and recent time periods based on recall of key informants.

Multiple respondents from a sampling unit can be treated as replicate surveys for the primary sampling seasons, that can be used to account for imperfect detection. Thus, sampling difficult-to-detect species across a large area and multiple time periods is possible using this method. Distribution maps of snow leopard, blue sheep and ibex are presented for the two time periods using appropriate covariates. The implications of the findings are discussed in the context of snow leopard conservation initiatives at the state, national and global levels.

Materials & methods

Study area

An area of 14,616 km^2 between 3,200m-5,200m altitude (potential snow leopard habitat, SLN, 2014) covering the contiguous potential snow leopard habitat across the Greater and Trans-Himalaya Mountains in Himachal Pradesh constituted the study area (Figure 1.1). The vegetation in Trans-Himalaya is largely dry alpine steppe (Champion & Seth, 1968), with gentle-rolling uplands, interspersed with steep cliffs and rocky outcrops. The terrain is rugged with cliffs and sharp ridgelines interspersed with alpine and sub-alpine tracts in the Greater Himalaya. The south-eastern and north-western extremities of the study area were characterized by relatively moist climate and forested tracts. The entire region represents Palaearctic conditions, annual temperature ranges between *ca*. - 40°C during winter to *ca.* 35°C in summer. The region is drained by three major rivers, the Sutlej in Kinnaur District, the Spiti in Spiti sub-division and part of northern Kinnaur, and the Chandra-Bhaga or Chenab in Lahaul and Pangi sub-divisions.

Owing to the difficult terrain, limited plant productivity and extreme climate, the local agro-pastoralist communities inhabit the landscape at low densities (1 individual/km^2 in Lahaul & Spiti; 13 individuals/km^2 in Kinnaur; 11 individuals/km^2 in Pangi). Kinnaur, Lahaul and Pangi are inhabited primarily by followers of Hindu religion, with Buddhists inhabiting only the uppermost villages; while Spiti is inhabited primarily by Buddhists. Their traditional dependence on natural resources for food (including wildlife), fuel, livestock grazing (sheep-goat, cattle, yak, yak-cattle hybrid), fodder, construction material and medicinal plants is widespread and varies across the landscape (Mishra, 2001). The regional economy has shifted from a subsistence and barter-based system to being cash-based and market-driven (Mishra, 2000; Bhatnagar & Singh, 2011). The advent of green-pea (*Pisum sativum*) as cash-crop from 1985 onward and the opening up of Kinnaur District and Spiti sub-division to tourists in 1992 have accelerated these changes.

Development and agricultural intensification are increasing job opportunities, attracting non-native labourers to the landscape. Additionally, migratory herders from Shimla, Kangra and Chamba districts graze livestock in the high-altitude pastures across most of the study area during summer (June-August).

Carnivores in the study area include snow leopard, wolf (*Canis lupus*) and brown bear (*Ursus arctos*) in areas above 3,000m altitude, while common leopard (*Panthera pardus*) and Himalayan black bear (*Ursus thibetanus*) occur in areas below 3,000m altitude (Jayapal & Ramesh, 2010; Mishra *et al.*, 2010). Among wild-herbivores, Himalayan tahr (*Hemitragus jemlahicus*), Himalayan serow (*Capricornis thar*), musk deer (*Moschus leucogaster*) and

Himalayan goral (*Naemorhedus goral*) are found in the Greater Himalaya, while blue sheep and Asiatic ibex are found in both Greater and Trans-Himalaya.

Survey design & data collection

Key-informant interviews were used with structured questionnaire to document occurrences of snow leopard and prey for two time periods: 1985-1992 and 2008-2012 (following Pillay *et al.*, 2011 and Taubmann *et al.*, 2016). The survey was carried out during summer season (June-September) of 2012. The entire study area was divided into 88 grid cells (sites) of 15km x 15km (area 225 km^2) each, the area being similar to estimated mean home-range size of snow leopard (Johansson *et al.*, 2016).

The questionnaire (Supplementary material S1) contained two broad sections. The first dealt with information related to the attributes of the respondents that might have affected reliable detection of the study species (Table 1.1). The second section contained questions regarding detections of the study species for the two time periods, the locations, year and month of the detections.

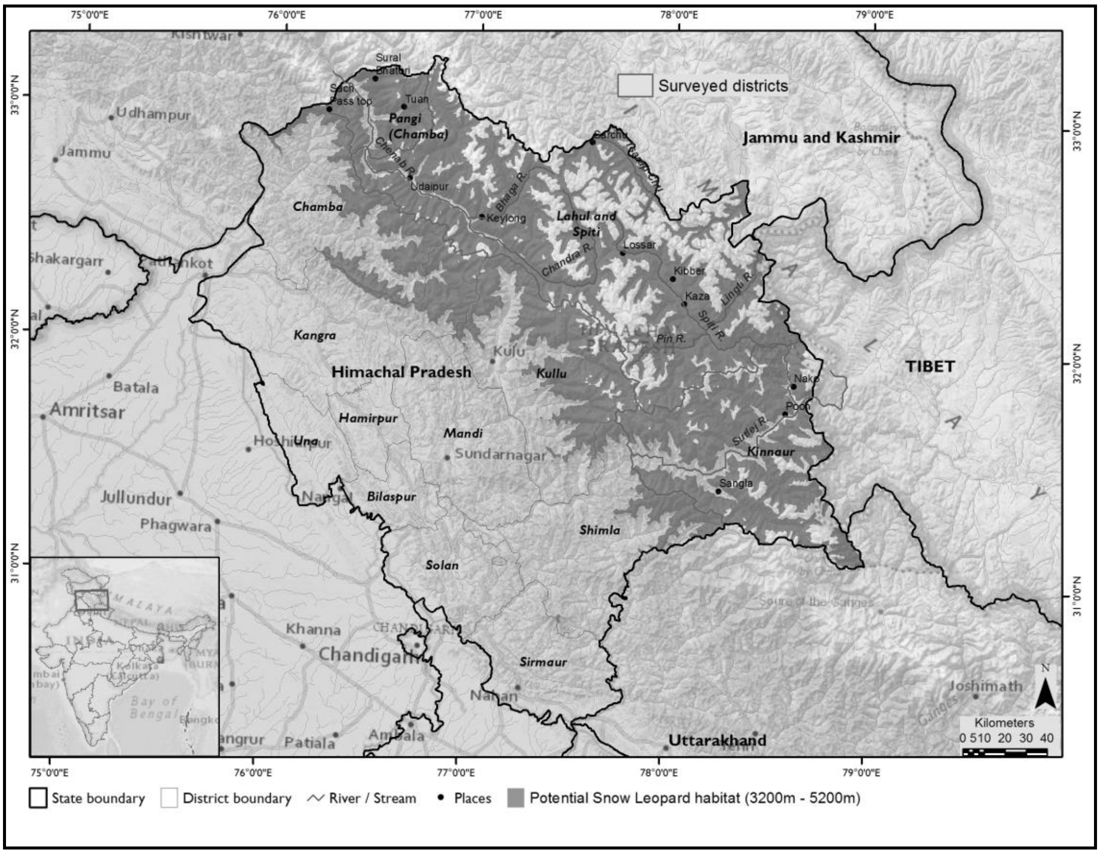

Figure 1.1: The study area in Himachal Pradesh, India, including Kinnaur, Lahaul & Spiti and Pangi sub-division of Chamba District. The shaded region denotes altitude range 3,200m-5,200m, the potential snow leopard habitat in Himachal Pradesh.

Upon reaching a village, two or three people (focus group) were identified with thorough knowledge of the concerned grid cell. With their help, resource maps were prepared (Suryawanshi *et al.*, 2013) with approximate locations of settlements, agricultural areas, pastures, seasonal use of pastures, number of livestock and areas used for biomass extraction. This information was transferred on printed maps of the area. During this exercise, species detection/non-detection were not documented, as the reports of one person could be influenced by another in such a group. These respondents and others were later interviewed individually only by AG, specifically about detection/non-detection of snow leopard and prey. The resource mapping helped plot detection locations on a map. The broad categories of respondents interviewed included herder, active and former hunter, cattle attendant, medicinal plant collector, forest department official, staff and contractual worker, military personnel, tourist guide, porter and photographers. Key-informants were shown images of study species mixed with images of numerous other carnivore and mountain ungulate species, such as, Tibetan wolf, brown bear, common leopard, Asiatic black bear, Himalayan tahr, Himalayan serow, musk deer, Himalayan goral, Kashmir stag or Hangul *Cervus elaphus hangul*, Markhor *Capra falconeri*, Kiang *Equus kiang*, Tibetan gazelle *Procapra picticaudata*, Tibetan argali *Ovis ammon hodgsoni*, wild yak *Bos mutus* and Ladakh urial *Ovis vignei*. Respondents failing to identify study species from the images were dropped from the analyses. Additionally, respondents were asked to provide location, year and month of sighting. Respondents unable to provide reliable information on location of species detection were also dropped. The identity of the respondents has been kept confidential.

Conservation threats to snow leopard and wild-prey in Kinnaur, Lahaul and Spiti and Pangi were identified based on discussion with the focus groups and personal observations. The threats were ranked based on area of spread, intensity and urgency following Margoluis & Salafsky (2001). For a particular threat in a region, score of 1 represented low, while 14 represented severe threat. Thus, total ranking of a threat (sum of scores for area, intensity and urgency) in a region ranged from three to 42. A total ranking of 3-14 represented low threat (light grey), 15-28 medium threat (grey) and 29-42 severe threat (dark grey).

Table 1.1: Site and survey covariates used in the occupancy analyses to assess changes in distribution of snow leopard and wild prey across two time periods in the Greater and Trans-Himalaya of Himachal Pradesh.

Site covariates	Description	Variable type	Expected relationship with site use and detection probability
Altitude	Mean altitude	Continuous	Positive correlation with site use of study species upto about 5,200m amsl
Ruggedness	Terrain Ruggedness Index	Continuous	Positive correlation with site use of study species
NDVI	Mean NDVI	Continuous	Positive correlation with site use of blue sheep and ibex
Migratory livestock grazing	Presence or absence of migratory livestock grazing	Binary	Negative correlation with site use of blue sheep and ibex
Livestock population	Number of sheep-goat	Continuous	Negative correlation with site use of blue sheep and ibex
Survey covariates			
Active	Whether respondent was active or not during the primary sampling periods	Binary	Active respondents are more likely to encounter study species
Time spent	Number of months for which the respondent is active in the area of knowledge	Continuous	Respondents spending more time in area of knowledge are more likely to detect study species
Familiarity	Number of years for which a respondent is familiar with the area of knowledge	Continuous	Respondents with higher familiarity are more likely to detect study species
Age	For each respondent in years	Continuous	Mixed effect on encounter of study species
Profession	Categorical variable representing sedentary, semi-outdoor work and outdoor work	Categorical	Respondents with outdoor work are more likely to detect study species

Data analyses

To define the past time period, two landmark events were chosen, the introduction of green-pea in Lahaul & Spiti in 1985, and opening up of Kinnaur and Spiti to tourists in 1992. The recent time period was defined as being the five-year period ending with the survey (2008-2012). Since five years is a considerably long period to assume population closure within sampled units, the occupancy estimates were considered to reflect the probability of the sites being used by the study species in the respective time periods. This interpretation of the conventional occupancy estimate as the probability of site-use allows for changes within the sampling units and relaxation of closure assumption (MacKenzie *et al.* 2006; Taubmann *et al.*, 2016). This design assumes that the changes in probability of site-use within each sampling unit during each sampling period were random and described by the specific covariates applied. Probability of colonization (γ) was estimated as the probability of a site being used by a species during the recent time period that was not used during the past time period, while probability of extinction (ε) was estimated as the probability of a site not being used by a species during the recent time period that was used during the past time period (MacKenzie *et al.*, 2003). The probabilities of local colonization and local extinction can be interpreted as probability of distribution expansion and contraction of species, respectively, between the two primary periods.

Data on reports of snow leopard, blue sheep and ibex sightings generated through interviews were arranged in a detection/non-detection (1/0) framework for past and recent time periods. Each interviewee's report from a particular site was assigned as a replicate survey within the site. Site-covariates that could influence probability of site-use by a species were modelled using logistic insertions (Table 1.1). Topographic covariates such as mean altitude above mean sea level and proportion of rugged area in a site (terrain ruggedness index) and proportion of vegetated area in a site (Normalized Difference Vegetation Index) were generated using Shuttle Radar Topographic Mission (SRTM) and Landsat data, respectively. Since snow leopards are known to occur between 3,200m (above tree-line) to 5,200m (approximate lower limit of permafrost and limit of vegetation growth) in the Himalaya (PSL, 2008; SLN, 2014), mean altitude and its square were used to model probability of site-use as a linear and quadratic function of altitude. The probability of site-use was expected to be higher in sites with greater proportion of terrain ruggedness (SLN, 2014; McCarthy & Mallon, 2016). A higher proportion of vegetated area was expected to favor wild-prey distribution. The presence of migratory livestock grazing reflected areas which were used for grazing only during the peak summer (mid-June – mid-August) and were far from villages, hence not grazed by local livestock. Presence of migratory livestock grazing was expected to lower probability of site-use of wild-prey. Population of livestock represented number of sheep-goat in a site and was expected to negatively influence the probability of site-use by wild-prey. If the confidence interval (CI) of the coefficient of a variable included zero, the variable was interpreted to have a statistically non-significant association.

Covariates that might have influenced the probability of detection of a species and its reporting to the researcher were used as survey covariates to model detection probability (Table 1.1). These included respondent age, profession, duration (in years) of familiarity with the area of knowledge, duration of time spent annually in the area of knowledge and a binary variable defining whether active or not in each time period.

The probability of site-use and detection probability were modelled through single-species multi-season models for snow leopard, blue sheep and ibex using the program PRESENCE 10.9 (MacKenzie *et al.*, 2003; Hines, 2006). The models were parameterized to empirically estimate historic and recent probabilities of site-use and probability of distribution expansion. Estimates of probabilities of distribution contraction were derived. Models were ranked in ascending order based on the Akaike's Information Criterion (AIC, Akaike, 1973; Burnham & Anderson, 2002).

The analyses yielded multiple models with similar AICs, thus indicating that no one model, by itself, could explain the observed variation in the data adequately. Thus, following multi-model inference approach (Burnham & Anderson, 2002) a set of models were considered with a cumulative Akaike weight of ≥ 0.95 to yield the best approximating model by using model averaging (Burnham & Anderson, 2002; Symonds & Moussalli, 2011). Models that did not converge were dropped from the model set before model averaging. The model averaged estimates of past and current site use probability were plotted to develop probabilistic maps of past and recent distributions of snow leopard and wild-prey.

Results

A total of 351 systematic key-informant interviews were carried out across Kinnaur, Lahaul, Spiti and Pangi. For analyses, 349 key-informant interviews were used after dropping two respondents with unreliable information. Respondents reported snow leopard and wild-prey detection / non-detection from a mean of 2 grids per respondent (range: 1-7). The mean number of respondents per grid for snow leopard was 6.64 (range: 1-30; SD = 4.70), while that of wild prey was 7.60 (range: 1-33; SD = 5.34). The number of detections of each species and number of respondents per species for the two time periods is summarized in Table 1.2. The analyses resulted in 31 competing single-species multi-season occupancy models for snow leopard, 35 for wild-prey together, 37 for blue sheep and 33 for ibex (Supplementary table S3).

Table 1.2: Detections and number of respondents reporting detections of snow leopard, wild-prey (cumulative detections of blue sheep and ibex), blue sheep and ibex in the Greater and Trans-Himalaya of Himachal Pradesh.

		Past	Recent
Detections	Snow leopard	54	110
	Wild-prey	330	351
	Blue sheep	51	144
	Ibex	55	214
Number of respondents	Snow leopard	24	30
	Wild-prey	27	33
	Blue sheep	27	33
	Ibex	27	33

Naïve estimates of proportion of sites used by snow leopard for the past and recent time periods were 0.37 and 0.49, respectively. Naïve estimates of proportion of sites used by wild-prey for the past and recent time periods were 0.87 and 0.80, respectively. When analyzed individually, naïve estimates of proportion of sites used by blue sheep for the past and recent time periods were 0.26 and 0.34, respectively, and that of ibex for the past and recent time periods were 0.34 and 0.52, respectively.

Detection probability

Null models showed detection probability of snow leopard, wild-prey, blue sheep and ibex to be 0.24 ± SE 0.02, 0.62 ± SE 0.015, 0.38 ± SE 0.02 and 0.39 ± SE 0.02, respectively. When modelled with survey covariates, detection probability of snow leopard, wild-prey, blue sheep and ibex varied between the past (1985-1992) and recent (2008-2012) time periods (Table 1.3). Age of the respondent showed a weak negative effect on snow leopard, blue sheep and wild-prey detections. Familiarity of area of knowledge was an important factor for ibex detection. Time spent each year by a respondent in area of survey had little effect on detection probability. Profession of a respondent had a positive effect on detection probability of all species.

Snow leopard site-use, distribution expansion and contraction

Model averaged estimate of probability of site-use of snow leopard for the past time period was 0.74 (SD = 0.10) and for recent time period was 0.75 (SD = 0.10) (Figure 1.2a & 1.2b). Probability of site-use for past time period ranged between 0.47 (± SE 0.30) - 0.92 (± SE 0.11), while for recent time period ranged between 0.48 (± SE 0.71) - 0.92 (± SE 0.10). Probability of site-use by snow leopard showed weak positive correlation with terrain ruggedness index (β_{tri} = 0.89 ± SE 0.52; CI -0.14 – 1.90) and altitude ($\beta_{alt.mean}$ = 0.73 ± SE 0.73; CI -0.70 – 2.16) (Table 1.3), however the coefficients were not statistically significant.

In the 75% of the area used by snow leopards, the probability of site-use by snow leopards was relatively high (> 0.50). Relatively higher probability of site-use (> 0.70) was found in Spiti and majority of Kinnaur. Central and western Lahaul and Pangi showed relatively low probabilities of site-use by snow leopard (Figure 1.2a & 1.2b).

There was no clear evidence for distribution expansion of snow leopard ($\gamma = 0.31 \pm$ SE 0.24; CI -2.63 – 1.13). Estimated probability of distribution contraction of snow leopard was 0.04 (SD = 0.05), indicating no clear evidence for overall contraction, and ranged between 0.03 (± SE 0.04) – 0.41 (± SE 0.97) (Supplementary Figure S4).

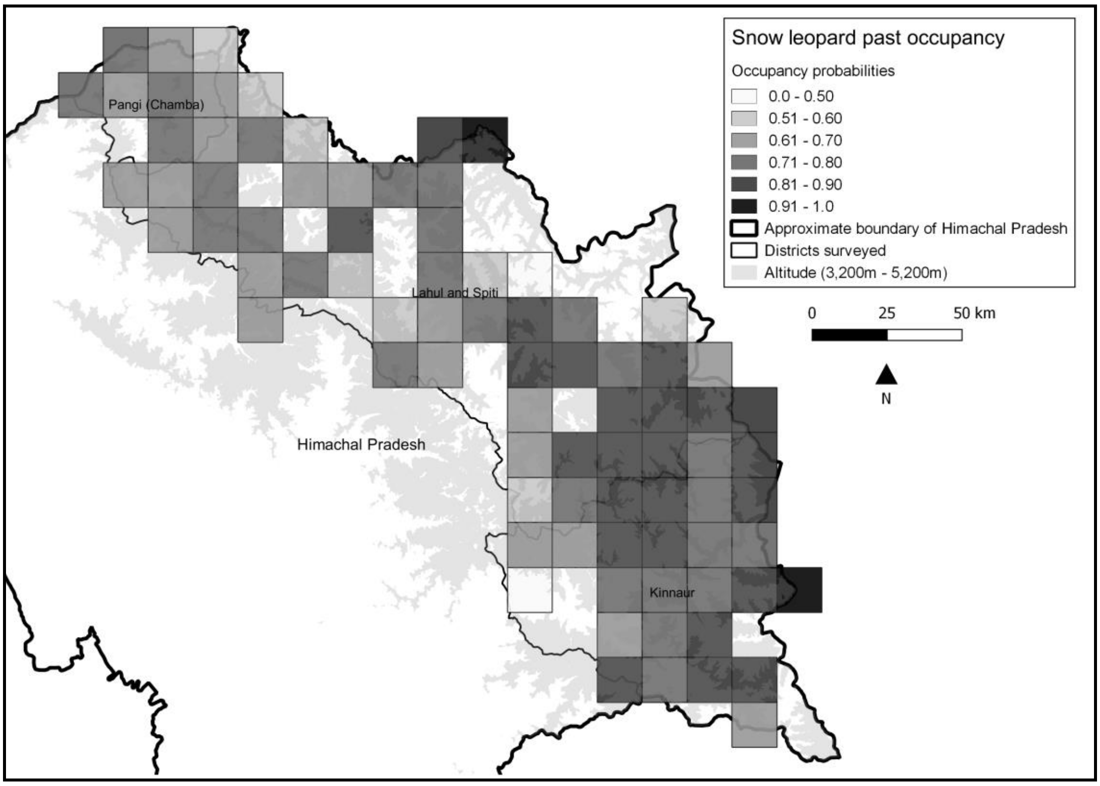

Figure 1.2a: Past probability of site-use by snow leopard across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

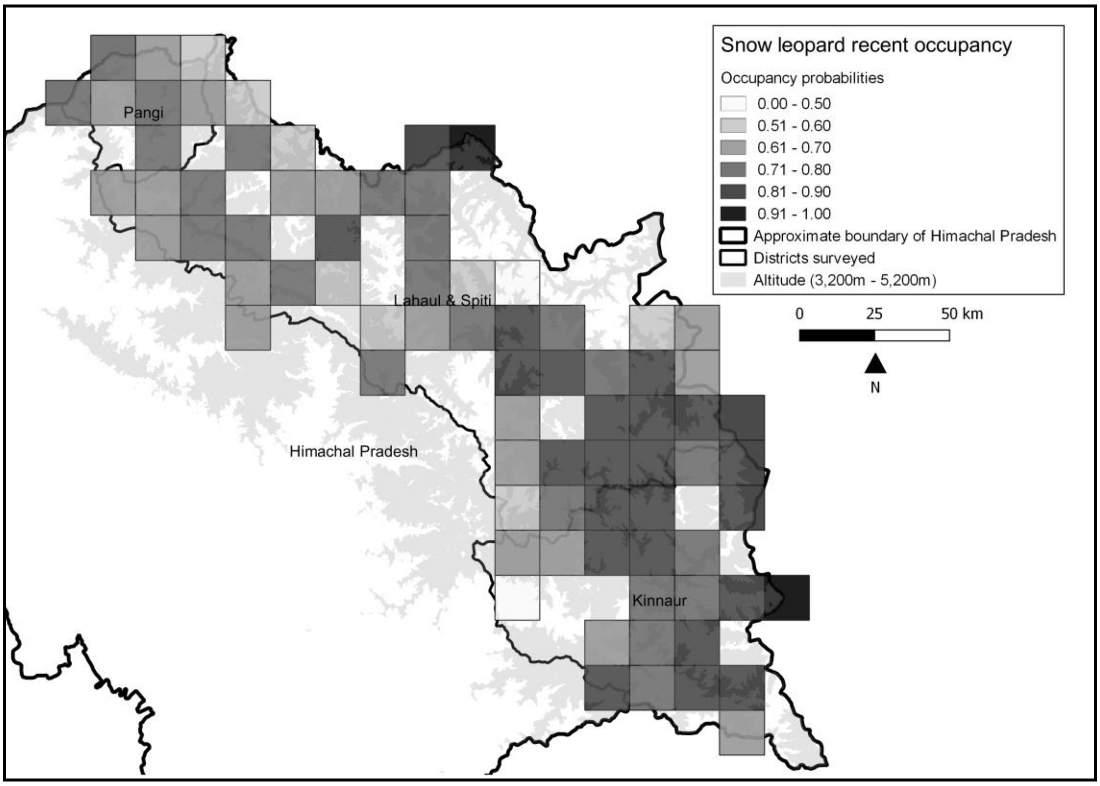

Figure 1.2b: Recent probability of site-use by snow leopard across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

Table 1.3: Untransformed estimates of coefficients (β) and standard errors (SE) from top-most models of snow leopard, wild-prey, blue sheep and ibex model sets given the respective model sets. *

	Snow leopard		Blue sheep		Ibex		Wild prey	
	β	β_SE	β	β_SE	β	β_SE	β	β_SE
Intercept (ψ)_psi1	1.27	0.42	0.97	0.42	-0.77	0.32	3.44	0.66
Intercept (ψ)_psi2	1.27	0.42	0.97	0.42	-0.77	0.32	2.26	0.46
Altitude	0.73	0.73	-0.36	0.34	-	-	-1.13	0.52
Altitude_squared	-	-	-	-	-	-	-0.49	0.19
Migratory livestock grazing	-	-	-2.67	0.61	4.26	1.01	-	-
Ruggedness	0.89	0.52	-	-	-	-	-	-
Intercept (γ)	-0.75	0.96	-3.54	0.98	-1.53	0.52	-1.39	1.29
Intercept (*p1*)	-2.59	0.26	-1.89	0.23	-1.30	0.16	0.54	0.13
Intercept (*p2*)	0.58	0.21	1.21	0.21	1.21	0.19	-0.52	0.13
Age	-0.06	0.02	-0.06	0.01	-	-	-0.03	0.01
Familiarity	0.04	0.02	-	-	-0.05	0.01	0.01	0.01
Time spent	0.02	0.01	-	-	-	-	-	-
Prof1	1.30	0.27	0.32	0.29	-	-	0.28	0.17
Prof2	1.36	0.25	1.12	0.23	-	-	0.39	0.14

* Ψ – Probability of site-use; γ – probability of distribution expansion; *P* – probability of detection; psi1 – past probability of site-use and psi2 – recent probability of site-use. Site covariates: altitude – mean of altitude in a site; altitude_squared – square of mean altitude; Ruggedness – proportion of rugged area in a site derived from terrain ruggedness index (TRI); Migratory livestock grazing – presence (1) / absence (0) of migratory livestock grazing in a site; Age - age of a respondent in years; Familiarity – years or months for which a respondent is familiar of the area of knowledge; Time spent - time spent in months or days by a respondent in area of knowledge per year; Prof1 - sedentary profession (e.g. office worker), and Prof2 - sedentary and outdoor profession (e.g. forest guard).

Wild-prey site-use, distribution expansion and contraction

Model averaged estimate of probability of site-use of wild-prey for past time period was 0.94 (SD = 0.04) and for recent time period was 0.86 (SD = 0.08) (Figure 1.3a & 1.3b). Probability of site-use for past time period ranged between 0.80 (± SE 0.27) - 0.98 (± SE 0.02), while for recent time period ranged between 0.59 (± SE 0.66) - 0.94 (± SE 0.07). Probability of site-use by wild-prey varied as a quadratic function of altitude ($\beta_{alt.mean}$ = -1.13 ± SE 0.53, CI -2.15 - -0.11; $\beta_{alt.sq}$ = -0.49 ± SE 0.19; CI -0.86 - -0.12), and increased with ruggedness (β_{tri} = 0.70 ± SE 0.35; CI 0.01 – 1.39). Probability of site-use by wild-prey did not show a clear relationship with proportion of vegetated area (NDVI) (β_{ndvi} = -0.26 ± SE 0.43; CI -1.10 – 0.58) and presence/absence of migratory livestock grazing (β_{migrh} = -0.12 ± SE 0.67; CI -1.44 – 1.30) (Table 1.3).

Probability of site-use by wild-prey was high (> 0.50) in most of the study area. Central Lahaul, parts of northern Spiti and parts of Kinnaur (especially area along Sutlej river valley) showed relatively lower probabilities of site-use by wild prey (< 0.50) (Figure 1.3a & 1.3b).

There was no clear evidence for distribution expansion of wild-prey (γ = 0.22 ± SE 0.30; CI -3.51 – 1.14). Estimated probability of distribution contraction of wild-prey was 0.20 (SD = 0.17) (Supplementary Figure S4), indicating evidence for marginal overall distribution contraction and ranged between 0.04 (± SE 0.03) – 0.32 (± SE 0.21). Probability of distribution contraction of wild-prey was relatively high (ε > 0.20) in 11% of the sites. These areas were found in western Lahaul, northern and eastern Spiti, south-western Spiti and Kinnaur, respectively (Supplementary Figure S4).

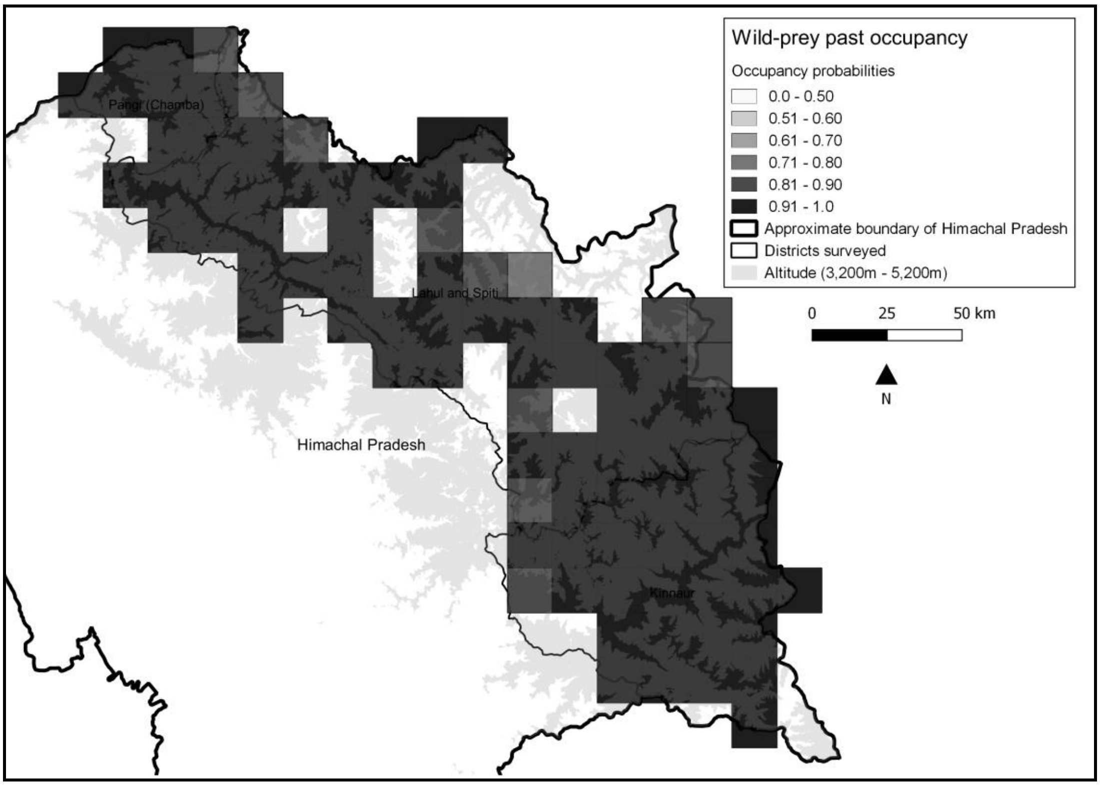

Figure 1.3a: Past probability of site-use by wild-prey across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

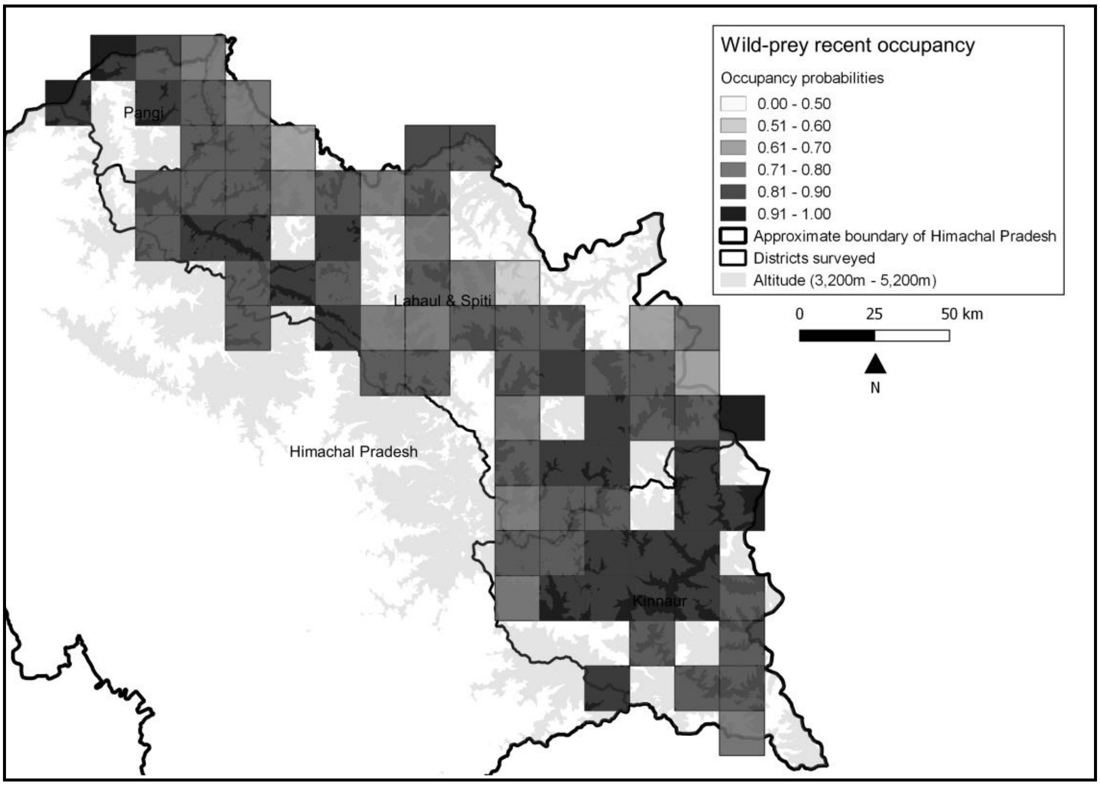

Figure 1.3b: Recent probability of site-use by wild-prey across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

Blue sheep site-use, distribution expansion and contraction

When analysed separately, model averaged estimate of probability of site-use of blue sheep for past time period was 0.42 (SD = 0.28) and for recent time period was 0.41 (SD = 0.28) (Figure 1.4a & 1.4b). Probability of site-use for past time period ranged between 0.12 (± SE 0.07) - 0.87 (± SE 0.12), while for recent time period ranged between 0.11 (± SE 0.06) - 0.86 (± SE 0.13). Probability of site-use by blue sheep showed a negative correlation with migratory livestock grazing (β_{migrh} = -2.67 ± SE 0.61; CI -3.87 - -1.47) (Table 1.3). There were no clear relationships between probability of site-use by blue sheep and altitude ($\beta_{alt.mean}$ = -0.36 ± SE 0.34; CI -1.02 – 0.30) and ruggedness (β_{tri} = 0.03 ± SE 0.53; CI -1.02 – 1.06), respectively (Table 1.3).

High probability of site-use (> 0.50) by blue-sheep was estimated in majority of Spiti and Kinnaur. South-western Spiti, entire Lahaul and Pangi showed low probabilities of site-use (< 0.50) for blue sheep (Figure 1.4a & 1.4b).

There was no clear evidence of probability of distribution expansion for blue sheep (γ = 0.03 ± SE 0.03; CI -0.03 – 0.09). Estimated probability of distribution contraction of blue sheep was 0.01 (SD = 0.05), indicating no clear evidence for overall contraction and ranged between 0.01 (± SE 0.03) – 0.21 (± SE 0.22) (Supplementary Figure S4).

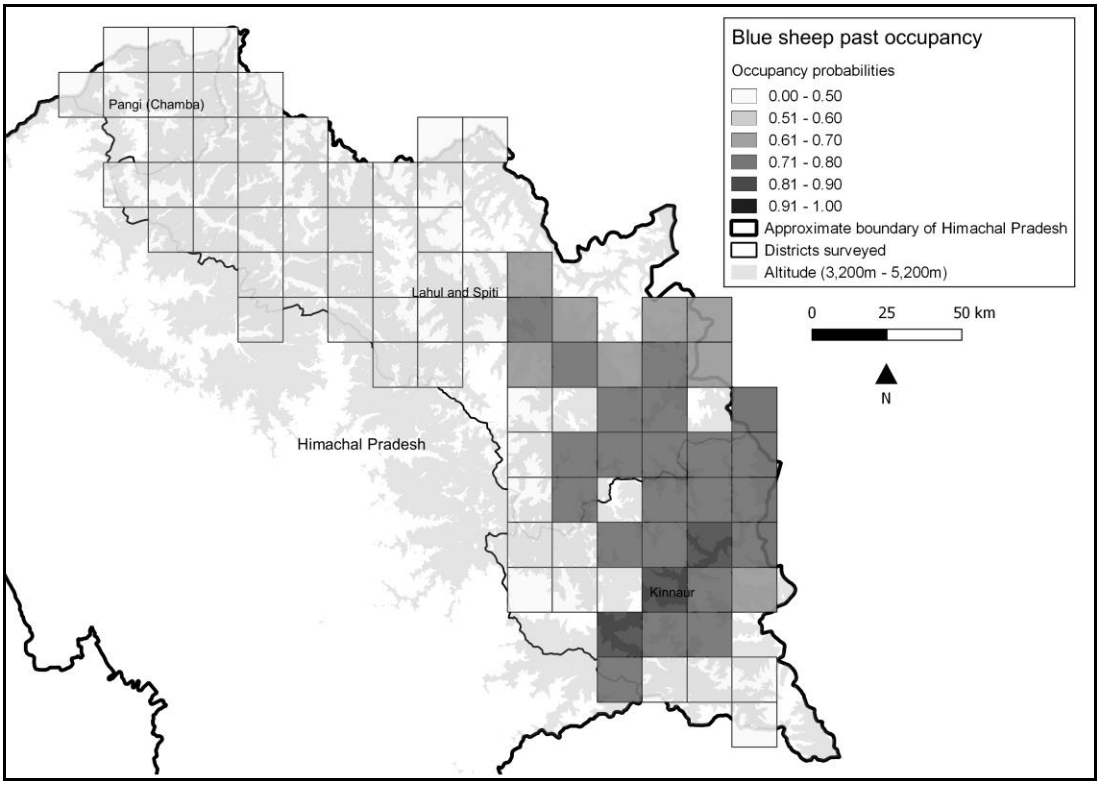

Figure 1.4a: Past probability of site-use by blue sheep across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

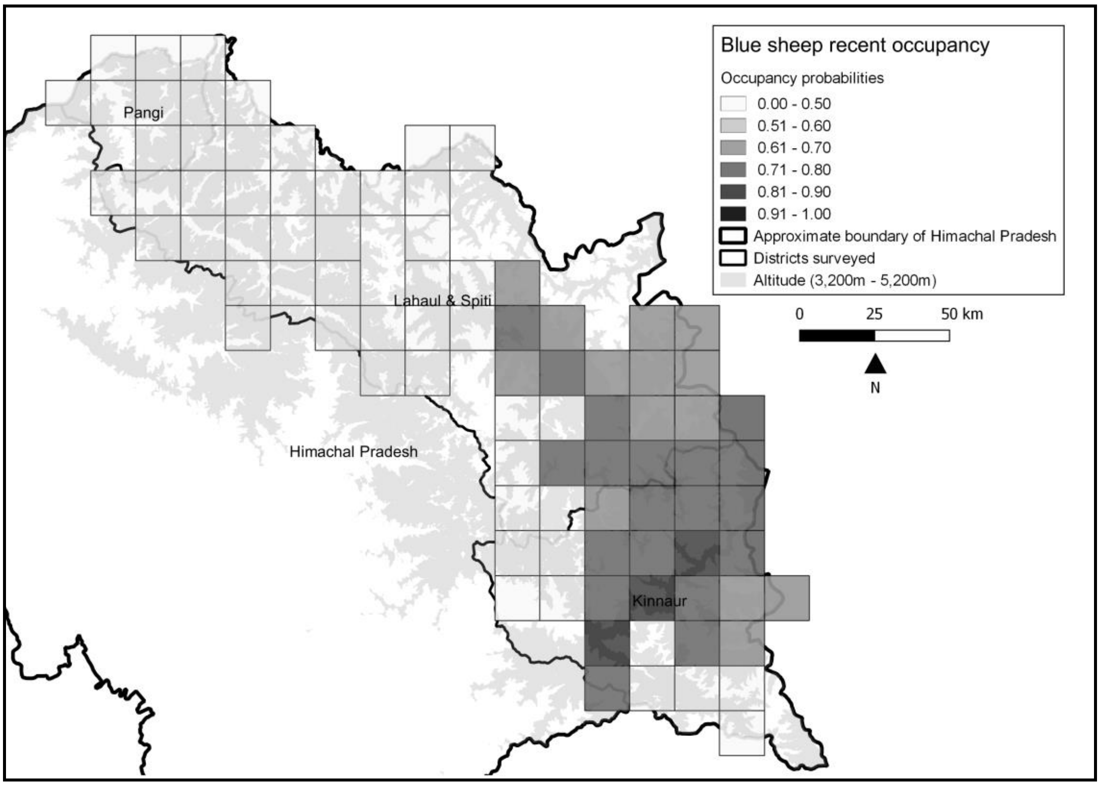

Figure 1.4b: Recent probability of site-use by blue sheep across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

Asiatic ibex site-use, distribution expansion and contraction

Estimated probability of site-use of ibex was same for past and recent time periods (ψ = 0.61; SD = 0.28) (Figure 1.5a & 1.5b). Probability of site-use for both past and recent time periods ranged between 0.30 (± SE 0.08) - 0.97 (± SE 0.03). Ibex site-use probability showed a positive correlation with migratory livestock grazing (β_{migrh} = 4.26 ± SE 1.01; CI 2.28 – 6.24) (Table 1.3). Relationship between ibex site-use and mean altitude was unclear ($\beta_{alt.mean}$ = -0.20 ± SE 0.31; CI -0.81 – 0.41) (Table 1.3).

High probability of site-use (> 0.50) by ibex was found in Lahaul, Pangi and in south – western parts of Spiti and Kinnaur, respectively. Central, south and eastern Spiti and northern, eastern and south-eastern Kinnaur showed low probabilities of site-use (< 0.50) by ibex (Figure 1.5a & 1.5b).

There was no clear evidence for distribution expansion for ibex across the study area (γ = 0.18 ± SE 0.10; CI -0.02 – 0.38). Estimated probability of distribution contraction of ibex was 0.003 (SD = 0.04), indicating no clear evidence for overall contraction and ranged between 0.006 (± SE 0.006) – 0.44 (± SE 0.26) (Supplementary Figure S4).

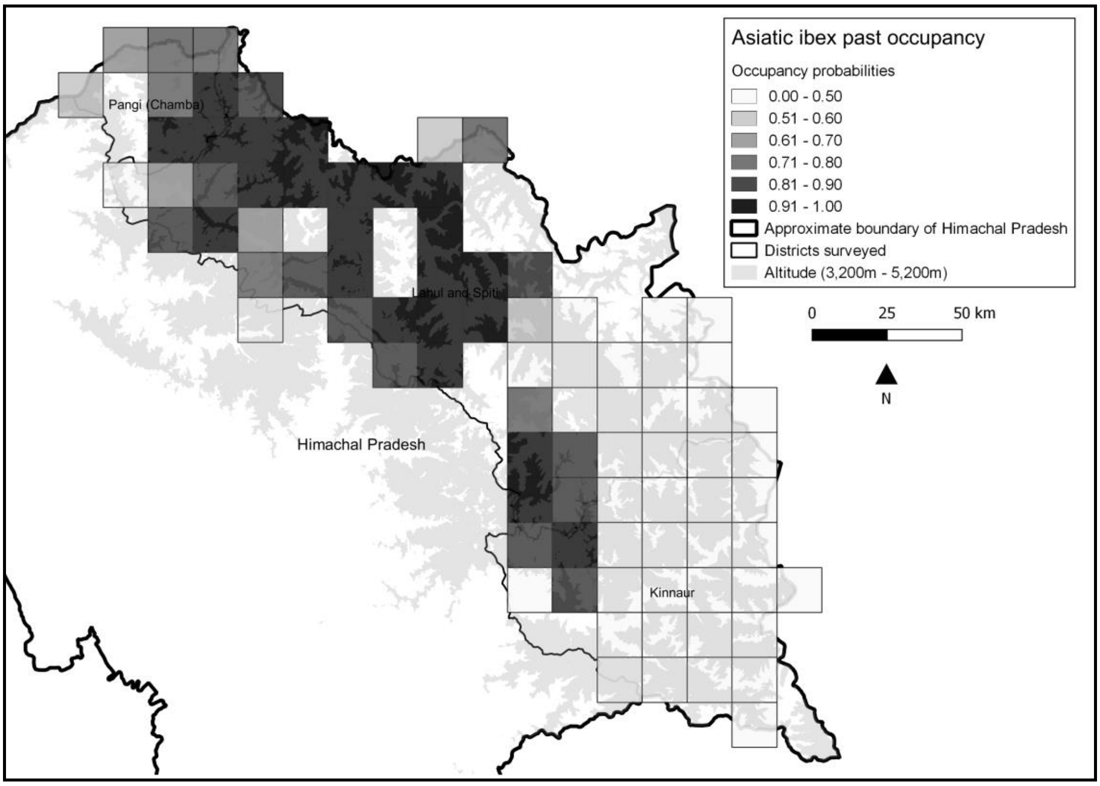

Figure 1.5a: Past probability of site-use by Asiatic ibex across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

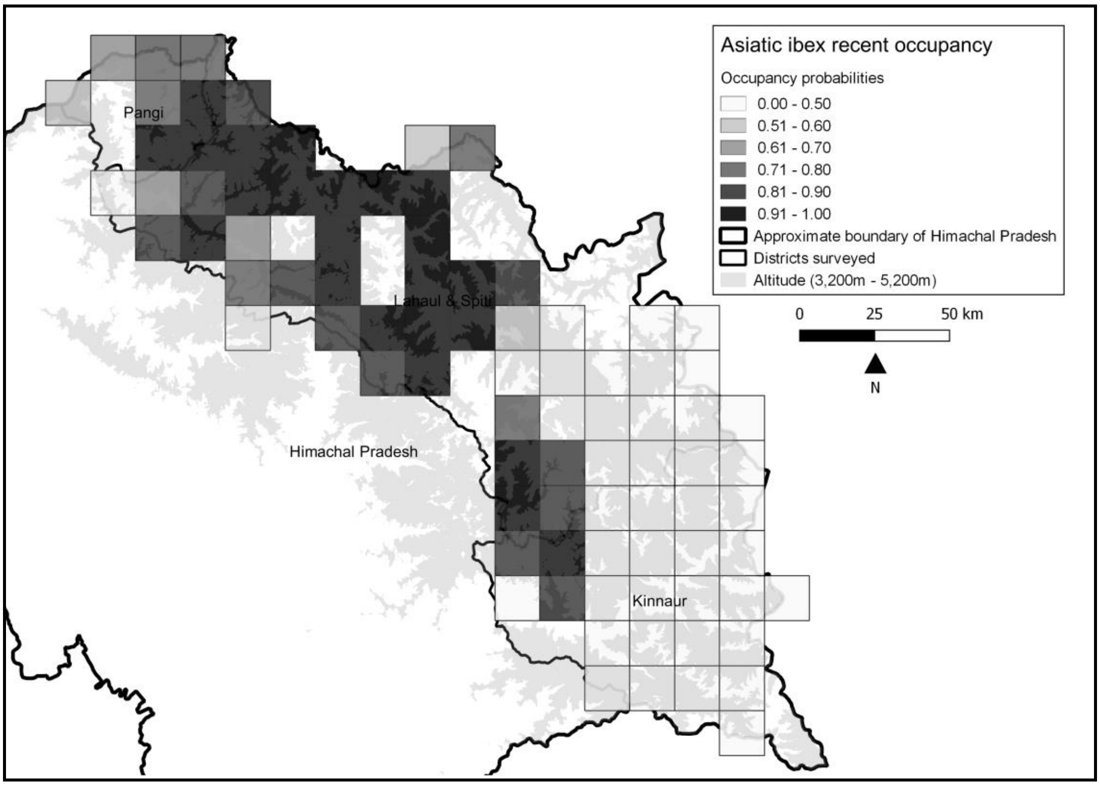

Figure 1.5b: Recent probability of site-use by Asiatic ibex across the Greater and Trans-Himalaya mountains of Kinnaur, Lahaul & Spiti and Pangi, Himachal Pradesh, India.

Conservation threats

Threats assessment (Table 1.4 & Supplementary Figure S2) suggested prey reduction due to competition with local livestock, prey reduction due to competition with migratory livestock, prey reduction due to subsistence hunting by local community, illegal hunting & wildlife trade by local community, illegal hunting & wildlife trade by immigrant laborer & migratory community and depredation of wildlife and livestock by free-ranging dogs to be severe the threats across the study area.

In Kinnaur, prey reduction due to competition with local livestock, prey reduction due to subsistence hunting by local community, illegal hunting & wildlife trade by immigrant laborer & migratory community and depredation by dogs were identified as severe threats. Local livestock grazing was practiced in and around villages all across Kinnaur, while migratory livestock grazing was prevalent in south-eastern and south-western Kinnaur (Supplementary Figure S2). Southern and south-western Kinnaur also experienced hunting and wildlife trade by local and migratory herder communities and immigrant labourers. The issue of depredation of wildlife and livestock by free-ranging dog was found to be widespread.

In Spiti, prey reduction due to competition with local and migratory livestock and depredation by dogs were severe threats. Local livestock grazing was widespread in Spiti, except a few villages in eastern Spiti on the left bank of Spiti River. Migratory livestock grazing was prevalent in north-western, western and south-western Spiti (Supplementary Figure S2). Depredation on wildlife and livestock by free-ranging dogs is an emerging conservation threat in Spiti.

Table 1.4: Threat ranking based on area, intensity and urgency following Margoluis & Salafsky (2001) for Kinnaur, Lahaul, Spiti and Pangi, Himachal Pradesh, India. Threat ranking values: 1 = low threat to 14 = severe threat level. Area: how widespread a threat is? Is it present across large areas or limited to a few portions (1 = least widespread; and 14 = most widespread); intensity: how serious/severe is a threat (1 = low intensity; 14 = severe intensity); urgency: immediacy of a threat. How immediate/urgent is the threat (1 = least urgent; and 14 = most urgent). Color shades: light grey – low threat, grey – medium threat level and dark grey – severe threat level.

Threat categories & heads	**Kinnaur**				**Spiti**				**Lahaul**				**Pangi (Chamba)**			
	Area	Intensity	Urgency	Total ranking	Area	Intensity	Urgency	Total ranking	Area	Intensity	Urgency	Total ranking	Area	Intensity	Urgency	Total ranking
Livestock - wild prey interactions																
Prey reduction due to competition with local livestock	14	13	5	32	13	13	4	30	7	3	4	14	3	4	5	12
Prey reduction due to competition with migratory livestock	7	14	6	27	12	14	9	35	14	14	10	38	14	14	10	38
Prey reduction due to disease from livestock	1	2	3	6	5	6	3	14	2	2	2	6	5	3	4	9
People-wildlife interactions																
Retaliatory killing of snow leopard and wild-prey by local community	2	8	7	17	6	5	12	23	3	8	3	14	4	8	9	21
Prey reduction due to subsistence hunting by local community	13	9	8	30	3	2	10	15	8	9	9	26	9	11	12	32
Illegal hunting & wildlife trade by local community	6	10	13	29	4	4	11	19	10	10	13	33	10	12	13	35

Threat categories & heads	Kinnaur				Spiti				Lahaul				Pangi (Chamba)			
	Area	Intensity	Urgency	Total ranking	Area	Intensity	Urgency	Total ranking	Area	Intensity	Urgency	Total ranking	Area	Intensity	Urgency	Total ranking
Illegal hunting & wildlife trade by immigrant labourer & migratory community	12	11	14	37	7	8	13	28	12	13	14	39	12	13	14	39
Developmental activities																
Impacts of roads on snow leopard habitat	4	7	10	21	8	9	8	25	4	7	6	17	7	6	7	20
Impacts of hydro-electric projects on snow leopard habitat	5	6	11	22	2	1	6	9	9	5	11	25	6	5	6	17
Other human disturbances																
Fodder/fuel wood collection by local community	10	3	1	14	11	7	1	19	5	6	1	12	8	7	1	16
Medicinal plant collection by local & migratory communities & immigrant laborer	9	4	2	15	10	10	2	22	11	12	5	28	11	9	8	28
Illegal hunting by military personnel	3	5	9	17	1	3	5	9	1	1	8	10	1	1	3	5
Unregulated tourism (off-roading/camping/hiking in wilderness, garbage mismanagement)	8	1	4	13	9	11	7	27	6	4	7	17	2	2	2	6
Depredation of wildlife & livestock by free-ranging dogs	11	12	12	35	14	12	14	40	13	11	12	36	13	10	11	34

In Lahaul, prey reduction due to competition with migratory livestock, illegal hunting & wildlife trade by local community, illegal hunting & wildlife trade by immigrant laborer & migratory community and depredation by dogs were the severe threats. Migratory livestock grazing was pervasive in Lahaul at relatively high densities (Supplementary Figure S2). Migratory livestock grazed areas were also prone to illegal hunting by migratory herders and depredation on wildlife by dogs (migratory herders are accompanied by guard-dogs). Hunting was prevalent among local community of western Lahaul. Along major roadways in Lahaul immigrant labor camps were abundant and our respondents consistently reported laborer to be involved in illegal hunting of wildlife and trade.

In Pangi, prey reduction due to competition with migratory livestock, prey reduction due to subsistence hunting by local community, illegal hunting & wildlife trade by local community, illegal hunting & wildlife trade by immigrant laborer & migratory community and depredation by dogs were identified as the severe threats. Similar to Lahaul, migratory livestock grazing was widespread in Pangi and these areas experienced illegal hunting and depredation of wildlife by free-ranging dogs. Hunting for subsistence and wildlife trade was prevalent in Pangi, not only by the local community but also immigrant laborers.

Discussion

I set out to examine distributions of snow leopard and wild-prey and conservation status across Greater and Trans-Himalaya Mountains of Himachal Pradesh between two time periods, past (1985-1992) and recent (2008-2012). Given the two time periods and the large spatial scale I was interested in, recall-based key-informant survey was used to collect information on detection/non-detection of snow leopard and wild-prey for past and recent time periods. This data was analysed in single species, multi-season site-occupancy framework accounting for imperfect detection. Here I caution about interpreting the effects of variables on site use as causation, e.g. NDVI data was used to represent proportion of vegetated area in a site. However, NDVI do not represent palatable forage for wild-prey and may explain absence of a clear relationship between proportion of vegetated area and site-use of wild-prey.

The results suggest snow leopard distribution remained largely unchanged over the last two decades. There was no evidence of overall distribution expansion or contraction for snow leopard in the study area. Wild-prey (blue sheep and ibex combined) faced marginal contraction in overall distribution over the past two decades. Snow leopard distribution essentially overlapped with wild-prey distribution, with blue sheep and ibex showing mutually exclusive distributions with marginal overlap.

Within the study area, high probabilities of snow leopard site-use across large patches were recorded in Spiti and Kinnaur (Figure 1.2). These were areas where migratory livestock grazing either did not occur or the intensity was low, as was the intensity of other threats such as, hunting and natural resource extraction (Table 1.4 & Supplementary Figure S2). Among areas that showed a relatively high probability of distribution contraction of snow leopard (Supplementary Figure S4), 82% were in south-western parts of Kinnaur and Spiti that experienced migratory livestock grazing and hunting by local and migratory people as well as immigrant laborers. Migratory grazing was prevalent in *ca.* 51% of the snow leopard distribution within the study area (Supplementary Figure S2), of which relatively intense migratory livestock grazing (*ca.* 90 livestock/km^2) occurred in *ca.* 40% of the area, especially in Lahaul and Pangi (Supplementary Figure S2). Intense migratory livestock grazing, along with hunting by migratory herders and immigrant laborers in Lahaul continue to be serious threats to the otherwise contiguous habitat of snow leopard from Pangi to the west, Spiti and Kinnaur to the east and south-east, respectively. The study area was also contiguous with the snow leopard habitats of Hemis in Ladakh (Jammu and Kashmir) to the north.

Within the study area, 25% of the area traditionally considered as potential snow leopard habitat (PSL, 2008; SLN, 2014) showed a negligible probability of use by snow leopards. This is despite the fact that areas above altitude of 5,200m (mainly rocky area with snow and ice) and below 3,200m (forested zone) had been excluded from the study area. Thus, low likelihood of snow leopard occurrence in a quarter of the surveyed potential habitat is noteworthy. Large scale projections of snow leopard distributions and populations have relied on extrapolation of information based on opinions and geo-physical modelling (e.g., SLWS, 2013; SLN, 2014; McCarthy & Mallon, 2016). The results from this work caution against such extrapolations which are likely to substantially overestimate snow leopard occurrence.

Blue sheep and ibex distributions were largely mutually exclusive in the study area, marginally overlapping along Sutlej and Spiti rivers (Figure 1.4 & Figure 1.5). Blue sheep occurred in the eastern and south-eastern parts of the study area, which are less rugged with rolling mountains (Figure 1.4). Ibex occurred in the western and south-western parts of the study area, which are more rugged with steeper mountains (Figure 1.5). Therefore, in Himachal Pradesh, blue sheep and ibex provide important prey base for snow leopard in mostly mutually exclusive areas (Suryawanshi *et al.*, 2013). Overall wild-prey distribution appeared to have declined by 8% over the last two decades. These areas (Supplementary Figure S4), similar to areas with snow leopard distribution contraction, were in south-western Kinnaur, and central and western Lahaul experiencing intense migratory livestock grazing, widespread presence of free-ranging dogs, illegal hunting and wildlife trade by local and migratory herder communities and immigrant laborers (Table 1.4 & Supplementary Figure S2).

Across Pangi, Lahaul and northern and south-western Spiti, ibex is the only large wild-prey of snow leopard. These are also the areas where migratory livestock grazing, depredation by free-ranging dog, illegal hunting and wildlife trade by local and migratory herder communities and immigrant laborer are pervasive and intense (Table 1.4 and Supplementary Figure S2). Migratory livestock grazing has been a long-standing, widespread and constantly changing practice (Saberwal, 1996; Axelby, 2007) in parts of Kinnaur and Spiti and entire Lahaul and Pangi, covering almost totally the estimated ibex distribution. The use by migratory herders of these relatively steeper areas, which are also the habitats of the ibex, resulted in the positive correlation between probability of site-use by ibex and presence of migratory livestock grazing. There is evidence of interference competition between migratory livestock and ibex (Bagchi *et al.*, 2004). Migratory livestock spatially displaces ibex from pastures through forage removal and direct disturbance. Understanding impacts of migratory livestock grazing on forage availability and ibex densities (exploitative competition) at a finer spatial scale would be useful.

Blue sheep, on the other hand, is found extensively and at relatively high densities in Spiti, especially along the eastern bank of Spiti River and parts of western bank (Suryawanshi *et al.*, 2012). The terrain in these areas is relatively gentle and ibex are largely absent. These are also areas used only for local livestock grazing, rather than migratory livestock grazing (USL, 2011) and hence the negative correlation between site-use by blue sheep and migratory livestock grazing.

Snow leopard and wild-prey occurred in large parts of the study area and were not restricted to the seven protected areas that cover 18% (3,875 km^2) of the study area. In this, Himachal Pradesh thus mirrors a global pattern (Johansson *et al.*, 2016) where large parts (*ca.* 10,336 km^2) of snow leopard and wild-prey distribution lie outside protected areas. This makes landscape scale participatory conservation approaches, such as, India's Project Snow Leopard (PSL, 2008), implemented in the Upper Spiti Landscape of Himachal Pradesh (USL, 2011), and the ongoing Global Snow Leopard and Ecosystem Protection Program (GSLEP; SLWS, 2013), more appropriate in the context of snow leopard and wild-ungulate conservation in the Indian Himalaya.

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Chapter 3

Migratory livestock grazing outcompetes a wild-ungulate through reduced forage availability in the Indian Trans-Himalaya

Abstract

Competition is an important mechanism explaining inter-specific interactions in low productivity ecosystems. Outcompetition of native wild ungulates by resident livestock grazing has been well documented. I examined impacts of migratory livestock grazing on Trans-Himalayan rangeland and Asiatic ibex *Capra sibirica*, a wild ungulate and primary prey of the endangered snow leopard. Vegetation cover and biomass and ibex density and demography were sampled in intensely grazed (livestock density 63 sheep-goat km^{-2}) and ungrazed areas, during spring (before livestock grazing), summer (during livestock grazing) and autumn (after livestock grazing). Proportionate to vegetated area, randomly laid 1mX1m plots were sampled for vegetation cover and biomass estimation across both treatments and three time-periods, respectively. Ibex densities and young:adult-female ratios were estimated by repeatedly sampling 17 trails using double-observer method across both treatments and three time periods. Graminoid and herb biomass were significantly higher in ungrazed than grazed area (ANOVA; Graminoid: $F_{Treatment}$=16.05; P=<0.001; Herb: $F_{Treatment}$=22.75; P=< 0.001). Overall vegetation composition was dissimilar across ungrazed and grazed area (Morisita Index 0.18), however, palatable species composition was similar (Morisita Index 0.70). Biomass of palatable species was 2.25 times higher in ungrazed than grazed area. Ibex density was 1.80-7.0 times higher in ungrazed than grazed area. Grazing did not have a clear effect on overall young:adult-female ratios and kid:adult-female ratios. However, yearling:adult-female ratio was six times higher in ungrazed than grazed area in summer (during livestock grazing period). Significantly reduced forage availability lowered ibex

density by spatial displacement of yearlings and adult females in grazed area, suggesting outcompetition of ibex by migratory livestock through exploitative competition.

Introduction

Interspecific competition and its effects on habitat use and population of species has been a major theme of ecological research (Hutchinson, 1959; Connell, 1961; Schoener, 1983; Whitfield, 2002). This is also one of the most debated topics in ecology, with polarity in scientific evidences and interpretation of facilitation and competition, especially in the context of interaction between domestic and wild ungulate species (Prins, 1992; Noss, 1994; Saberwal, 1996; Mishra & Rawat, 1998; Saberwal, 1998; Odadi et al., 2011).

In low productivity and arid ecosystems, domesticated herbivores at high densities are known to remove significant quantities of forage. Resource limitation due to forage removal can outcompete native wild ungulates (Mishra et al., 2004; Namgail, Fox & Bhatnagar, 2007; Suryawanshi, Bhatnagar & Mishra, 2010). The impacts of livestock grazing on rangeland vegetation and wild ungulate populations have been a long-standing conservation concern globally (Prins, 1992; Bagchi *et al.*, 2004; Mishra *et al.*, 2004; Madhusudan, 2004; Suryawanshi *et al.*, 2010). Livestock grazing is prevalent across more than a third of the world's landmass and supports livelihood of agro-pastoral and pastoral communities (Goldstein *et al.*, 1990; Pun & Mares, 2000; Madhusudan, 2004). Livestock grazing is an important form of livelihood in India and grazing is prevalent across majority of protected areas in the country (Kothari *et al.* 1989; Madhusudan, 2004; Davidar *et al.*, 2010). Grazing livestock continues to be one of the primary forms of livelihood and natural resource use in the arid and low-productivity Trans-Himalaya ecosystem of India (Bhatnagar, 1997; Bagchi *et al.*, 2004; Suryawanshi *et al.*, 2010; Bagchi *et al.*, 2012; Kohli *et al.*, 2014). Quantitative research shows resident livestock grazing (livestock herded by villagers and brought back to village by day end) in the Indian Trans-Himalaya lowers availability of forage for wild ungulates. Lowered forage availability reduces density and population performance (young to adult female ratios) of wild ungulates, such as blue sheep *Pseudois nayaur* (Mishra *et al.*, 2004; Suryawanshi *et al.*, 2010). Changes in vegetation or direct disturbance by livestock and accompanying herders and their dogs can in turn lead to displacement of wild ungulates to sub-optimal habitat (Bhatnagar, 1997; Bagchi *et al.*, 2004; Namgail *et al.*, 2007). Competition can also result in behavioral changes in wild ungulates through reduced foraging time and increased vigilance in areas with low forage availability (Namgail *et al.*, 2007; Kohli *et al.*, 2014). These forms of competition (interference and exploitative) lower population performance (young to adult female ratios) of wild ungulates, eventually leading to decline in their population densities.

While outcompetition of native wild ungulates by resident livestock grazing has been widely documented; understanding of competitive interactions between transhumant or migratory livestock grazing and native wild ungulates remains poor and contentious (Saberwal, 1996; Mishra & Rawat, 1998; Saberwal, 1998; Bagchi *et al.*, 2004). Migratory livestock grazing has been a long-standing livelihood option for mountain communities in India (Saberwal, 1996; Axelby, 2007; Bhasin, 2011). Migratory herders access high-altitude Trans-Himalayan rangelands during summer (June-August) and low altitude grazing grounds during winter (November-April). Due to this flexibility in seasonal movements they are not constrained by winter-forage availability, and can thus afford to maintain much higher livestock densities than resident communities. Given the low productivity of the Trans-Himalayan high-altitude ecosystem, migratory livestock grazing is likely to have serious impacts on rangeland vegetation (Bhatnagar, 1997; Bagchi *et al.*, 2004; Mishra *et al.*, 2004; Suryawanshi *et al.*, 2010; Bagchi *et al.*, 2012).

In the state of Himachal Pradesh in northern India, migratory livestock grazing overlap with about 60% of available snow leopard distribution range and nearly the entire distribution range Asiatic ibex *Capra sibirica* (Ghoshal *et al.*, in review). Bagchi *et al.*, (2004) found that migratory livestock causes interference competition for ibex population through direct displacement of ibex from pastures and reported strong diet overlap between sheep-goat and ibex, both being predominantly grazers.

In this chapter, I examine the impacts of migratory livestock grazing on forage availability, ibex population density and demographics, in Pin Valley National Park, Lahaul & Spiti District, Himachal Pradesh, India. I hypothesized that while migratory livestock grazing outcompetes ibex through interference competition (Bagchi *et al.*, 2004), grazing will also cause exploitative competition through reduced forage availability. I predicted forage availability will be lower in areas grazed by migratory livestock. Further, ibex population density and recruitment were predicted to be lower in areas grazed by migratory livestock. I tested these predictions by comparing the vegetation cover and biomass and ibex density and demographics in two areas; one grazed by migratory livestock annually and one ungrazed area.

Materials & methods

Study area

The study was conducted in the Pin Valley National Park (Area: 675 km^2; Location: 32.004003 N; 77.946217 E) in Spiti sub-division, Lahaul & Spiti District, Himachal Pradesh, India (Figure 2.1). The area is a cold-desert, characterized by rugged terrain (Bhatnagar, 1997; Bagchi *et al.*, 2004). Pin Valley experiences mild summers (maximum temperature around 25° C), while winter temperatures dip below minus 30° C. The vegetation in Pin Valley is 'dry alpine-steppe' (Champion & Seth, 1968).

The human population of Spiti sub-division is 12,445, with a density of *ca.* 1 person/km^2. The local agro-pastoralist community grows green-pea *Pisum sativum* as the main cash-crop. This reliance has fuelled a shift in the local economy from subsistence, barter-based system to cash-based and market-oriented, over the last three decades (Mishra, 2000). Apart from green-pea, people grow barley *Hordeum vulgare*, potato *Solanum tuberosum* and black pea. People own a mixture of livestock including sheep, goat, donkey, horse, cattle, yak and hybrids of cattle and yak.

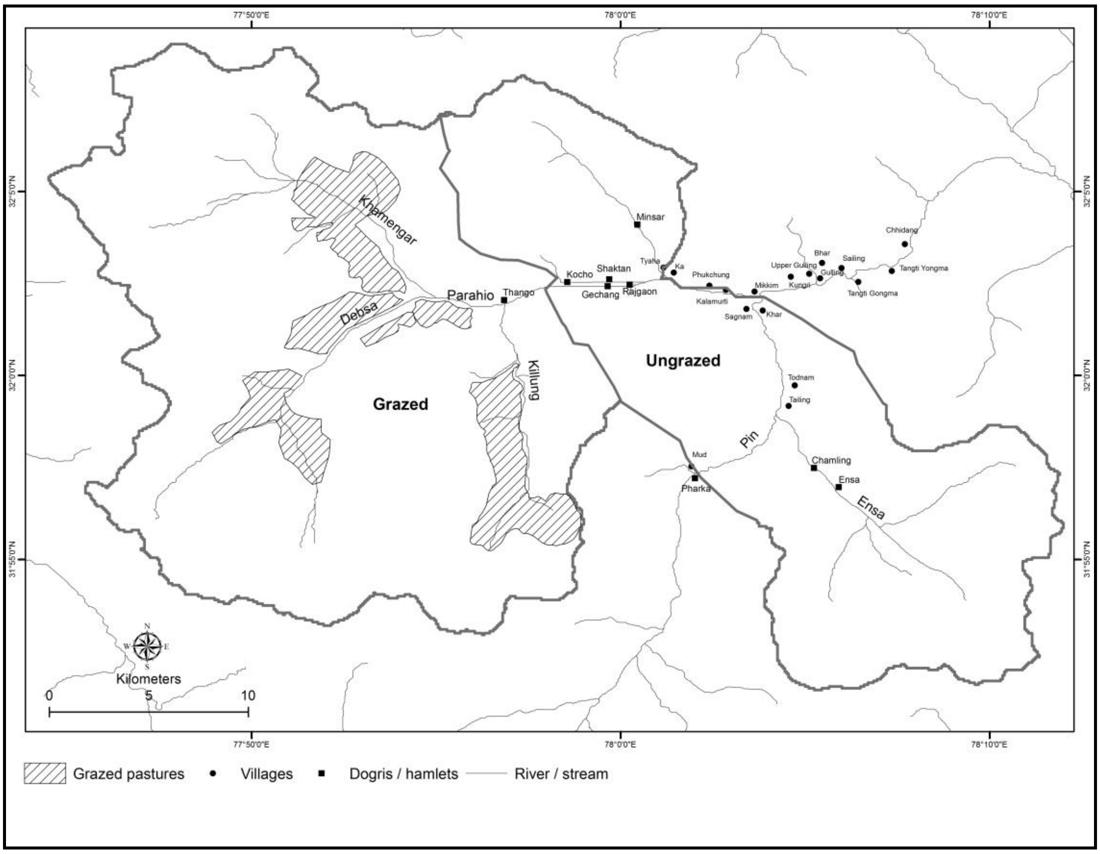

Figure 2.1: The study was carried out in Pin Valley National Park, Lahaul & Spiti District, Himachal Pradesh, India. The grazed area is drained by Parahio River and its tributaries namely Debsa, Khamengar and Minsar and the ungrazed area is drained by Pin River and its tributaries namely Ensa.

The local agro-pastoralist community practice resident livestock grazing (livestock herded by villagers and brought back to village by day end; livestock stall-fed at village during winter). The total population of sheep-goat in Pin Valley was 1,127 and 468 in 2015 and 2016, respectively. Migratory livestock grazing practice uses the natural variation in availability of resources across space and time through transhumance by accessing high-altitude pastures for grazing livestock during summer (June-August), while using pastures in the Himalayan foothills during winter (November-April). Migratory herders from neighboring Kinnaur District visit Pin Valley during summer. A total of 40-45 groups of herders with approximately 55,000-60,000 sheep-goat graze pastures in Pin Valley every year. While resident livestock grazing is a chronic and regulated form of rangeland use, migratory livestock grazing is a remarkably intense pulse of rangeland use.

Study design & data collection

Within Pin Valley two areas were identified, with and without migratory livestock grazing (Figure 2.1). The grazed treatment consisted of areas upstream Gechang along the Parahio Valley and its tributaries Killung, Khamengar and Debsa (Bhatnagar *et al.*, 1997). This area is experienced long-standing migratory livestock grazing for centuries at relatively high density. Total geographic area of the grazed treatment was 466 km^2, while the area of grazed pasture was 61 km^2. A total of 3,870 migratory livestock (sheep-goat) grazed these pastures corresponding to sheep-goat density of 63 individuals km^{-2}. The ungrazed area consisted of lower stretch of Parahio Valley downstream Gechang and its tributary Minsar nala, stretch along the Pin River from Sagnam to Mud and the Ensa Valley, a tributary of Pin River. This area has no history of migratory livestock grazing (area 308 km^2). Both grazed and ungrazed areas experience resident livestock grazing, but, as mentioned above, at a much lower level than migratory livestock grazing. The grazed area and ungrazed area are adjacent to each other within the same larger valley system and exhibit comparable habitat and climatic characteristics. Here on, the terms 'grazed' and 'ungrazed' are used strictly with respect to migratory livestock grazing and not resident livestock grazing.

Livestock density was estimated using resource maps (USL, 2011; Suryawanshi *et al.*, 2013) during summer of 2015. I used Normalized Difference Vegetation Index (NDVI) to determine the area under vegetation within each treatment. The total vegetated area in ungrazed and grazed areas was 237 km^2 and 127 km^2, respectively. A total of 237 and 127 random 1m X 1m plots were sampled in ungrazed and grazed areas, respectively, for each time period. Plant species and percent vegetation cover were recorded in each plot. Above ground biomass of vegetation was estimated by clipping every other plot. Double observer survey (DOS) following Suryawanshi *et al.*, (2012) was used to estimate ibex population densities for before, during and after livestock grazing time-periods across grazed and ungrazed areas for two consecutive years (2015 and 2016). Ibex population density was calculated as estimated abundance divided by sample area of treatment. Young:adult female ratios were estimated for before, during and after livestock grazing time periods in 2016. Kids (new born to six months old individuals) and yearlings (individuals greater than six months to two years old) were combined as young individuals.

Data analyses

Analysis of variance was used to examine effects of time (before, during and after livestock grazing time periods) and treatment (ungrazed and grazed) on percent cover and biomass of graminoid, herb and shrub. I used *R* version 3.1.0 (R Core Team, 2014) for all statistical analyses.

Results

Graminoid cover and biomass

Graminoid percent cover was consistently higher in ungrazed than grazed area. Graminoid cover was 1.20, 1.14 and 1.32 times higher in ungrazed than grazed area for before, during and after livestock grazing periods, respectively. The differences were statistically significant across treatments ($F_{\text{Treatment}} = 3.61$; $P = 0.05$), but not across time-periods ($F_{\text{Time-period}} = 0.41$; $P = 0.66$) (Figure 2.2a, Table 2.1).

Graminoid biomass was also consistently higher in ungrazed than grazed area. Graminoid biomass was 1.20, 5.25 and 2.44 times higher in ungrazed than grazed area for before, during and after livestock grazing periods, respectively (Figure 2.2a). Graminoid biomass showed statistically significant differences across treatments ($F_{\text{Treatment}} = 16.05$; $P = < 0.001$) and time periods ($F_{\text{Time-period}} = 7.20$; $P = < 0.001$), respectively (Figure 2.2a, Table 2.1).

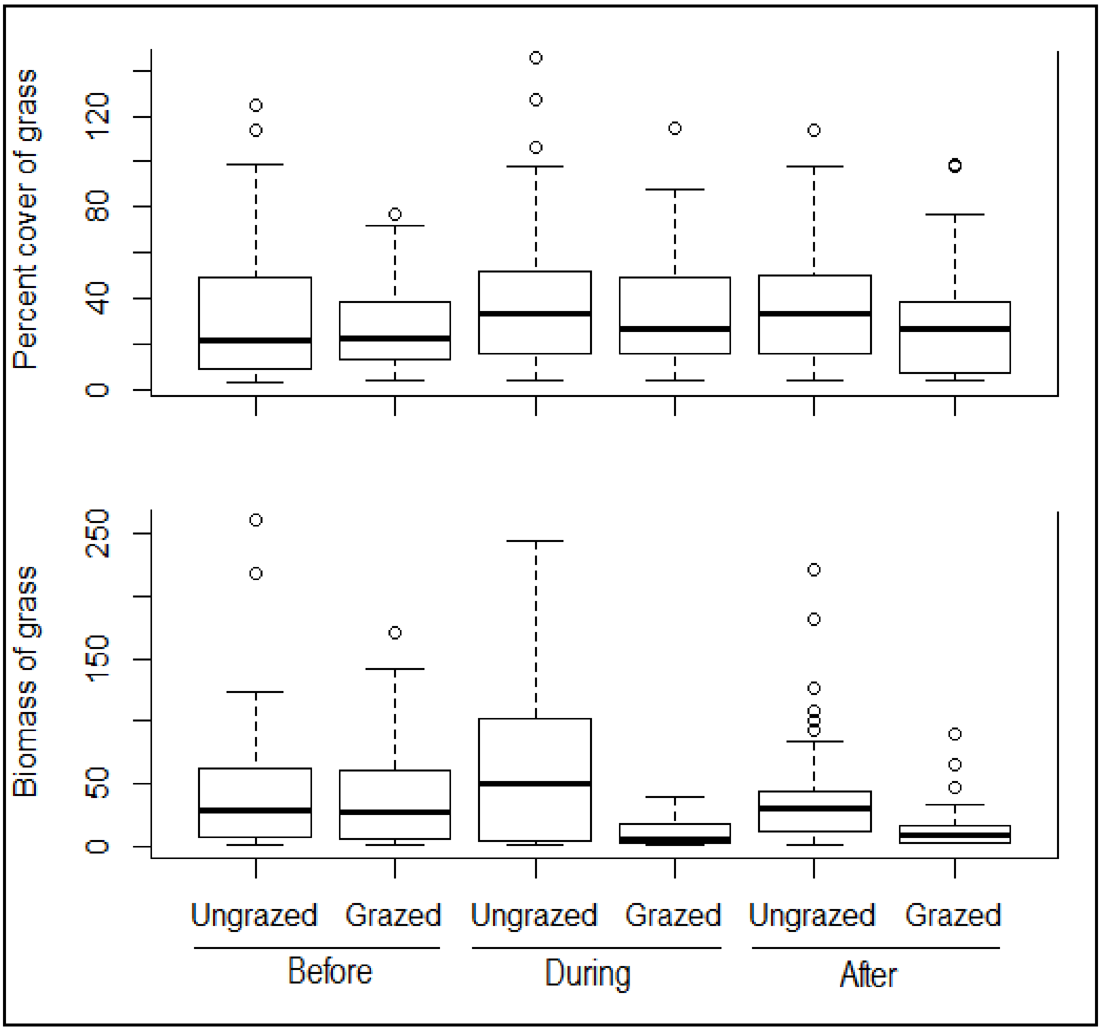

Figure 2.2a: Boxplots showing percent cover and biomass of graminoids across before, during and after migratory livestock grazing and ungrazed and grazed areas in Pin Valley, Himachal Pradesh, India.

Table 2.1: Analysis of variance (ANOVA) showing effects of treatment (grazed and ungrazed areas) and time (before, during and after-grazing time periods) on percent cover and biomass of graminoid, herb and shrub in Pin Valley, Himachal Pradesh, India.

Vegetation group	Attribute	Parameters	*df*	Sum of squares	Mean square	*F*	*Pr*(>*F*)
Graminoid	Percent cover	Treatment	1	1980	1980.5	3.611	0.05
		Time	2	447	223.6	0.408	0.66
		Residuals	633	347182	548.5		
	Biomass	Treatment	1	32626	32626	16.055	< 0.001
		Time	2	29184	14592	7.181	< 0.001
		Residuals	279	566955	2032		
Herb	Percent cover	Treatment	1	12920	12920	8.76	0.003
		Time	2	16700	8350	5.661	0.003
		Residuals	910	1342255	1475		
	Biomass	Treatment	1	51693	51693	22.75	< 0.001
		Time	2	196522	98261	43.25	< 0.001
		Residuals	439	997441	2272		
Shrub	Percent cover	Treatment	1	162	162.3	0.287	0.59
		Time	2	3784	1892	3.35	0.03
		Residuals	172	97142	564.8		
	Biomass	Treatment	1	2202	2202	0.665	0.41
		Time	2	33650	16825	5.082	0.008
		Residuals	66	218516	3311		

Herb cover and biomass

Herb percent cover was consistently higher in ungrazed than grazed area. Herb cover was 1.20, 1.10 and 1.24 times higher in ungrazed than grazed area for before, during and after livestock grazing periods, respectively. The differences were statistically significant across treatments ($F_{\text{Treatment}} = 8.76$; $P = 0.003$) and time periods ($F_{\text{Time-period}} = 5.66$; $P = 0.003$), respectively (Figure 2.2b, Table 2.1).

Herb biomass was also consistently higher in ungrazed than grazed area. Herb biomass was 1.43, 1.20 and 2.23 times higher in ungrazed than grazed area for before, during and after livestock grazing periods, respectively (Figure 2.2b). The differences were significant across treatments ($F_{\text{Treatment}} = 22.75$; $P = < 0.001$) and time periods ($F_{\text{Time-period}} = 43.25$; $P = < 0.001$), respectively (Figure 2.2b, Table 2.1).

Shrub cover and biomass

Shrub percent cover did not show a clear relationship with grazing. Shrub cover was 0.86 and 0.72 times lower in ungrazed than grazed area for before and after livestock grazing periods, respectively, while 1.46 times higher in ungrazed than grazed area for during livestock grazing period. Shrub cover did not show statistically significant differences across treatments ($F_{\text{Treatment}} = 0.29$; $P = 0.59$), but showed significant differences across time periods ($F_{\text{Time-period}} = 3.35$; $P = 0.03$) (Figure 2.2c, Table 2.1).

Shrub biomass was consistently higher in ungrazed than grazed area. Shrub biomass was 3.24, 1.76 and 1.30 times higher in ungrazed than grazed area for before, during and after livestock grazing periods, respectively (Figure 2.2c). However, shrub biomass differences were not statistically significant across treatments ($F_{Treatment}$ = 0.66; P = 0.41), but were significant across time periods ($F_{Time\text{-}period}$ = 5.10; P = 0.008) (Figure 2.2c, Table 2.1).

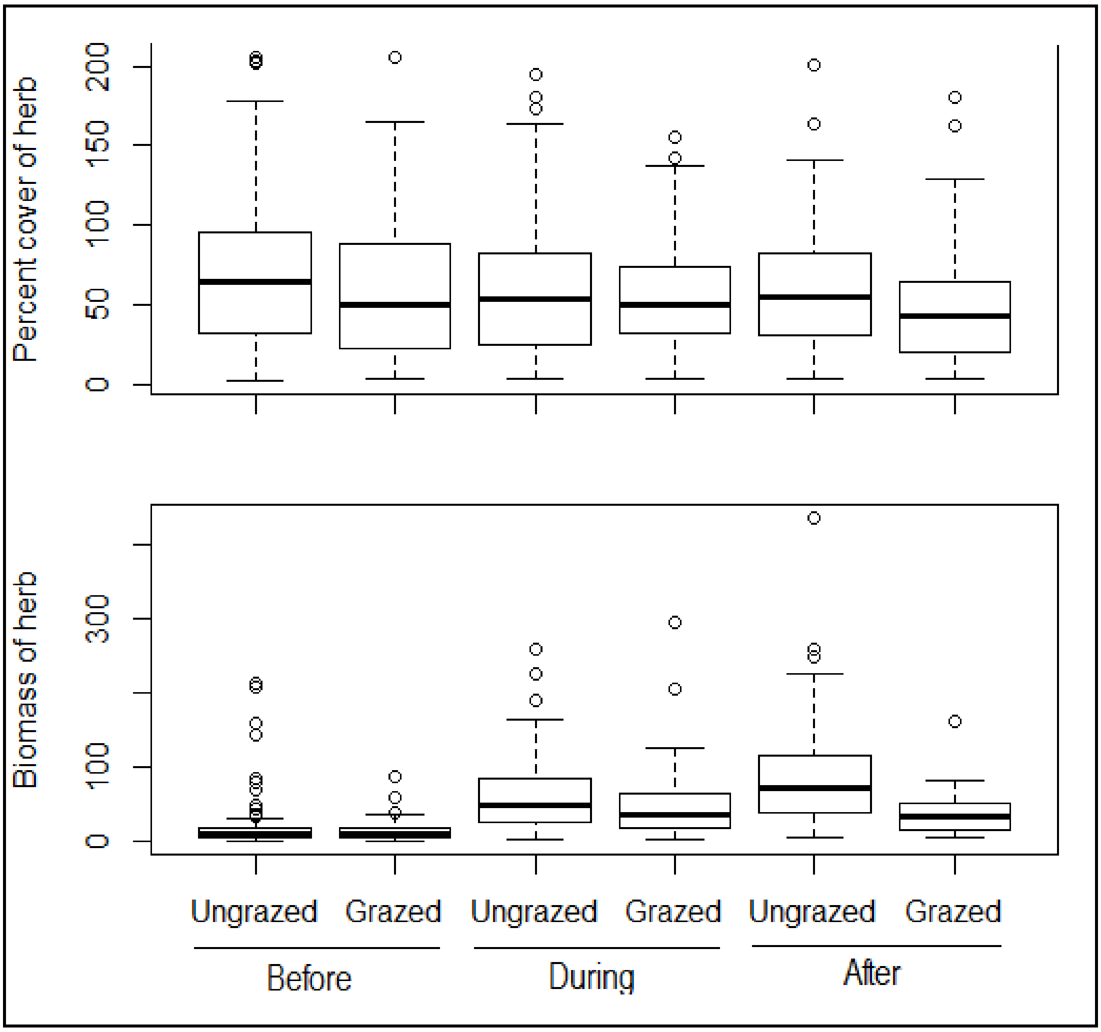

Figure 2.2b: Boxplots showing percent cover and biomass of herb across before, during and after migratory livestock grazing and ungrazed and grazed areas in Pin Valley, Himachal Pradesh, India.

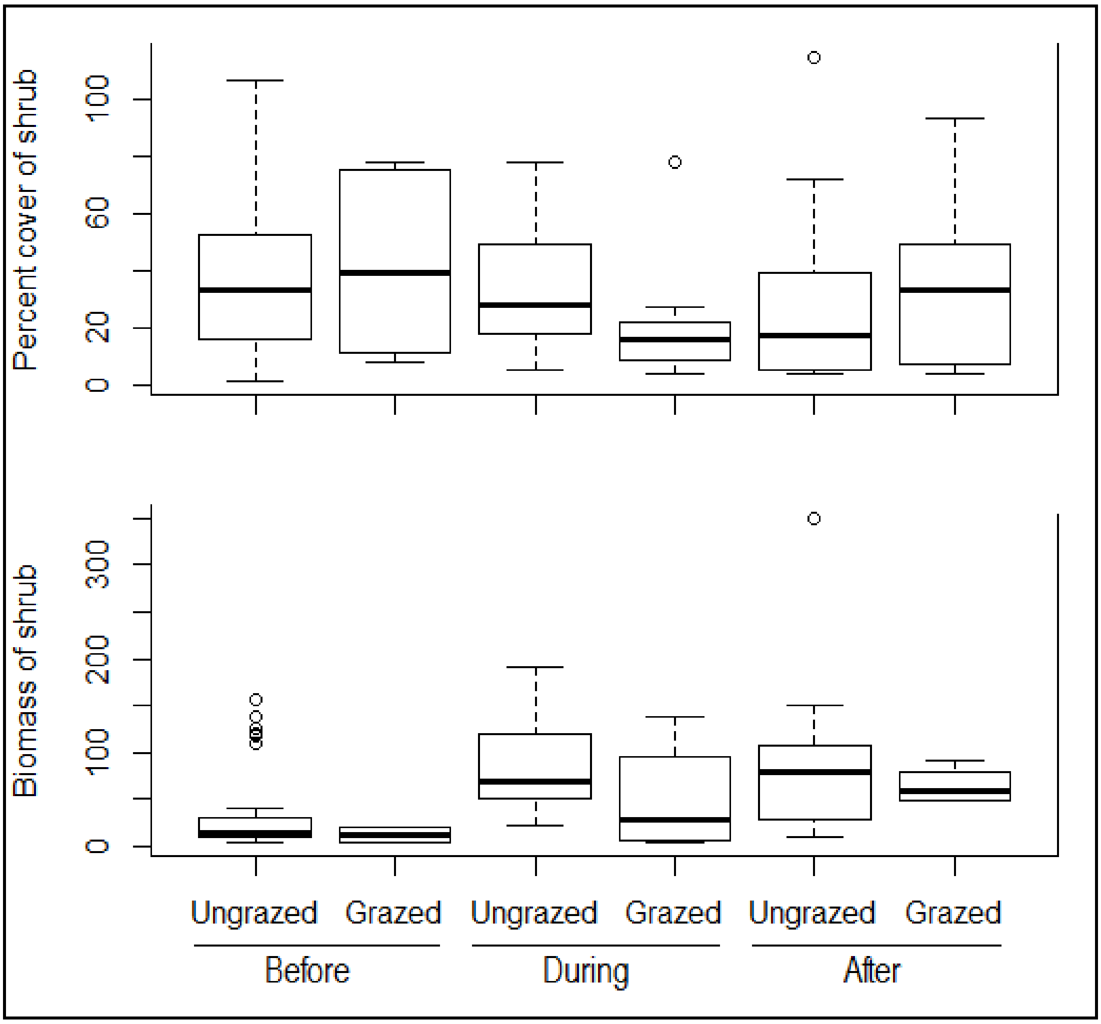

Figure 2.2c: Boxplots showing percent cover and biomass of shrub across before, during and after migratory livestock grazing and ungrazed and grazed areas in Pin Valley, Himachal Pradesh, India.

Vegetation composition

Overall vegetation composition tended to be dissimilar across ungrazed and grazed areas (Morisita Index of Similarity 0.18). A total of 25 palatable species for ibex and livestock was identified based on previous research on ibex and livestock diet from Pin Valley (Bhatnagar, 1997; Bagchi *et al.*, 2004). Palatable species composition was similar across ungrazed and grazed areas (Morisita Index of Similarity 0.70). However, mean biomass of top-five palatable species in ungrazed area was 2.25 times higher than grazed area for the after livestock grazing period (autumn season) (Figure 2.3). Mean biomass of top-five palatable species in ungrazed area was 60.25 gms m^{-2} (SE ± 5.44 gms m^{-2}), while that in grazed area was 26.70 gms m^{-2} (SE ± 3.85 gms m^{-2}). Individual biomass of the top palatable species was consistently higher in ungrazed than grazed area (Figure 2.4a & 2.4b).

Ibex population density

Ibex density was consistently higher in ungrazed than grazed area for before-, during- and after-grazing time periods across 2015 and 2016 (Figure 2.5a & 2.5b). Ibex density was 1.80-7.0 times higher in ungrazed than grazed area in 2015, while 2.45-4.7 times higher in ungrazed than grazed area during 2016.

Young to adult female ratios

Young:adult-female ratios in ungrazed and grazed areas were similar except for during-grazing time period (Figure 2.6). Young:adult-female ratio was higher in ungrazed than grazed area for during-grazing time period (Figure 2.6a). Yearling:adult-female ratio was about six times higher in ungrazed than grazed area for during-grazing period (Figure 2.6b). Kid:adult-female ratios were similar in ungrazed and grazed areas across all time periods (Figure 2.6c).

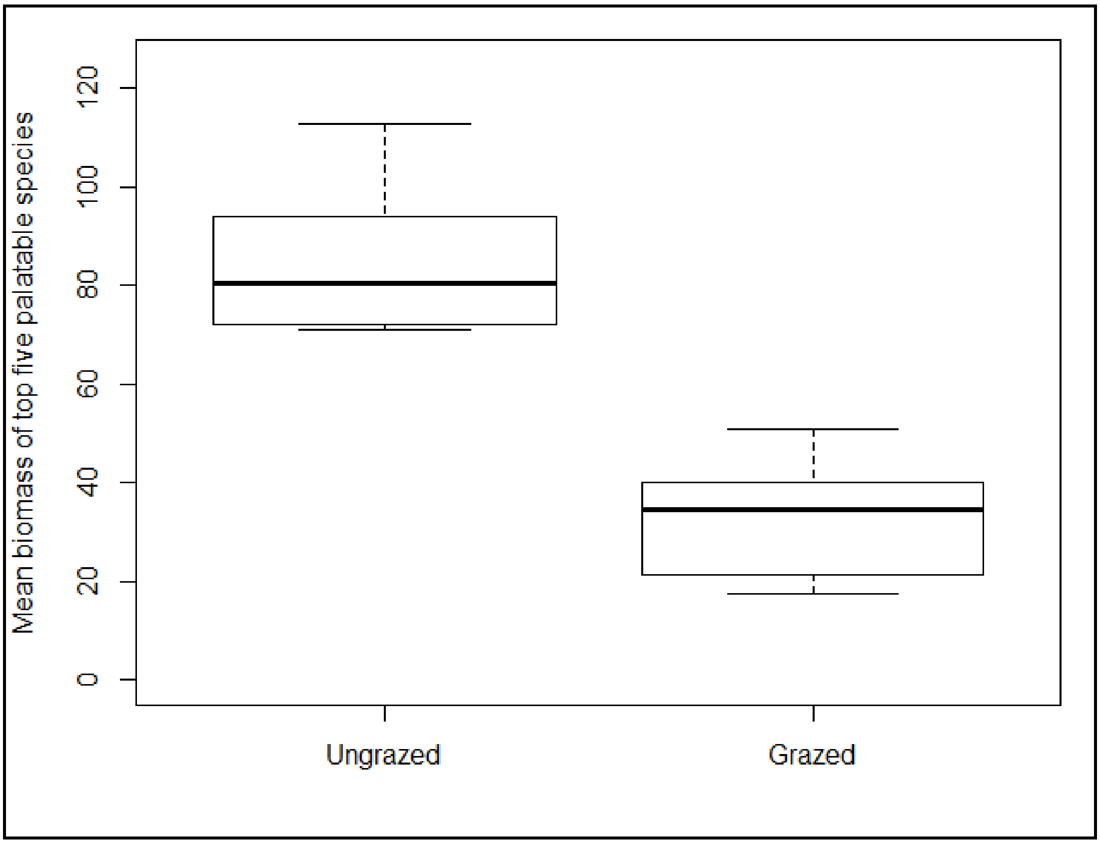

Figure 2.3: Overall mean biomass (gram per square meter) of top five palatable species in ungrazed area was 2.25 times higher than grazed area for after-grazing (autumn season) time period**.**

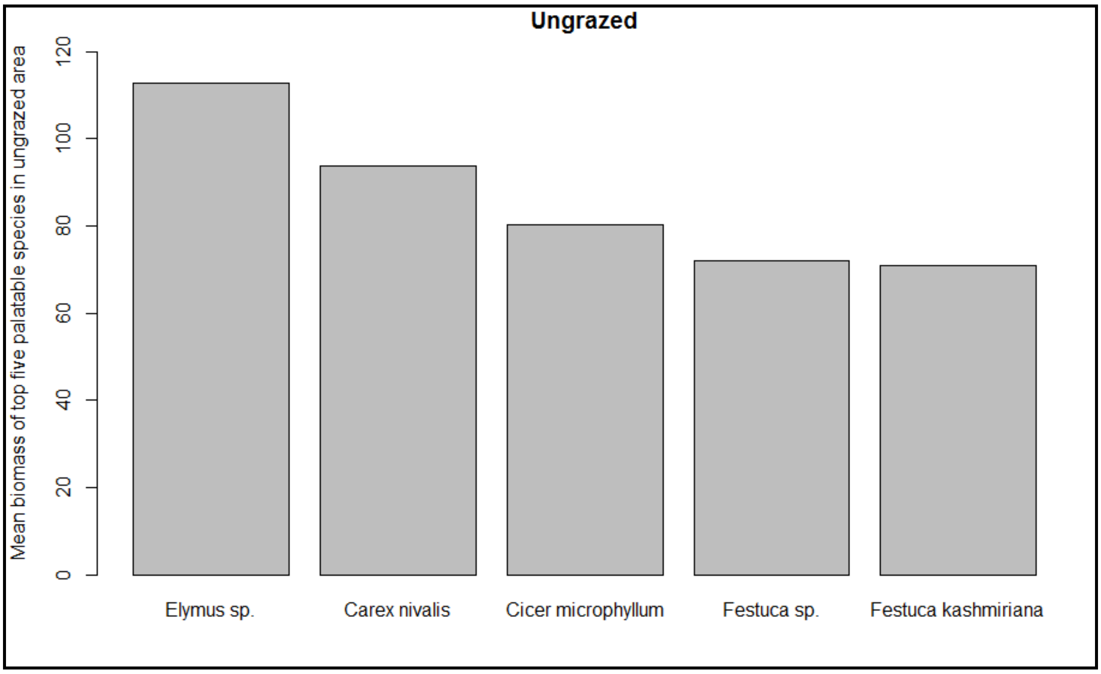

Figure 2.4a: Individual mean biomass (grams per square meter) of top five palatable species in ungrazed area for after-grazing (autumn season) time period.

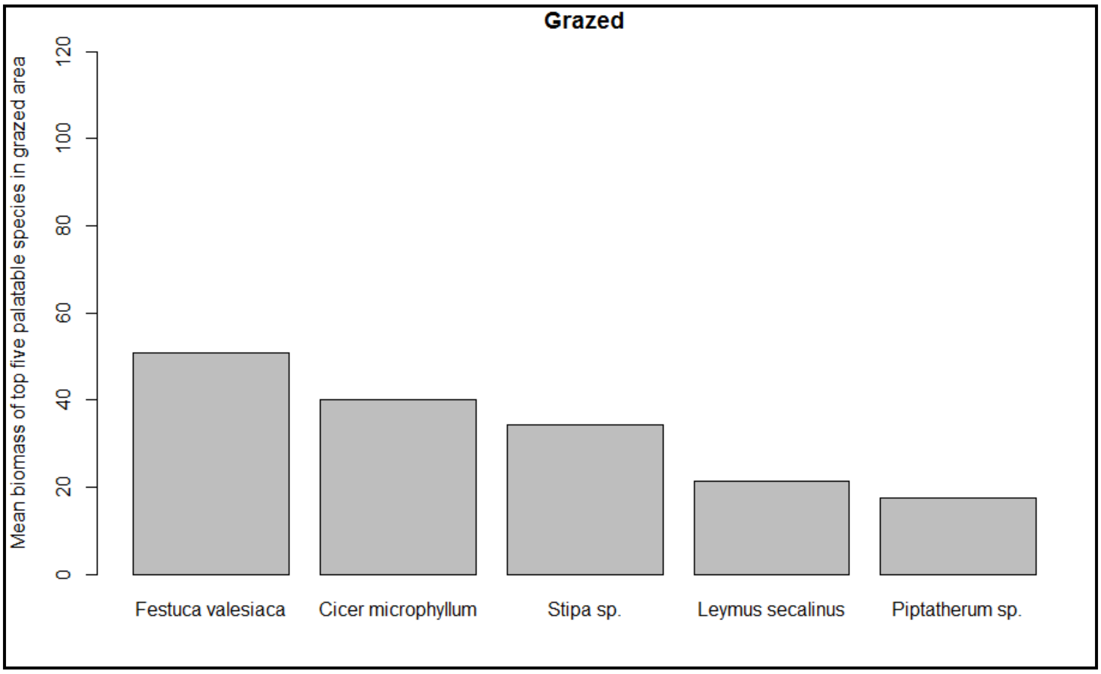

Figure 2.4b: Individual mean biomass (grams per square meter) of top five palatable species in grazed area for after-grazing (autumn season) time period.

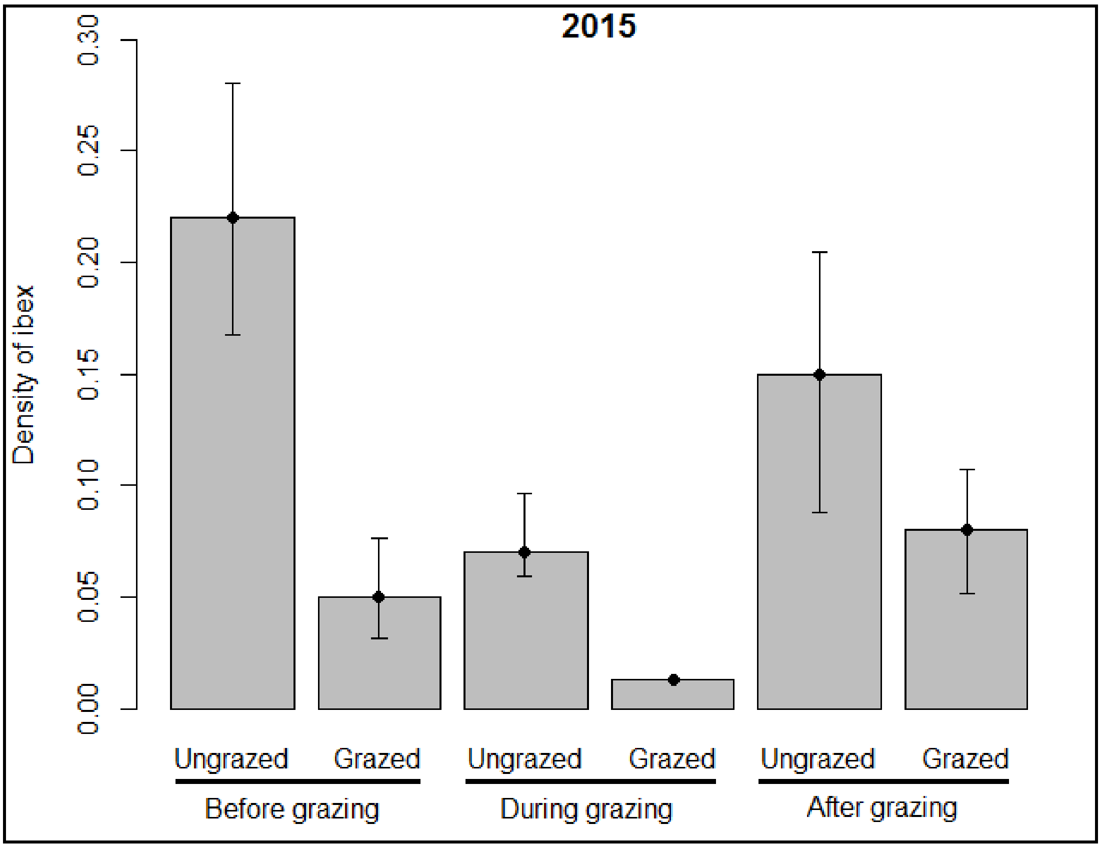

Figure 2.5: Population density of Asiatic ibex across before, during and after migratory livestock grazing time periods and ungrazed and grazed areas, in Pin Valley National Park, Himachal Pradesh, India

Figure 2.5a: In year 2015, for before-grazing time period (spring), ibex density in ungrazed and grazed areas were 0.22 ibex km^{-2} (95% CI 0.17 – 0.28 km^{-2}) and 0.05 ibex km^{-2} (95% CI 0.03 – 0.08 km^{-2}), respectively; for during-grazing (peak summer), densities were 0.07 ibex km^{-2} (95% CI 0.06 – 0.10 km^{-2}) and 0.01 ibex km^{-2} (only one sighting), respectively; while for after-grazing (autumn), densities were 0.15 ibex km^{-2} (95% CI 0.09 – 0.20 km^{-2}) and 0.08 ibex km^{-2} (95% CI 0.05 – 0.11 km^{-2}), respectively.

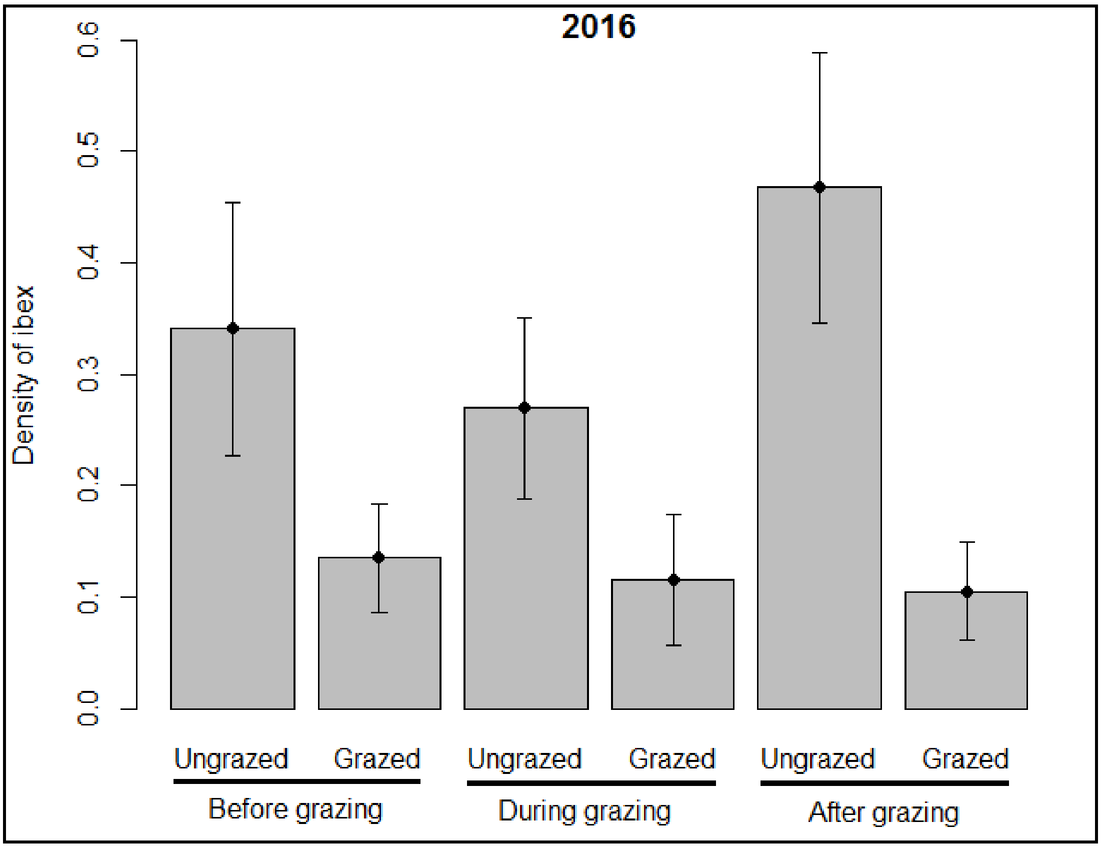

Figure 2.5b: In year 2016, for before-grazing time period (spring), ibex density in ungrazed and grazed areas were 0.34 ibex km^{-2} (95% CI 0.23 – 0.45 km^{-2}) and 0.13 ibex km^{-2} (95% CI 0.09 – 0.18 km^{-2}), respectively; for during-grazing (peak summer) densities were 0.27 ibex km^{-2} (95% CI 0.19 – 0.35 km^{-2}) and 0.11 ibex km^{-2} (95% CI 0.06 – 0.17 km^{-2}), respectively; while after-grazing (autumn) densities were 0.47 ibex km^{-2} (95% CI 0.34 – 0.59 km^{-2}) and 0.10 ibex km^{-2} (95% CI 0.06 – 0.15 km^{-2}), respectively.

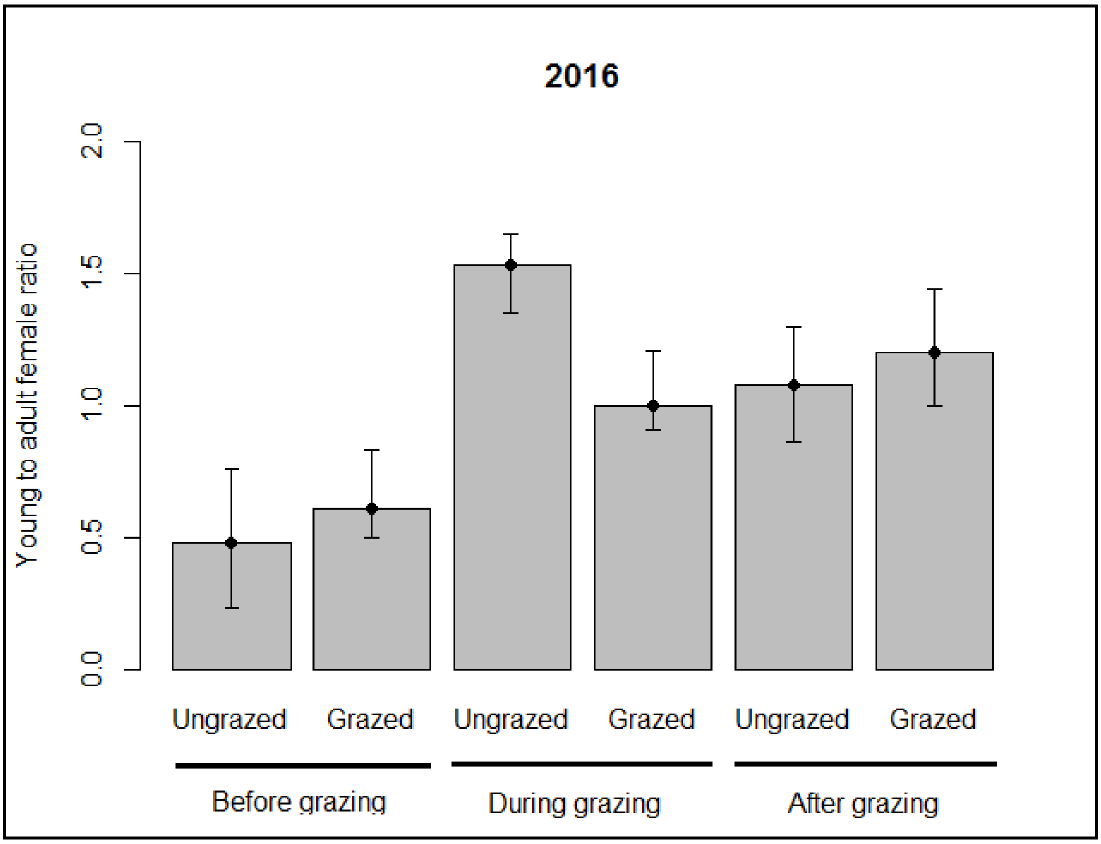

Figure 2.6a: Young to adult female ratios in Asiatic ibex populations in ungrazed and grazed areas across before-, during- and after-grazing time periods in Pin Valley, Himachal Pradesh, India.

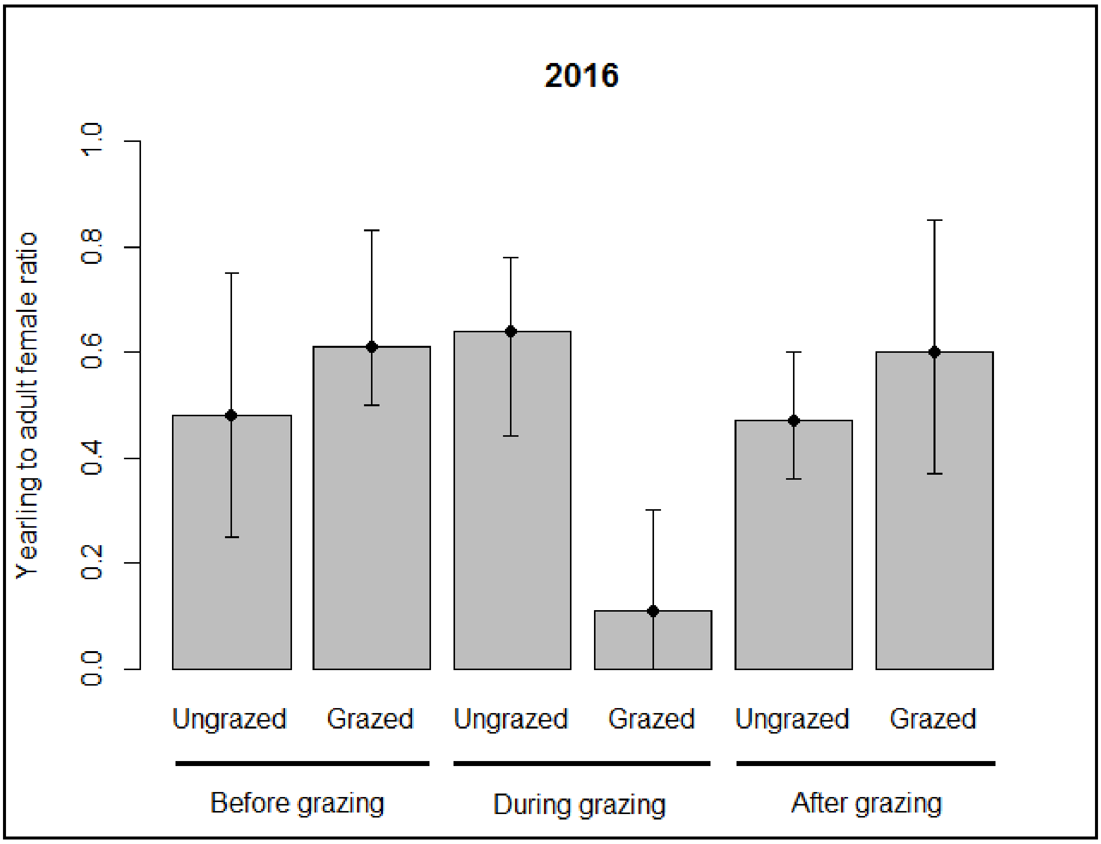

Figure 2.6b: Yearling to adult female ratios in Asiatic ibex populations in ungrazed and grazed areas across before-, during- and after-grazing time periods in Pin Valley, Himachal Pradesh, India.

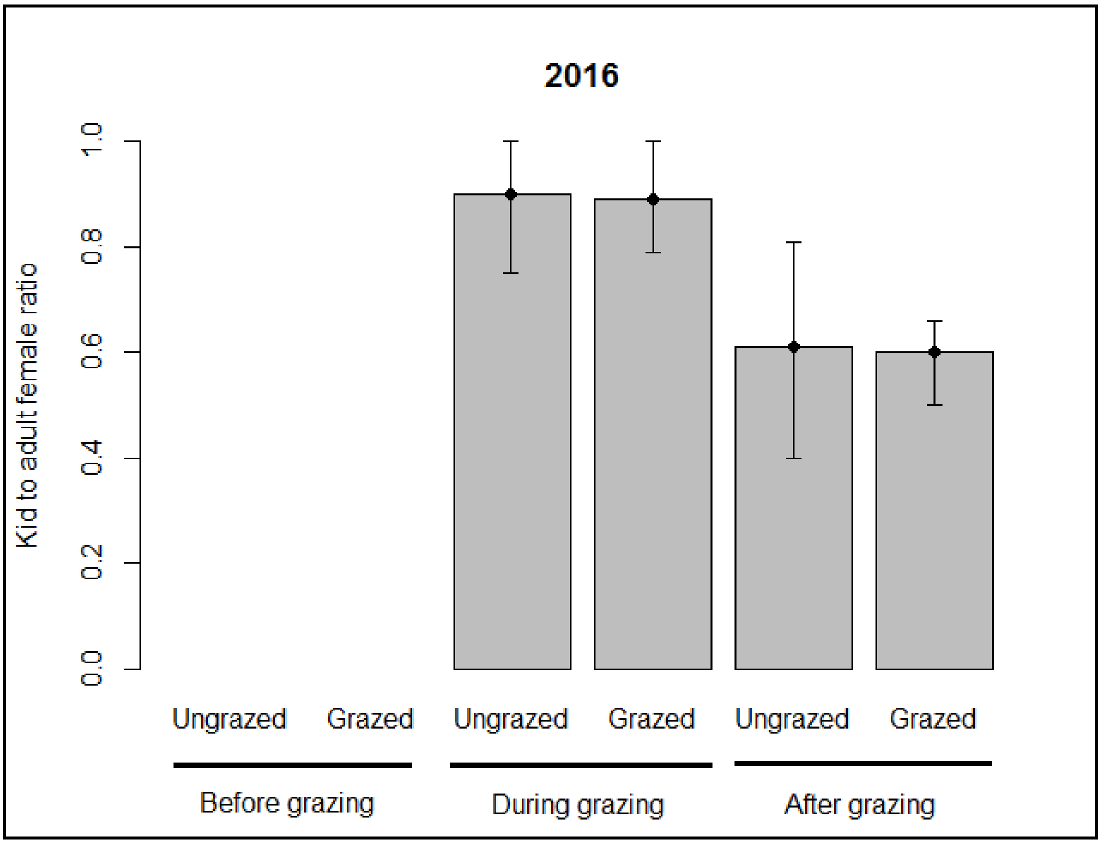

Figure 2.6c: Kid to adult female ratios in Asiatic ibex populations in ungrazed and grazed areas across before-, during- and after-grazing time periods in Pin Valley, Himachal Pradesh, India. During spring season, coinciding with before-grazing time period, the young individuals of ibex population only consists of yearlings.

Discussion

This study examined impacts of migratory livestock grazing on rangeland vegetation and a Trans-Himalayan wild-ungulate, the Asiatic ibex, by comparing an area grazed by migratory livestock with an ungrazed area. Migratory livestock grazing significantly reduced graminoid and herb biomass. Sharp decline in forage biomass in grazed area was due to high level of dry forage off-take by migratory livestock. Dry forage off-take by migratory livestock was derived following Bagchi *et al.* (2004), using information on average body-weight, bite-rate, bite-weight of livestock and proportion of sheep-goat individuals foraging, hours foraged per day by sheep-goat and forage removed by sheep-goat in Pin Valley. A total of 3,870 sheep-goat off-takes a mean of 650,160 kg (208,980 kgs-1,950,480 kgs) of dry forage over two months (mid-June to mid-August) from 61 km^2 of grazed pastures. This corresponds to an offtake of 10,658.40 kg km^{-2}, equivalent to forage requirement of *ca*. 250 adult male ibex individuals for three months (Fedosenko & Blank, 2001). The biomass of palatable species that remained in the grazed area during autumn (after migratory livestock has left the study area and the beginning of the lean season) was 2.25 times lower than the ungrazed area.

Reduction in graminoid and herb biomass availability lowered ibex population density in grazed area, indicating strong exploitative competition. Ibex density was 1.80-7.0 times higher in ungrazed than grazed area in 2015, while 2.45-4.7 times higher in ungrazed than grazed area during 2016 (Figure 2.5a & 2.5b). I emphasize that ibex density was consistently higher in the ungrazed than grazed area despite the ungrazed area having the main motorable road of Pin Valley and six villages with 169 resident sheep-goat.

Migratory livestock grazing did not have a clear effect on overall young:adult-female ratios during spring (before grazing) and autumn (after grazing) seasons (Figure 2.6a). However, young:adult-female ratio was 1.50 times greater in ungrazed than grazed area during peak summer (during grazing) season. Kid:adult-female ratios were similar in ungrazed and grazed areas for peak summer and autumn seasons (Figure 2.6c). However, yearling:adult-female ratio was six times higher in ungrazed than grazed area in peak summer season (Figure 2.6b). But, yearling:adult-female ratios were slightly higher in grazed than ungrazed area during spring and autumn. This suggests, adult females with yearlings are spatially displaced from areas grazed by migratory livestock during summer.

In the state of Himachal Pradesh, ibex distribution spatially overlaps with areas of migratory livestock grazing (Chapter 2). At a finer scale, ibex is spatially segregated from migratory livestock grazed areas as a result of strong interference competition from livestock (Bagchi *et al.*, 2004). This study indicates migratory livestock grazing significantly lowered forage availability, in turn reducing ibex density through apparent displacement of adult female and young individuals. Ibex density is a primary factor affecting abundance of snow leopard, the top-predator of the Central and South Asian mountain system and 'flagship' for conservation of the Indian Himalaya (PSL, 2008; SLN, 2014). Decline in wild-ungulate populations due to lowered forage availability by migratory livestock grazing continues to be a serious problem to snow leopard conservation.

The question of how migratory livestock grazing impacts Himalayan and Trans-Himalayan rangelands and wild-ungulate populations has been controversial and much debated in India (Saberwal, 1996; Mishra & Rawat 1998; Saberwal 1998). The controversy has been prevalent since the colonial time period (Saberwal, 1996), fueled by lack of robust scientific evidence and the notion of a 'traditional' practice cannot negatively impact an ecosystem. In turn, management of rangelands in the Himalaya and Trans-Himalaya has been compromised (Mishra & Rawat, 1998; Bagchi & Ritchie, 2010; Bagchi, Bhatnagar & Ritchie, 2012). The Himalayan and Trans-Himalayan rangelands form a crucial resource, not only for wildlife, but also for sustenance of migratory herder and local agro-pastoralist communities. I emphasize that policy towards conservation and management of Himalayan and Trans-Himalayan rangelands must be based on scientific empirical evidences.

Migratory livestock grazing supports livelihood of numerous agro-pastoralist communities in the Himalayan ecosystem (Saberwal, 1996; Axelby, 2007; Bhasin, 2011). The practice, although considered 'traditional', seems to be constantly adapting (Axelby, 2007) in response to changes in state and central government policies, developmental scenario (hydro-electric and road construction projects offering job opportunities) and market-oriented economy (advent of cash-crop, such as green pea and apple). The situation is further complicated by the linkage between migratory livestock grazing in snow leopard habitat and local, regional and national markets for wool, milk and meat (Axelby, 2007; Bhasin, 2011; Bhatnagar & Singh, 2011). These linkages contribute to economic demand for larger herd sizes. The strong linkage between trade-driven livestock production systems and decimation of natural prey-base of snow leopard is well established (Bhatnagar & Singh, 2011; Berger *et al.*, 2013). Therefore, documentation of changes in grazing practices is much needed to understand challenges and prospects of engaging with migratory herder community (PSL, 2008; USL 2011; SLN 2014).

This study provides evidence of exploitative competition between migratory livestock and a Trans-Himalayan wild-ungulate. Participatory conservation interventions with local agro-pastoralist communities to counter outcompetition of wild-ungulates by resident livestock have been successful elsewhere in the Trans-Himalaya (Mishra *et al.*, 2003). Given the widespread and intensive nature of migratory livestock grazing, I emphasize the need to engage with the migratory herder community to develop science-based participatory rangeland management practices in the Indian Trans-Himalaya.

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Chapter 4

Changes in migratory livestock grazing practices, its implications on a pastoral system and conservation of wildlife in the Indian Trans-Himalaya

Abstract

Migratory livestock grazing is widely practiced as a major livelihood in areas of high seasonal variation and limited natural resources. Rangelands systems with poorly-managed grazing practices face risk of degradation and in turn dispose stakeholders and native wildlife populations dependent on such rangelands to several critical issues, such as declining grazing areas and reduced quality of forage. Quantitative research in the low-productivity rangelands of the Indian Himalaya show evidence of outcompetition of native wild-ungulate populations by livestock grazing through habitat shift (interference competition) and lowered forage availability (exploitative competition). Understanding ways of engaging with the migratory herder community is needed to design effective participatory rangeland management program. Changes in migratory livestock grazing practice over the past decade were assessed in *Kinnaura* community of migratory herders of Kinnaur District, Himachal Pradesh, India. Perceptions of migratory herder and local communities were also assessed on changes in pasture quality and implications of the changes, and potential to diversify livestock products, using key-informant interviews and focus group discussion. Herd size increased by 87.51%, although individual livestock holding declined by 19.23%, over the past decade. Prices of goat and sheep increased by more than 200% and that of wool by about 70%, over the past decade. Pasture quality was perceived to be degrading by migratory herder and local communities and availability of palatable forage declining as a result of pasture degradation. Climate change, intense livestock grazing and pollution were perceived causes of pasture degradation. Frequent disease in livestock, decrease in body-size and milk production of livestock were perceived as main implications of pasture degradation. Reducing livestock numbers and rotation of pastures were suggested to mitigate pasture degradation. Results suggest high potential for wool and milk product diversification as an option to increase return from livestock. The opportunity to develop short- and long-term participatory rangeland management practices in the Indian Himalaya are discussed.

Introduction

Migratory livestock grazing is widely practiced as a major livelihood in areas of high seasonal variation and limited natural resources (Sinclair & Fryxell, 1985; McCabe, 1994; Saberwal, 1996; Coppolillo, 2000; Axelby, 2007; Bhasin, 2011). Rangeland or pasture serves as the key resource not only to migratory communities, but also resident agro-pastoralist communities and native wildlife (Saberwal, 1996; Mishra, 2001; Axelby, 2007). Globally, rangelands are facing poorly-managed grazing practices and climatic variations (Prins, 2000, 1992; Rawat, 1998; Mishra, 2001; Sankaran *et al.*, 2008). Rangelands under intensive multiple-use are especially facing risk of degradation. In turn, this disposes stakeholders and wildlife populations dependent on such rangelands to several critical issues, such as declining grazing areas and reduced quality of forage (Allsopp *et al.*, 2007; Singh, Sharma & Babu, 2015).

Migratory livestock grazing is widespread in the Indian Himalaya and Trans-Himalaya (Saberwal, 1996; Axelby, 2007; Bhasin, 2011; Mitra *et al*, 2013). The ecological effects of migratory livestock grazing on rangeland vegetation and wildlife, especially wild-ungulate populations have been debated for long (Saberwal, 1996; Saberwal, 1998;

Mishra & Rawat, 1998). The debate has been fuelled by a lack of robust empirical evidence of impacts of migratory livestock grazing on vegetation and wildlife, challenges to monitor and regulate livestock population and socio-political issues (Saberwal, 1996; Bagchi *et al.*, 2004).

Vegetation of the Trans-Himalaya, in general, has much lower annual net primary production than the global average (Mishra *et al.*, 2010). However, consumption of vegetation as forage by native wild-ungulates and livestock is comparable to the global average, despite below average vegetation production. Over the past one and a half decade, several ecological studies suggest serious negative impacts of local and migratory livestock grazing on Himalayan rangelands and wildlife. The negative impacts are manifested through degradation of pastures and competition between livestock and wild-ungulates (Mishra, 2001; Mishra, Prins & van Wieren, 2002; Bagchi *et al.*, 2004; Namgail, Fox & Bhatnagar, 2007; Suryawanshi *et al.*, 2010; Bagchi & Ritchie, 2010; Bagchi, Bhatnagar & Ritchie, 2012). There is strong evidence of interference competition between migratory livestock and Asiatic ibex *Capra sibirica*, a primary prey of the endangered snow leopard *Panthera uncia* (Bagchi *et al.*, 2004). Exploitative competition between livestock and blue sheep *Pseudois nayaur* has led to decline in blue sheep populations due to reduced survival of young individuals (Mishra *et al.*, 2004; Suryawanshi *et al.*, 2010). A study using natural conditions of a migratory livestock grazed and ungrazed area in the Indian Trans-Himalaya showed evidence of exploitative competition between migratory livestock and ibex (Chapter 3). Significant declines in forage availability (graminoid and herb biomass) in grazed areas lowered ibex density through spatial displacement of young individuals.

Additionally, migratory livestock grazing in the snow leopard habitat has linkages with local, regional and national markets for wool, milk and meat (Axelby, 2007; Bhasin, 2011; Bhatnagar & Singh, 2011). These linkages contribute to economic demand for larger herd sizes. The strong linkages between trade-driven livestock production systems and decimation of natural prey-base of snow leopard are well established (Bhatnagar & Singh, 2011; Berger *et al.*, 2013).

With this background, understanding changes in herding practice, perceptions of herder communities on changes in pasture quality and ways of engaging with them is important to develop effective participatory rangeland management program (USL, 2011; SLN, 2014). In this chapter, I examine changes in migratory livestock grazing practice over the past decade in *Kinnaura* community of migratory herders of Kinnaur District, Himachal Pradesh, India. The perceptions of migratory herder community and local community were assessed using key-informant interviews and focus group discussion, respectively, on perceived changes in pasture quality, implications of changes in pasture quality, potential mitigations to counter change in pasture quality and potential to diversify livestock products.

Materials & Methods

Study area

This study was carried out in the Rupi-Bhaba area of Kinnaur District and Pin Valley National Park, Lahaul & Spiti District, Himachal Pradesh, India (Figure 3.1). Rupi-Bhaba area, ranging in altitude from 2,100m – 5,900m, represents sub-tropical conditions towards the lower reaches while temperate and alpine conditions in the interiors (Jayapal & Ramesh, 2010). Pin Valley represents a cold-desert, characterized by rugged terrain, interspersed with 'dry-alpine steppe' meadows (Chandra Sekar & Sivastava, 2009). The landscape is amongst the least productive ecosystems globally (Mishra, 2001). Altitude varies from about 3,450m (near confluence of Pin and Spiti rivers) to more than 6,500m. Winter temperatures dip below -30° C.

The migratory herder community of Rupi-Bhaba area, Kinnaur, traditionally graze pastures in Pin Valley, Spiti, with their sheep-goat during summer (June-August). The migratory herders have settled villages with agriculture of food crops, such as wheat, millet, vegetables, red kidney-beans (*rajma*) and cash-crop, such as apple and apricot. The male members of numerous families engage in migratory grazing (Axelby, 2007). A few donkeys or horses are taken along with sheep-goat as pack-animals. The migratory herders use the Bhaba Valley of Kinnaur to access Pin valley across the Pin-Bhaba Pass.

The local people of Pin Valley are primarily settled agro-pastoralists (Bhatnagar, 1997; Bagchi *et al.*, 2004). They grow a single summer crop comprising mainly green- and black-pea, barley, potato and vegetables. Local livestock include sheep, goat, cow, yak, horse, donkey and yak-cattle hybrids (male – *dzo*, female – *dzomo*). Local small livestock holding in villages with widespread green-pea cultivation (e.g. Mud and Sagnam) declined over the past three decades, similar to a pattern in certain other parts of Spiti, owing to advent of green-pea as cash-crop during late 1980s (Mishra, 2001; Singh *et al.*, 2015). Each village and the main monastery of Pin Valley at Kungri, hold traditional rights on rangelands or pastures to graze livestock and use natural resources.

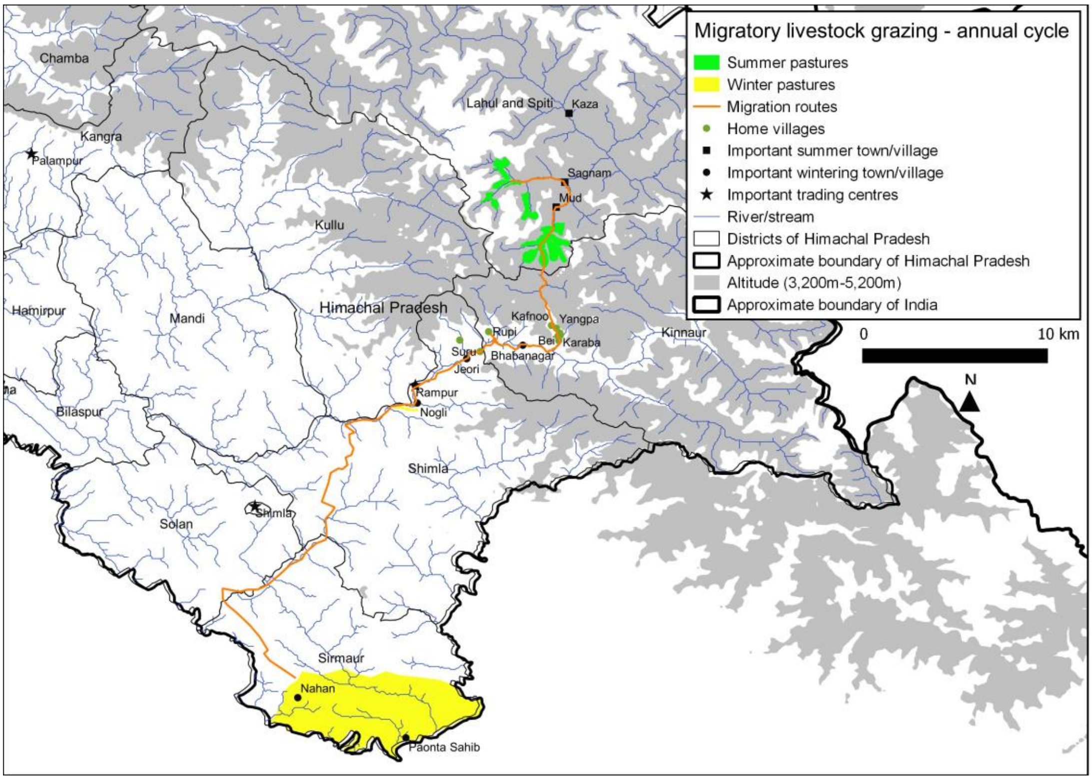

Figure 3.1: Map representing the villages, routes, summer and winter pastures of *Kinnaura* migratory herders of Kinnaur, Himachal Pradesh, India.

Methods

Key-informant interviews using semi-structured questionnaire and informal discussion were carried out with migratory herders (White *et al.*, 2005). Data on migratory herding practice and changes over the last decade was collected, e.g. changes in individual livestock holding and herd sizes; changes in livestock composition; perceived changes in pasture quality; perceived reasons behind changes in pasture quality, changes in prices of livestock products and potential for diversification of livestock products. A total of 40-45 groups of migratory herders graze livestock in Pin Valley. I interviewed 25 lead-herders of these groups, representing > 50% of herder groups using structured questionnaire (Supplementary material S5). The respondent herders were involved in grazing livestock for years and even for decades.

Focus group discussion were carried out with the local community (members of the village council, elderly villagers and local herders) in three villages of Pin Valley, Sagnam, Tailing and Mud, to understand their interface with migratory herders, e.g. willingness to lease pastures to migratory herders, rationale for giving access to pastures and perceived impacts of migratory livestock grazing on rangelands (Supplementary material S6). These are the villages practicing *de facto* rights on pastures of Pin Valley, which the migratory herders of Rupi-Bhaba area access each summer.

Box-plots were used to illustrate changes in livestock holding, herd-sizes, livestock composition and prices of livestock products. Descriptive statistics were used to represent data from interviews and focus group discussion.

Results

Changes in herd size

Herd size of migratory livestock increased by 87.51% over the past decade (Figure 3.2). Mean livestock herd size was 591.66 (SE ± 55.30) in 2005, while 1109.41 (SE ± 101.69) in 2015.

Changes in individual livestock holding

Individual livestock (sheep-goat) holding declined by 19.23% over the past decade (Figure 3.2). Mean individual livestock holding was 170 (SE ± 25.12) in 2005, while 137.30 (SE ± 38.15) in 2015.

Changes in individual livestock holding composition

Individual goat holding by migratory herders increased by 24.20% over the past decade (Figure 3.3). Individual mean goat holding was 68.05 (SE ± 11.08) in 2005 and 84.52 (SE ± 24.09) in 2015. Individual sheep holding decreased by 36.10% over the past decade (Figure 3.3). Individual mean sheep holding was 91.90 (SE ± 15.50) in 2005 and 58.75 (SE ± 15.61) in 2015.

Changes in herd composition

Livestock composition of herds changed over the past decade, with 139.14% increase in goat and 42.60% increase in sheep (Figure 3.3). Mean number of goat in a herd was

255.40 (SE ± 28.96) in 2005 and 610.77 (SE ± 71.46) in 2015. Mean number of sheep in a herd was 313.84 (SE ± 24.85) in 2005 and 447.50 (SE ± 35.53) in 2015.

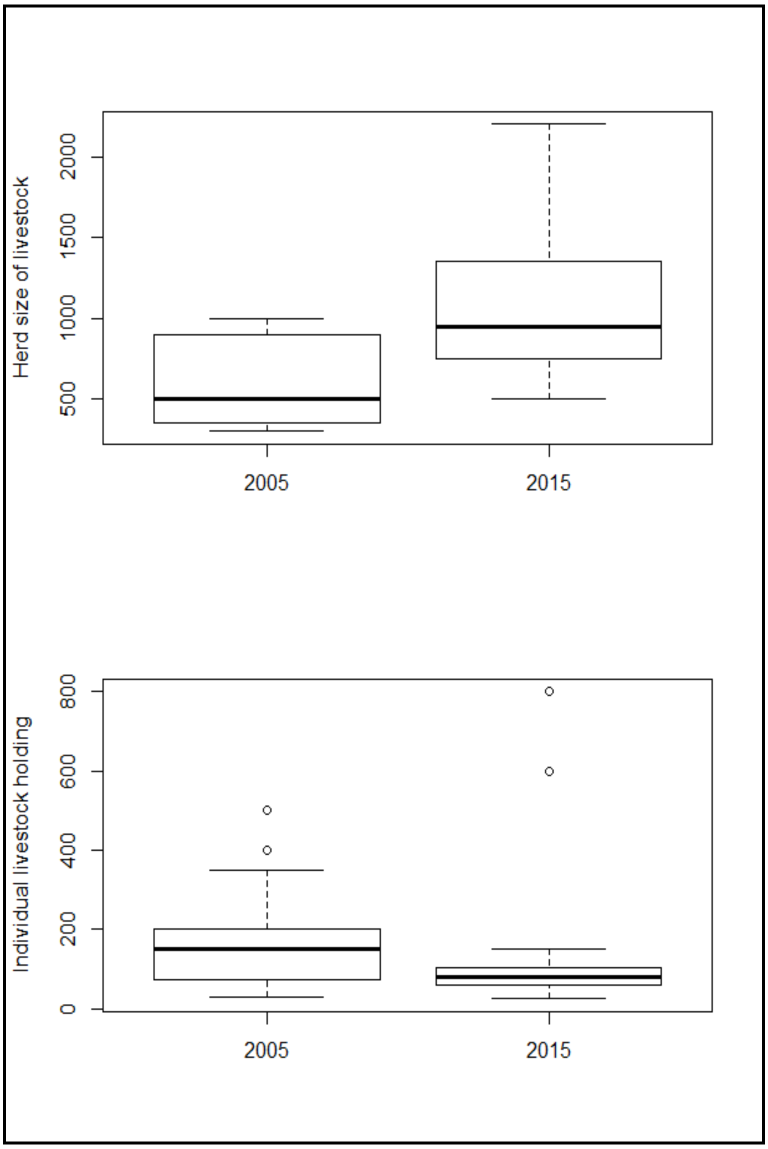

Figure 3.2: Changes in herd size and individual livestock holding of migratory herder community over the past decade.

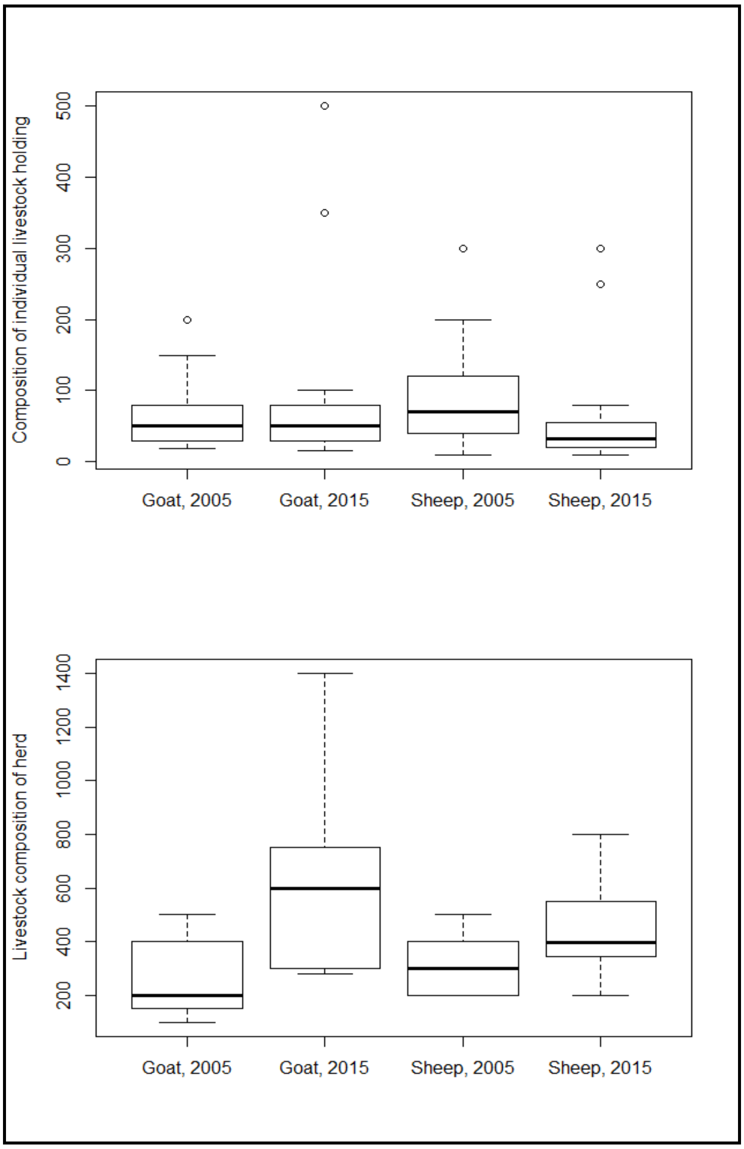

Figure 3.3: Changes in individual livestock (sheep-goat) holding composition and herd composition of migratory herder community over the past decade.

Changes in prices of livestock products

Prices of livestock products (adult sheep-goat and wool) increased over the past decade (Figure 3.4). Over the past decade, mean minimum and mean maximum prices of adult goat increased by 288.72% and 209.76%, respectively (Figure 3.4a). For an adult goat, mean minimum price was INR 3,692.31 (SE ± 468.23) in 2005, while mean minimum price was INR 14,352.94 (SE ± 505.09) in 2015. Mean maximum price of adult goat was INR 5,428.57 (SE ± 438.25) in 2005 and INR 16,815.80 (SE ± 470.40) in 2015.

Over the past decade, mean minimum and mean maximum prices of adult sheep increased by 271.85% and 298.75%, respectively (Figure 3.4a). For an adult sheep, mean minimum price was INR 2,375.50 (SE ± 281.50) in 2005, while INR 8,833.33 (SE ± 380.13) in 2015. Mean maximum price was INR 2,884 (SE ± 181.35) in 2005, while INR 11,500 (SE ± 279.30) in 2015.

Over the past decade, white-wool price increased by 71.8%, while black-wool price increased by 68.85% (Figure 3.4b). Mean price of white-wool was INR 39.00 (SE ± 4.60) in 2005, while INR 67.00 (SE ± 1.64) in 2015. Mean price of black-wool was INR 30.50 (SE ± 5.14) in 2005, while INR 51.50 (SE ± 2.36) in 2015.

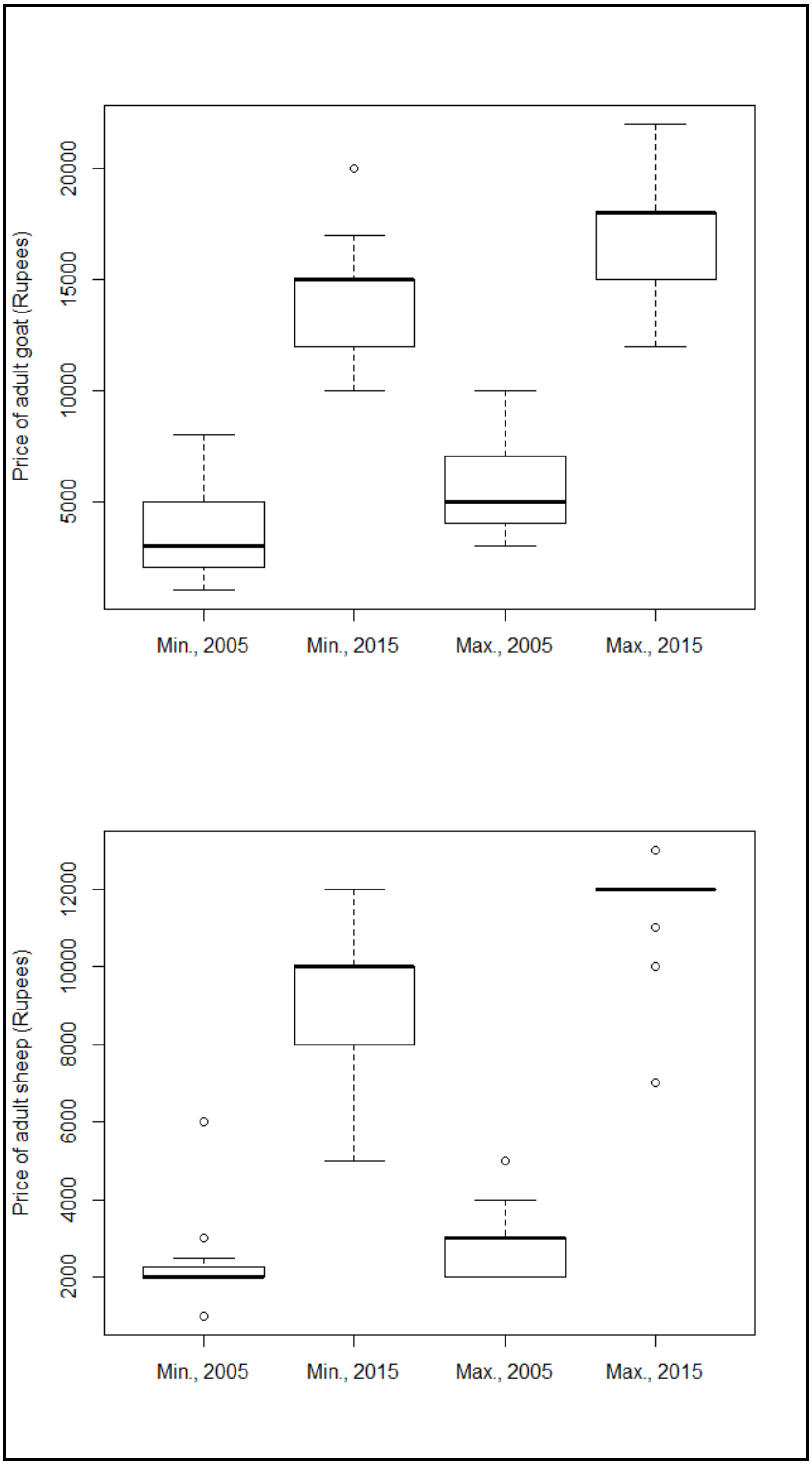

Figure 3.4a: Changes in prices of adult goat and adult sheep of migratory herder community over the past decade.

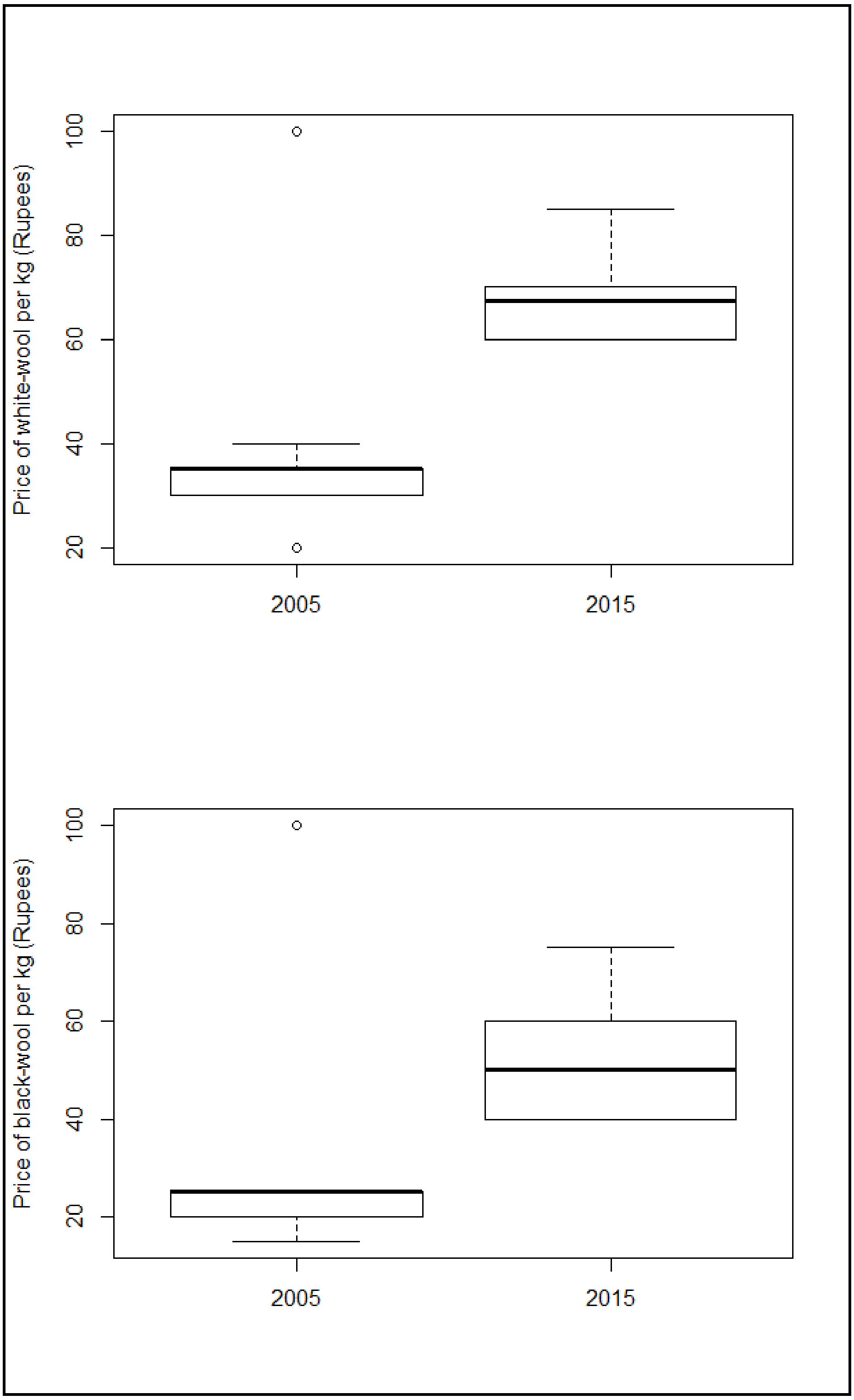

Figure 3.4b: Changes in prices of white- and black-wool of migratory herder community over the past decade.

Changes in pasture quality

<u>Perceptions of migratory herders</u>

Indicator of pasture quality

Migratory herders identified 14 palatable species as indicator of pasture quality. Grasses were reported as indicator by 88% herders, while herbs were reported by 96% herders. Out of the 25 herders interviewed, 40% reported *Leymus* sp., 36% reported *Cicer* sp., 24% reported *Stipa* spp., 16% reported *Aconogonum* sp. and *Artemisisa* sp., respectively, 12% reported *Nepeta* sp. and *Kobresia* sp., respectively, 8% reported *Lindelophia* sp. and 4% reported *Elymus* sp., *Festuca* sp., *Poa* sp. and *Astragalus* sp., respectively, as indicator species. A couple of species (reported by two respondents) remained unidentified. Migratory herders identified 11 unpalatable species, of which only four could be verified and identified, namely, *Caragana*, *Eremurus*, *Potentilla* and *Stipa*. The herders suggested *Stipa*, although palatable by livestock during spring (April-May), was unpalatable during peak summer (July-August).

Perceived changes in pasture quality

Pasture quality was reported to be changing over the past decade by 96% migratory herders. Only one herder reported no change in pasture quality. The 96% respondents reported degradation of pasture quality.

Perceived changes in vegetation attributes in pasture

The migratory herders reported three changes in vegetation attributes of pastures, namely, 'decreasing pasture area' – the extent of pastures are declining, 'palatable forage decreasing' – availability of palatable plant species are declining and 'unpalatable forage increasing' – availability of unpalatable plant species are increasing. Decline in availability of palatable species was reported by 76% herders. About one-third (28%) of herders reported decreasing pasture area and increase in availability of unpalatable species, respectively.

Perceived reasons for change in pasture quality

Migratory herders reported seven reasons for changes in pasture quality over the past decade, namely, climate (irregular rain and snow, increasing aridity and increasing summer and winter temperatures), fodder collection by local villagers, intense grazing, pollution (dirt deposition on snow hastening melting), repeated grazing in same pastures, restricted access to pasture and soil erosion (Table 3.1a). Majority of respondents (60%) reported irregular rain and snow as the reason for changes in pasture quality, 52% reported intense grazing, 36% reported pollution, 12% reported soil erosion, 8% reported increasing aridity, increasing summer and winter temperatures and restricted access to pasture, respectively, while 4% reported fodder collection by local villagers and repeated grazing in same pastures, respectively.

Perceived implications of changes in pasture quality

As a result of changes in pasture quality, seven implications were identified by migratory herders: chronic weakness in livestock (sheep-goat), decreasing body-size of livestock, reduced milk production by livestock, occurrence of frequent disease (foot and mouth disease, respiratory disease and lose-motion) in livestock, sudden mysterious death of livestock, lowered regeneration in pastures and seeking new pastures. Occurrence of frequent disease was reported as an implication by 44% herders, 32% reported decreasing body-size of livestock and reduced milk production by livestock, respectively, 20% reported they had to find new pastures every three to five years, 8% reported chronic weakness in livestock and low regeneration in pastures, respectively, while one herder (4%) reported livestock dying suddenly, potentially due to consumption of unpalatable species.

Table 3.1a: Perceived reasons for decline in pasture quality by migratory herder community of Rupi – Bhaba area, Kinnaur, Himachal Pradesh.

Perceived reasons for decline in pasture quality	**Percentage of respondents**
Climate-irregular snow and rain	60
Intense livestock grazing	52
Pollution-air	36
Soil erosion	12
Restricted access to pastures	8
Climate-aridity	8
Climate-increasing temperature	8
Repeated grazing on same pastures	4
Fodder collection	4

Suggested mitigations to address changes in pasture quality

Migratory herders offered four mitigation options to address perceived degradation of pasture quality, restriction on access to pastures be lifted, increasing return from livestock, reducing livestock numbers and rotation of pastures (Table 3.1b). These options were offered by 11 out of the 25 (44%) herders interviewed, while the rest (56%) did not suggest any mitigation option. Of the 11 herders offering mitigation options, 45% suggested reducing livestock numbers, 36% suggested rotation of pastures, while 9% (one herder) suggested increasing return from livestock and restriction on access to pastures be lifted, respectively.

Table 3.1b: Suggested mitigation options to counter decline in pasture quality by migratory herder community of Rupi – Bhaba area, Kinnaur, Himachal Pradesh.

Perceived mitigation options	Percentage of respondents
Reducing livestock population	45
Rotational grazing on pastures	36
Increasing return from livestock	9
Increasing access to pastures	9

Perceptions of local community

Indicator of pasture quality

The local community identified the following factors as indicators of pasture quality: availability of grass, herb, water, medicinal plants and fuel-wood, soil moisture and presence of gentle slope. Decline in grass availability, denudation and increasing rock - cover were identified as indicators of pasture degradation.

Leasing pastures to migratory herders

Villages traditionally hold rights over pastures of the study area for local livestock grazing, agriculture and collection of natural resources (building materials, fuel-fodder and medicinal plants). Local community of all three villages expressed willingness to lease pastures to migratory herders. Their willingness to lease pastures was based on six rationales: Tradition – for centuries the migratory herders from neighboring Rupi-Bhaba area have been coming to Pin Valley to graze livestock during summer. Income: the migratory herders pay fees for pasture grazing (ranging from INR 2,000 – 16,000 per year per pasture) and trail-damage (trampling of route to pasture; INR 2,500 per year) to village councils. These fees are used for communal activities in villages, e.g. repairing community hall, contribution toward religious activities. Dung – excreta of sheep-goat is considered as one of the most effective manure for agricultural fields. Villagers collect dung of sheep-goat of migratory herders from pastures during autumn to be used as manure on agricultural fields for the coming spring. Source of meat – migratory herders gift sheep-goat individuals to key members of local community based on long-standing relationship, either with the herder himself and/or his forebears. The key members may share the meat with other villagers. Unused pasture – pastures far away from villages are often not accessed or directly used by local community. Such pastures when leased to migratory herders yield income to villages and dung to villagers. The migratory herders are not allowed to graze areas where free-ranging large livestock (donkey, horse, yak, cow and yak-cattle hybrids) of villages graze. Spiritual – A local deity of the neighboring Rupi-Bhaba area, worshipped and revered by both local community of Pin Valley and migratory herders of Rupi-Bhaba, had designated Pin Valley as an area to which herders should have access. The local community of Pin Valley continue to comply with this decision.

Perceived effects of migratory livestock grazing on pastures

The local community suggested migratory livestock grazing affects pasture quality through degradation (rapid degradation was suggested by two villages, while one village suggested gradual degradation).

Degradation of pasture quality was suggested to be manifesting through five ways: lowered seed dispersal – continuous foraging on plants by migratory livestock since late - spring through summer (the main growing period) impairs flowering, seed formation, seed development and dispersal; reduced plant growth – repeated foraging on same tracts of a pasture hinder growth of plants; increase in unpalatable species – owing to high intensity of grazing palatable species are overcome by unpalatable species; decline in medicinal plant availability – areas grazed by migratory livestock show low availability of medicinal plants; and landslide / denudation – trampling by livestock loosens top-soil making pastures grazed by migratory livestock prone to landslide and subsequent denudation.

Mitigations suggested to address effects of migratory livestock grazing

The following mitigation options were suggested by the local community to manage migratory livestock grazing: reducing livestock numbers – reduction in livestock population will reduce grazing pressure on pastures; restricting pasture area to be used for migratory livestock grazing – demarcating certain areas within a larger pasture for migratory livestock grazing; rotational grazing – certain pastures be left ungrazed for two-three years; pastures rich in medicinal plants be identified and protected; and short-term lease contract with migratory herders rather than open ended or long-term contract.

Potential for migratory livestock product diversification

Wool product diversification

Majority of migratory herders (56%) reported there is potential for diversification of wool products from migratory livestock, 40% were not sure, while 4% did not think there is a potential (Table 3.2a).

Table 3.2a: Perceived potential for livestock product diversification to increase income of migratory herders in Rupi-Bhaba area, Kinnaur, Himachal Pradesh.

	Wool	**Milk**	**Meat**
Agree	56	24	-
Disagree	4	28	36
Not sure	40	48	64

Migratory herders suggested nine wool products that might be used to increase income from livestock, blanket, carpet, men's coat, gloves, rope, shawl, sock, sweater and women's local attire (Table 3.2b). More than a third of the herders (36%) suggested blanket and women's local attire, respectively, nearly one - third (28%) suggested carpet, men's coat and sock, respectively, 24% suggested gloves, 20% suggested shawl, while 4% suggested rope and sweater, respectively.

Milk product diversification

Sheep-goat milk produce was suggested to be inadequate for subsistence consumption. However, domesticated cow's milk was suggested to be widely available. For milk products, 24% reported potential for diversification, 48% were not sure, while 28% did not think there is a potential (Table 3.2a). Overall, nine products were suggested, cheese, butter, yoghurt, clarified butter (*ghee*) and lassi (yoghurt-based drink) (Table 3.2b).

Cheese was suggested by 24% herders, 16% suggested yoghurt and clarified butter, respectively, 12% suggested butter, while 8% suggested lassi.

Meat product diversification

For meat product diversification, 64% were not sure, while 36% did not think there is a potential (Table 3.2a). No meat products were suggested by migratory herders as potential diversification product.

Table 3.2b: Suggested wool and milk products for livestock product diversification by migratory herder community of Rupi – Bhaba area, Kinnaur, Himachal Pradesh.

Livestock resource	Products	Percentage of respondents
Wool	Blanket	36
	Women wear	36
	Carpet	28
	Coat	28
	Socks	28
	Gloves	24
	Shawl	20
	Sweater	4
Milk	Cheese	24
	Clarified butter (ghee)	16
	Yoghurt	16
	Butter	12
	Lassi	8

<u>Steps suggested to implement diversification of livestock products</u>

Migratory herders suggested five requirements to diversify livestock products, training, improvement of quality of products, better packaging, better marketing and financial support. Training was suggested by 40% herders, 28% herders suggested better marketing, 8% suggested quality improvement of products and better packaging, respectively, while 4% suggested the need for financial support.

Discussion

I set out to understand changes in migratory livestock grazing practice in *Kinnaura* community of the Himalaya over the past decade. I also examined perceptions on changes in pasture quality, perceived implications of these changes on pasture quality and livestock health and ways to mitigate challenges in migratory herder and local communities. Herd size nearly doubled, while individual livestock holding showed marginal decline over the past decade in migratory herding practice. Number of goat in individual livestock holding marginally increased, while that of sheep declined over the past decade. Number of goat in herd increased sharply while that of sheep marginally increased over the past decade. Migratory herder and local communities consistently reported degradation of pasture quality over the past decade, mainly owing to intense livestock grazing, climate change (irregular rain and snow) and pollution. As a result of perceived pasture degradation, migratory herder community reported frequent disease outbreak and decrease in body-size of sheep-goat. The migratory herders now have to frequently seek out pastures that are not degraded. Reduction in livestock number and rotation of pastures were suggested as potential mitigations to address pasture degradation. There is high potential to diversify livestock products to increase income of migratory herders.

The Kinnaur District, from where the Kinnaura migratory herders belong, experienced a steady growth in apple cultivation as a cash-crop since 1950s (Sharma, 2005; Rana *et al.*, 2011; Basannagari & Kala, 2013). In 1980s, cash-based and market-oriented cultivation of apple emerged in Kinnaur (Sharma, 2005; Kala; 2007; Sarkar, 2010), as was observed in neighboring Spiti around the same time with green-pea cultivation (Mishra, 2001). Informal discussion with migratory herders suggest many pasture permit-holders (*bara maaldar*, with forest department permit to access summer and winter grazing areas), turned to apple cultivation. This shift in agriculture perhaps played an important role in decline of traditional polyandry and increase in monogamy (Mann, 1996; Pathania, Kaur & Pathania, 2008; Sarkar, 2008; Gautam & Kshatriya, 2011), in turn giving rise to more individuals with relatively smaller livestock holding, as maintaining large herd is labor intensive. Herders with limited land ownership and lack of other employment option, however, continued to practice migratory livestock grazing in place of the bara maaldar (an annual fee of INR 25,000 – 50,000 per annum is paid by herder to bara maaldar depending on area of pasture). These herders, now with *de facto* right on pastures of bara maaldars, in addition to their own livestock, pooled livestock of other local people who were unable to practice migratory livestock grazing. A similar trend of increasing contracting among herders can be observed in *Gaddi* community of migratory herders from other districts of Himachal Pradesh (Axelby, 2007), as well as Tibetan herder communities (Yeh *et al.*, 2017). The contributors of livestock to a herd pay a fee per animal (usually *ca*. INR 100 per goat per season and INR 50-70 per sheep per season) to the lead herder. The lead herder of a group, usually a man with extensive grazing experience having personal livestock holding, recruit *phoyal* (helper / labor). Phoyal might be unpaid, if they are fellow villagers or relatives joining a herd with their own livestock, or paid if they are immigrants from other states. Immigrant phoyal may be paid in cash (roughly INR 100,000 per year) and/or in kind (sheep-goat equivalent to INR 100,000). Some of the phoyals, thus, gradually grow their own small herd within three to five years of grazing with lead herders. Therefore, contribution of livestock from non-herding local peoples and immigrant laborers continue to increase overall herd size, while individual livestock holding of herders remains low.

A major motivation to increase goat in migratory livestock grazing practice is perhaps the sharp increase in market price for goat-meat, as reflected in the marked increase in prices of live adult goat (sold for meat) over the last decade. A drastic rise in goat numbers was observed in *changpa* community of neighboring Ladakh owing to increased demand of *pashmina* wool (Namgail *et al*., 2007; Bhatnagar & Singh, 2011). Additionally, goat is considered easier to herd than sheep by migratory herders, as they are more agile and adaptable to the rugged terrain of the mountains. While sheep price also increased over the last decade, the rise in sheep numbers was not as marked as goat, possibly owing to challenges in sheep herding. Sheep requires undulating meadows for grazing, largely unavailable during winter due to snow cover. Further, sheep requires fresh foliage during stall-feeding in winter, while goat can browse and survive on dry fodder.

The reported indicators of pasture quality (mainly species of grass and herbs) by migratory herder and local communities are in line with known palatable species of livestock in the study area (Bagchi *et al.*, 2004). Migratory herder and local communities consistently reported degradation of pasture quality over the last decade. Main reasons reported being climate change (irregular rain and snow), intense grazing and pollution. Similar reports of perceived degradation of pasture from pastoral communities have been described from South Asia (Sharma *et al.*, 2009; Singh *et al.*, 2015), East and South Africa (Solomon *et al.*, 2007; Allsopp *et al.*, 2007). While precipitation in Lahaul & Spiti District has indeed been irregular in recent times (Singh *et al.*, 2015), with marked decline in summer and winter precipitation, evidence of degradation of Trans-Himalayan rangelands due to intense livestock grazing is abundant (Mishra *et al.*, 2004; Bagchi & Ritchie, 2010; Suryawanshi *et al.*, 2010; Bagchi, Bhatnagar & Ritchie, 2012). The major implications of perceived pasture degradation on livestock were outbreak of disease (foot and mouth disease, respiratory disorder and lose motion), reduced body-size and milk production and need for migratory herders to find new pastures to graze livestock. These perceived factors indicate 'overstocking' of the pastures to a degree when livestock production is compromised (Mishra *et al.*, 2002).

In parallel with the perceptions of migratory herder and local communities on pasture degradation due to intense livestock grazing, an ecological assessment of impact of migratory livestock grazing on rangelands in Pin Valley found significant lowering of graminoid and herb biomass in areas intensely grazed by migratory livestock (Chapter 3). Graminoid and herb are key forage for livestock and wild-ungulates, such as ibex

(Bagchi *et al.*, 2004). Significantly lowered forage availability is a serious issue, not just for local communities, native wild-ungulates and endangered predator, such as the snow leopard, but also for migratory herder community themselves. This scenario provides a consensus between perception of key stakeholders (migratory herder and local communities) and independent ecological findings, thus offering an opportunity to develop participatory rangeland management practice.

Livestock-free community reserves in partnership with stakeholders have been suggested as an immediate intervention for conservation of Trans-Himalayan rangelands and wild-ungulates facing intense livestock grazing (Mishra *et al.*, 2003; Suryawanshi *et al.*, 2010). Migratory herder community suggested mainly reduction in livestock numbers as a potential option to mitigate perceived degradation of pasture quality. However, actually reducing livestock numbers at community level has been a long-standing challenge for conservation practitioners and management agencies (Mishra *et al.*, 2004; Suryawanshi *et al.*, 2010). In the long-term, along with livestock-free reserves, diversification of livestock products (wool, milk and meat) in partnership with migratory herder community might be a potential option to incentivize gradual reduction in livestock numbers. Initiatives based on local handicrafts (Mishra *et al.*, 2003; SLN, 2014) have been able to increase household income of about 250 herders by 40% across four countries in Central and South Asia, including India, through training, improving quality of products, better packaging and marketing. The combination of livestock-free community reserves and diversification of livestock products will account for economic and ecological interests of migratory herder and local communities, while strengthening conservation of rangelands, wild-ungulates and endangered large carnivores, such as the snow leopard, in the Himalaya and Trans-Himalaya.

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Chapter 5

Synthesis

This thesis explores the factors affecting patterns of occurrences and relative abundance of snow leopard and wild-prey across a large mountainous landscape and at fine spatial scale. In this chapter, I present a synthesis of the main findings from the thesis. I also discuss the limitations of this work and explore future research and conservation avenues for strengthening ecological understanding on snow leopard and wild-prey and their conservation in the Indian Himalaya at broad and fine spatial scales and in the short- and long-term.

Snow leopard and wild-prey distribution

Overall, snow leopards and wild-prey continue to occur across the Greater and Trans-Himalaya mountains, not restricted to the protected areas. This finding is consistent with a handful of other empirical studies looking at snow leopard distribution across large landscape (Johansson *et al*., 2016; Taubmann *et al*., 2016). Snow leopard and wild-prey distribution were likely to be positively affected by ruggedness and varied as a quadratic function of altitude. This indicates snow leopard and wild-prey occurrence is more likely to occur in areas with rugged terrain within an altitudinal range of 3,200m-5,200m, as also suggested by studies of snow leopard and wild-prey habitat use at finer spatial scales (Chundawat, 1992; Bhatnagar, 1997; McCarthy, 2000).

A noteworthy finding was snow leopard had very low likelihood to occur in 25% of presumed snow leopard habitat within the surveyed area. Large scale analysis of snow leopard populations (e.g., SLWS, 2013; SLN, 2014; McCarthy & Mallon, 2016) often extrapolate snow leopard distribution across large areas of potential habitat, but fail to account for the inherent variations in intensity of use within. The results caution against such extrapolations, and emphasize the importance of assessing snow leopard distribution using replicable methods that account for imperfect detection.

Blue sheep and ibex are known to be negatively affected by intense livestock grazing. For blue sheep, research shows out-competition by local livestock in heavily grazed areas due to interference and exploitative competition (Mishra, 2001; Suryawanshi *et al.*, 2010; Kohli *et al.*, 2014). Ibex faces intense interference competition from migratory livestock grazing through spatial segregation of ibex to cliff-dominated areas from pastures during summer (Bhatnagar, 1997; Bagchi *et al.*, 2004). Exploitative competition is manifested through strong overlap in graminoid-dominated diet of ibex and migratory livestock (Bagchi *et al.*, 2004), forage removal by livestock, decline in population density and spatial displacement of adult females and yearlings of ibex (this study). At wide spatial scale these patterns hold in the context of blue sheep and ibex distributions. Blue sheep distribution was restricted to areas not grazed by migratory livestock (in central and south-eastern Spiti and central, northern and eastern Kinnaur), while ibex still persists in such areas at low density (south-western Spiti and Kinnaur, Lahaul and Pangi).

Blue sheep and ibex differ in terms of their origin, ibex originating and dispersing from Mediterranean and the Middle East, while blue sheep originating and dispersing from the Tibetan Plateau (Schaller, 1977). In Himachal Pradesh, ibex appears to be radiating in from the north-west, while blue sheep appears to be radiating in from the north, east and north-east. Both species use cliffs as escape terrain similarly (Schaller, 1977; Schaller, 1998; Namgail, 2006), but ibex, being a true goat species, is more cliff-bound than blue sheep (Schaller, 1977; Bhatnagar, 1997). The two species, thus, appear to pose considerable resistance to each other to radiate into their respective ranges along the area where their distributions meet from the Sutlej and Spiti valleys in Himachal Pradesh, through Ladakh in Jammu and Kashmir, to the Taxkorgan Reserve in Xinjiang (Schaller, 1998).

Through radiations during the Pleistocene (Schaller, 1977), ibex might have colonised and established populations in areas which are now extensively and heavily grazed by migratory livestock, perhaps before blue sheep could. Blue sheep might not have been able to penetrate and establish population in Lahaul, northern and south-western Spiti and south-western Kinnaur this far, potentially owing to a combination of resistance (competition) from established ibex populations (Schaller, 1997; Schaller, 1998), competition with migratory livestock and topographic constraints. Relatively broken and cliff-dominated terrain in northern Spiti may have restricted westward penetration of blue sheep into ibex-occupied areas of Lahaul. Blue sheep is found extensively and at relatively high densities in downstream areas of the Spiti Valley, especially the left bank and parts of the right bank (USL, 2011; Suryawanshi *et al.*, 2012), where terrain is relatively gentle and ibex and migratory livestock are largely absent. Ibex seems to persist in intensely grazed areas of Pangi, Lahaul, northern and south-western Spiti and south-western Kinnaur, probably at much low density, in the very steep cliff-dominated areas, which are rarely accessed by livestock (Bagchi *et al.*, 2004). The combination of intense migratory livestock grazing and sparse occurrence of wild-prey may already have rendered Lahaul (especially the Chandra Valley) and northern Spiti (areas adjoining Kunzum La to Lossar, including Kabji and Pilung nalas) unsuitable for snow leopard, though apparently extensive tracts of potential snow leopard habitat exist. Such 'gap' in the otherwise contiguous habitat of snow leopard may reduce the potential for genetic exchange between snow leopard populations inhabiting areas to the west and east of Lahaul and northern Spiti.

Migratory livestock grazing: its ecological impacts on snow leopard habitat

Having explored the distributions of snow leopard and wild-prey across a large landscape in the second chapter that suggests an overwhelming role of migratory livestock grazing in shaping blue sheep and ibex distributions, the third chapter attempted to answer the questions whether and how migratory livestock grazing affects the snow leopard habitat. I looked into an area heavily grazed by migratory livestock versus another contiguous area not grazed by migratory livestock. I compared vegetation cover and biomass and ibex densities and young : adult female ratios across these two areas by repeated sampling.

Migratory livestock grazing showed significant negative impacts on vegetation biomass. Graminoid and herb biomass were significantly lower in grazed than ungrazed area. Overall vegetation composition was dissimilar across grazed and ungrazed areas, but palatable species composition was similar. However, the overall biomass of palatable species in ungrazed area was double that of the grazed area. Majority of top contributing individual palatable species showed much lower biomass in grazed than ungrazed area. The overall off-take of dry forage biomass by migratory livestock in grazed area was 10,656 kgs/km^2 over two months of grazing.

Ibex density was consistently higher in ungrazed than grazed area. Young to adult female ratios and kid to adult female ratios were similar across grazed and ungrazed areas. However, yearling to adult female ratio was six times higher in ungrazed than grazed area during peak summer. This indicates spatial displacement of adult females along with yearlings by migratory livestock in the grazed area.

The fact that despite the ibex population in this study may not be a 'closed' population (since grazed and ungrazed areas are contiguous) and still the patterns of lower ibex densities is evident in the grazed area reiterates the results. Poor forage biomass availability in grazed area is lowering ibex population density through exploitative competition, although fecundity in ibex is similar in ungrazed and grazed areas.

Existing research shows interference competition between migratory livestock and ibex (Bagchi *et al.* 2004). This study indicates prevalence of exploitative competition between migratory livestock and ibex. These findings contribute to resolve the long-standing challenge of unavailability of scientific evidence on impacts of migratory livestock grazing on Himalayan rangelands and wild-herbivore population (Saberwal, 1996; Mishra & Rawat, 1998; Saberwal, 1998). Researchers, managers, bureaucrats and politicians will be benefited from the results suggesting exploitative competition between a primary prey of snow leopard and migratory livestock grazing. Snow leopard density is closely related to wild-prey densities (Suryawanshi, 2013; Sharma *et al.*, 2015). Perhaps owing to low density of ibex, snow leopard density in the Pin Valley National Park is also low (Density 0.53 individuals/100 km^2; 95% Confidence Interval 0.21 - 1.36 individuals/100 km^2; Unpublished Data, NCF). This pattern may also explain the very low likelihood of snow leopard site-use in parts of Lahaul as explained in the previous section.

Changes in migratory livestock grazing practice: its implications on the pastoral system and snow leopard habitat

Given the impacts of migratory livestock grazing on rangeland vegetation and ibex density, the fourth chapter explored the underlying reasons due to which the impacts were being manifested. Visiting the summer and winter grazing pastures of migratory herders and their home-villages, through interviews with more than 50% of the migratory herders grazing in the study area, I assessed changes in herd sizes and composition, individual livestock holding and composition and prices of livestock products. I also assessed perceptions of the migratory herders on changes in pasture quality, reasons for changes in pasture quality, its perceived implication on rangeland vegetation and livestock health and perceived mitigations. Since migratory herders access summer pastures, the *de facto* rights of which are with villages, I looked into perceptions of local community on impacts of migratory livestock grazing, their motivations to lease out pastures to migratory herders and perceived options to counter the impacts of migratory livestock grazing.

Results suggest herd size nearly doubled over the past decade. The trend of livestock population in the Himalaya and Trans-Himalaya has been long debated, again, due to lack of robust evidence (Saberwal, 1996). This has seriously hindered rangeland management in the Himalaya (Rawat, 1998; Mishra, 2001). The results showing sharp increase in livestock population is consistent with the pattern of livestock population increase across the Himalaya (Tulachan, 2001). Individual livestock holding marginally declined over the past decade, presumably owing to reduced availability of man-power, following a boom in apple market during 1980s and splitting of joint families into nuclear families (Sharma, 2005; Kala; 2007; Sarkar, 2010). Number of goats in individual livestock holding marginally increased, while that of sheep declined over the past decade. Number of goat in herd increased sharply while that of sheep marginally increased over the past decade. Migratory herder and local communities consistently reported degradation of pasture quality over the past decade, mainly owing to intense livestock grazing, climate change (irregular rain and snow) and pollution. As a result of pasture degradation, migratory herder community reported frequent disease outbreak, decrease in body-size of goat-sheep, decrease in palatable species and increase in unpalatable species. The migratory herders now have to seek new pastures that are not degraded. Reduction in livestock number and rotation of pastures were suggested as potential mitigations to address pasture degradation. There is high potential to diversify livestock products to increase income of migratory herders.

The findings from this work reflect the ecological impacts observed in the third chapter. Increase in livestock population in 'traditional' grazing communities has been reported in the *Changpa* community of the Changthang region of Ladakh (Namgail *et al.*, 2007). In case of the *Changpa*, the increase in overall livestock population, especially that of goat, has been attributed to increased market demand and price of *pashmina* wool. For the Kinnaura community of migratory herders, the increase can be attributed to higher income from selling adult goat in comparison to sheep and the relative ease of herding and stall-feeding goat than sheep, during summer and winter. Perceived degradation of pasture has been reported widely from numerous grazing communities of South Asia (Sharma *et al.*, 2009; Singh *et al.*, 2015), East and South Africa (Solomon *et al.*, 2007; Allsopp *et al.*, 2007). A significantly lowered forage availability is a serious issue, not just for local communities, native wild-ungulates and endangered predator, such as the snow leopard, but also for migratory herder community themselves. This scenario provides a consensus between perception of key stakeholders (migratory herder and local communities) and independent ecological findings, thus offering an opportunity to develop participatory rangeland management practice.

Findings from the third chapter suggest exploitative competition between migratory livestock and ibex, while the findings from the fourth chapter showed perceived pasture degradation due to intense grazing and climatic changes. Perhaps the immediate need is to set up livestock-free community reserves in areas intensely grazed by migratory livestock through consultation with migratory herder and local communities (Mishra *et al.*, 2002; Suryawanshi *et al.*, 2010). Such reserves have been able to improve blue sheep populations in the Trans-Himalaya (Mishra *et al.*, 2003). However, livestock-free reserves are usually relatively small with respect to the larger conservation needs of wild-ungulates and snow leopard. For the long-term, participatory and equitable options need to be explored to reduce livestock densities in Trans-Himalayan pastures for conservation of wild-ungulates, such as Asiatic ibex and endangered predator like the snow leopard. Initiatives such as Snow Leopard Enterprise (SLE) based on local handicrafts (Mishra *et al.*, 2003; SLN, 2014) have been able to increase household income of about 250 herders by 40% across four countries in Central and South Asia, including India, through training, improving quality of products, better packaging and marketing. The combination of livestock-free community reserves and promotion and diversification of livestock based products can account for economic and ecological interests of migratory herder and local communities, while strengthening conservation of rangelands, wild-ungulates and endangered large carnivores, in the Himalaya.

Limitations and opportunities

The results on snow leopard and wild-prey distributions in Chapter 2 showed associations of the *a priori* selected covariates with the probabilities of site use. These associations are only for probability of site use or occurrence, not density. A factor affecting probability of site use or distribution in a certain way (positive or negative association) may or may not affect density in the same way. This distinction is important to interpret results appropriately from occupancy based work and avoid far-fetching and misleading conclusions.

The observed patterns and associations are only relevant at the scale of the work (sampling unit was 15km X 15km grid cells considering mean snow leopard home range of 207 km^2). These patterns may or may not hold if the scale is varied. Further, I emphasize the associations of the covariates used to model probability of site use of snow leopard and wild-prey be treated only as 'correlation', not as 'causation'.

The approach of this work using secondary survey based occupancy analysis following Pillay *et al.* (2011) and Taubmann *et al.* (2016) is an effective way to assess past and recent distributions of hard-to-sample species over a large area. The method accounts for imperfect detection and is replicable. This kind of work across the Indian snow leopard habitat can provide reliable probabilistic distribution maps of snow leopard, co-predators and wild-prey, an important prerequisite for conservation planning in the Indian Himalaya. The method is also useful to explore threats, both traditional and emerging ones, that may have contributed to any declines or local extinction of populations of study species.

Since migratory livestock grazing was found to be a widespread threat in ibex distribution range and presumably an important factor affecting distribution of blue sheep (blue sheep was not found to occur in areas with migratory livestock grazing) (in Chapter 2), an ecological study was designed to estimate the effects of migratory livestock grazing on vegetation and ibex density at a much finer spatial scale (in Chapter 3). The study had to be implemented in one set of ungrazed versus grazed area within one valley system. Finding one or more appropriate replicate (comparable area with migratory livestock grazing and a sizeable ibex population) was a serious challenge in the mountainous terrain as biogeography and climate patterns vary, often from one valley to the next, in the Himalayas. Including areas that differ in biogeographic and climatic factors and in turn vegetation type and composition, as replicates, would confound results, limiting ability to draw clear conclusions despite intense efforts. Studies exploring impacts of migratory livestock grazing on other wild-prey of snow leopard will be useful to further strengthen our understanding on the subject, e.g. effects of migratory livestock grazing on blue sheep may be studied in Uttarakhand.

In Chapter 3, the effects of migratory livestock grazing were assessed on vegetation cover and biomass. Following up from this work, future investigators may look at the effects of migratory livestock grazing on productivity, plant species composition, below-ground biomass, plant and soil nutrient contents and spread of non-palatable species. These ecological understandings will help in strengthening participatory conservation planning with the resident and the migratory herder communities.

In Chapter 3, young to adult female ratios were observed to be similar in migratory livestock grazed and ungrazed area. Yearling to adult female ratio was six times higher in the ungrazed than grazed area only during peak summer (during grazing period). This finding is partially consistent with effects of livestock grazing on blue sheep population and young survival in the Himalaya (Mishra *et al*., 2004; Shrestha & Wegge, 2008; Suryawanshi *et al*., 2010). The results indicate young individuals of ibex are able to counter the effects of livestock grazing, perhaps by shifting to areas not grazed by migratory livestock or by being more cliff-bound. However, the mechanisms through which young survival is affected by migratory livestock grazing need better understanding. Based on existing literature (Scornavacca *et al*., 2016) young survival in wild-ungulates may decline due to reduced investment by adult females on maternal care towards young individuals to compensate high cost of self-maintenance. This might be manifested through lowered forage availability due to intense grazing by livestock.

The work on the perceptions of migratory herder and local communities on changes in pasture quality showed serious concerns for pasture degradation among both communities (Chapter 4). Although their perceptions were consistent with independent ecological findings showing drastic reduction in forage availability, the perceived reasons for pasture degradation and implications on rangeland vegetation and livestock health should not be treated as a causal relationship.

Chapter 3 and Chapter 4 focused on Kinnaura migratory herder community of Kinnaur, while the local community was represented by residents of Pin Valley, Spiti, where the Kinnaura herders access summer-pastures. There are other migratory herder communities across the Western Himalaya, e.g. *Gaddi* in Himachal Pradesh, *Gujjar* in Uttarakhand, *Changpa* in Ladakh and *Bakkarwal* in Kashmir, who seasonally access pastures in the snow leopard and wild mountain-ungulate habitat. Research on ecological impacts of grazing by these communities, changes in their grazing practices and understanding challenges and prospects can be useful to strengthen livestock grazing and rangeland management across the snow leopard habitat in Western Himalaya.

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Appendices

Supplementary material S1: Questionnaire for key-informant survey to document detection/non-detection of snow leopard and wild-prey in Greater and Trans-Himalaya of Himachal Pradesh, India.

Interview No: ________________; **Latitude:** ___________________________; **Longitude:** _____________________________

RESPONDENT'S ATTRIBUTES

Name ____; **Age:** ______________; **Gender** ____________________;

Occupation _________________________; **Village/Town** ______________________; **District** ____________________;

Community _________________

Q1. Details about your area of knowledge / activities

Area (valley/range name, show on map)

Activities (e.g. patrolling, grazing, fuel wood/fodder collection etc)

Time of activity (e.g. season)

Duration of time spend per year (days / months)

Total duration of familiarity with the area (in years)

RESPONDENT'S KNOWLEDGE ON SNOW LEOPARD

Q2. Have you heard of snow leopard/ barfila cheetah/ safed cheetah/Shin? Yes/ No

Q3. Have you seen Snow leopard: Yes / No; **evidence**: Yes / No (Scat / scrape / pug-mark / kill)

Q4. Which of these do you identify as snow leopard? (Showing photos of snow leopard along with some other similar sized felids)

Correct identification/ Wrong identification

Q5. Which of these do you identify as signs of snow leopard? (Showing photos of pug-mark, scat and scrape snow leopard along with signs of some other similar sized felids)

Correct identification/ Wrong identification

OCCURRENCE OF SNOW LEOPARD

Q6. Within your areas of knowledge / activity, where have you seen snow leopard/ evidence during 2008-2012?

Name of the area (e.g. Chomaling pasture, show on map)

Details about the area (e.g. slope towards south-west of the pasture, nearest village/town)

Year, Month/Season

Q7. Within your areas of knowledge / activity, where have you seen snow leopard/ evidence during 1985-1992?

____

____

Q8. What evidence seen? Direct sighting, scat, scrape, pug-mark, kill

Q9. Where did you see?

Name of the area (e.g. Chomaling pasture, show on map)

Details about the area (e.g. slope towards south-west of the pasture, nearest village/town)

Year, Month/Season

RESPONDENT'S KNOWLEDGE ON PREY BASE

Q10. Are you familiar with:

(a) Bharal/ nabo? Yes / No

(b) Ibex / Tungrol/ Kuras/Meyi? Yes/ No

(c) Hangul? Yes/No

(d) *Kastura*/ Musk deer/Raush/Bhenda? Yes/ No

(e) Tahr/Tehr/Tehrni/Karth/Meyi? Yes/ No

(f) Goral/Parj? Yes/ No

(g) Serow? Yes/ No

(h) Other (Please specify) ____

Q11. How do you know about them?

____

Q12. Identify those ungulates about which you have answered 'Yes' in the above question

Correctly identified

____

______

Could not identify

____

____

OCCURRENCE OF PREY BASE

Q13. What snow leopard prey species have you seen in your area of knowledge/activity?

(a) ___________________________; (b) ___________________________; (c)

____

(d) ___________________________; (e) ___________________________

Q14. Within your areas of knowledge, where have you seen the above mentioned species during 2008-2012?

Name of the area (e.g. Chomaling pasture, show on map)

Details about the area (e.g. slope towards south-west of the pasture, nearest village/town)

Month/Season when seen

Q15. Were prey species of snow leopard / evidence ever seen in the past (1985-1992)? Yes / No

Q16. Name them:

(a) ___________________________; (b) ___________________________; (c)

____

(d) ___________________________; (e) ___________________________

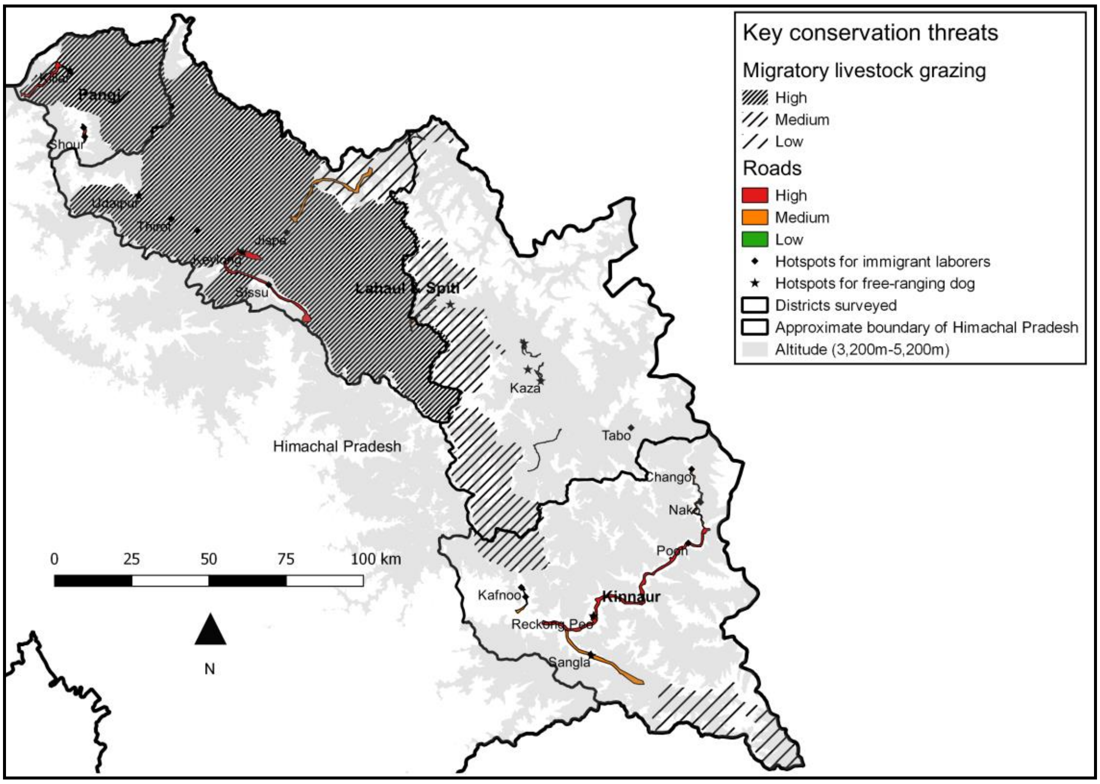
Q17. What evidence seen? Direct sighting / kill / footprint / dropping

Q18. Where did you see? (1985-1992)

Name of the area (e.g. Chomaling pasture, show on map)

Details about the area (e.g. slope towards south-west of the pasture, nearest village/town)

Year, Month/Season



Supplementary Figure S2: Map showing key conservation threats across Kinnaur, Lahaul & Spiti and Pangi in Himachal Pradesh, India.

Supplementary table S3: Candidate model sets for snow leopard, wild-prey, blue sheep and Asiatic ibex using single species multi season occupancy modelling, Himachal Pradesh, India. The models have been arranged in ascending order of Akaike Information Criteria (AIC) *

Snow leopard

Sl.No	**Models**	**AIC**	**Delta AIC**	**AIC weight**
1	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+a+f+ts+prof)	819.73	0	0.45
2	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+prof)	821.53	1.80	0.18
3	psi1(alt+tri), psi2(alt+tri),gamma(),p(s+a+f+ts+prof)	821.57	1.84	0.18
4	psi1(tri), psi2(tri),gamma(),p(s+a+f+ts+prof)	822.76	3.03	0.10
5	psi1(.), psi2(.), gamma(),p(s+a+f+ts+prof)	823.06	3.33	0.09
6	psi1(alt+tri), psi2(alt+tri),gamma(),p(s+a+prof)	823.21	3.48	0.00
7	psi(),gamma(),p(s+a+f+prof)	823.29	3.56	0.00
8	psi1(alt), psi2(alt+migrh),gamma(),p(s+a+f+ts+prof)	823.31	3.58	0.00
9	psi1(alt+tri), psi2(alt+tri+migrh),gamma(),p(s+a+f+ts+prof)	823.42	3.69	0.00
10	psi1(tri), psi2(tri+migrh),gamma(),p(s+a+f+ts+prof)	823.81	4.08	0.00
11	psi(),gamma(),p(s+a+ts+prof)	824.23	4.50	0.00
12	psi1(alt), psi2(alt),gamma(),p(s+a+f+ts+prof)	824.60	4.87	0.00
13	psi(),gamma(),p(s+a+prof)	824.69	4.96	0.00
14	psi1(tri), psi2(tri+migrh+lspop),gamma(),p(s+a+f+ts+prof)	825.58	5.85	0.00
15	psi(),gamma(),p(s+prof)	825.83	6.10	0.00
16	psi(),gamma(),p(s+ts+prof)	826.22	6.49	0.00
17	psi1(alt+tri), psi2(alt+tri),gamma(),p(s+f+prof)	826.36	6.63	0.00
18	psi(),gamma(),p(s+f+prof)	827.69	7.96	0.00
19	psi(),gamma(),p(s+f+ts+prof)	827.87	8.14	0.00
20	psi(),gamma(),p(prof)	830.37	10.64	0.00
21	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+a+f)	850.85	31.12	0.00
22	psi(),gamma(),p(s+a+f)	855.33	35.60	0.00
23	psi(),gamma(),p(s+a)	855.89	36.16	0.00
24	psi(),gamma(),p(s)	856.01	36.28	0.00
25	psi(),gamma(),p(s+a+f+ts)	857.18	37.45	0.00
26	psi(),gamma(),p(s+a+ts)	857.63	37.90	0.00
27	psi(),gamma(),p(s+f)	857.96	38.23	0.00
28	psi(),gamma(),p(s+ts)	857.97	38.24	0.00
29	psi(),gamma(),p()	858.98	39.25	0.00
30	psi1=psi2,gamma(),p()	859.28	39.55	0.00
31	psi(),gamma(),p(s+f+ts)	859.89	40.16	0.00

Sl.No	Models	AIC	Delta AIC	AIC weight
	Models that did not converge			
	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+a+prof)			
	psi1(.), psi2(migrh+lspop),gamma(),p(s+a+f+ts+prof)			
	psi1(.), psi2(lspop),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+tri), psi2(alt+tri+migrh+lspop),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+tri), psi2(alt+tri),gamma(),p(prof)			
	psi1(alt+tri), psi2(alt+tri),gamma(),p(s+ts+prof)			
	psi1(alt+alt_sq), psi2(alt+alt_sq),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+alt_sq+tri), psi2(alt+alt_sq+tri+migrh),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+alt_sq), psi2(alt+alt_sq+migrh),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+alt_sq+tri), psi2(alt+alt_sq+tri),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+alt_sq), psi2(alt+alt_sq+migrh+lspop),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+a)			
	psi1(alt+tri), psi2(alt+tri),gamma(),p(s+a+f+ts)			
	psi1(alt+alt_sq+tri), psi2(alt+alt_sq+tri+migrh+lspop),gamma(),p(s+a+f+ts+prof)			
	psi1(alt+tri+migrh)=psi2(alt+tri+migrh)gamma(.)p(s+a+f+ts+prof)			
	psi1(tri+migrh)=psi2(tri+migrh)gamma(.)p(s+a+f+ts+prof)			
	psi1(alt+migrh)=psi2(alt+migrh)gamma(.)p(s+a+f+ts+prof)			
	psi1(alt+alt_sq+migrh) = psi2(alt+alt_sq+migrh)gamma(.)p(s+a+f+ts+prof)			

Wild-prey

Sl. No	Models	AIC	Delta AIC	AIC weight
1	psi1(alt+alt_sq),psi2(alt+alt_sq),gamma(),p(s+a+f+prof)	1511.53	0	0.23
2	psi1(tri),psi2(tri),gamma(),p(s+a+f+prof)	1512.14	0.61	0.17
3	psi1(alt+tri),psi2(alt+tri),gamma(),p(s+a+f+prof)	1512.60	1.07	0.14
4	psi1(.),psi2(.),gamma(),p(s+a+f+prof)	1514.10	2.57	0.06
5	psi1(tri),psi2(tri+migrh),gamma(),p(s+a+f+prof)	1514.13	2.60	0.06
6	psi1(alt+tri+ndvi),psi2(alt+tri+ndvi),gamma(),p(s+a+f+prof)	1514.24	2.71	0.06
7	psi1(alt+alt_sq+tri),psi2(alt+alt_sq+tri+migrh),gamma(),p(s+a+f+prof)	1514.44	2.91	0.05
8	psi1(alt+alt_sq),psi2(alt+alt_sq+migrh),gamma(),p(s+a+prof)	1514.91	3.38	0.04
9	psi1(.),psi2(.),gamma(),p(s+a+f+ts+prof)	1515.33	3.80	0.03
10	psi1(.),psi2(.),gamma(),p(s+a+prof)	1515.48	3.95	0.03
11	psi1(tri)=psi2(tri),gamma(),p(s+a+f+prof)	1515.55	4.02	0.03
12	psi1(alt),psi2(alt),gamma(),p(s+a+f+prof)	1515.56	4.03	0.03
13	psi1(ndvi),psi2(ndvi),gamma(),p(s+a+f+prof)	1515.74	4.21	0.03

Sl. No	Models	AIC	Delta AIC	AIC weight
14	psi1(.),psi2(.),gamma(),p(s+a+ts+prof)	1516.47	4.94	0.02
15	psi1(tri)=psi2(tri),gamma(),p(s+a+prof)	1516.91	5.38	0.02
16	psi1(alt),psi2(alt+migrh),gamma(),p(s+a+f+prof)	1517.41	5.88	0.02
17	psi1(.),psi2(.),gamma(),p(s+a+f)	1517.49	5.96	0.01
18	psi1(.),psi2(.),gamma(),p(s+a+f+ts)	1519.30	7.77	0.01
19	psi1(alt+migrh) = psi2(alt+migrh),gamma(),p(s+a+f+prof)	1519.56	8.03	0.00
20	psi1(.),psi2(.),gamma(),p(s+a)	1519.64	8.11	0.00
21	psi1(tri)=psi2(tri),gamma(),p(s+a)	1521.09	9.56	0.00
22	psi1(.),psi2(.),gamma(),p(s+a+ts)	1521.35	9.82	0.00
23	psi1(alt+alt_sq),psi2(alt+alt_sq+migrh),gamma(),p(s+prof)	1523.43	11.90	0.00
24	psi1(.),psi2(.),gamma(),p(s+f+prof)	1523.99	12.46	0.00
25	psi1(.),psi2(.),gamma(),p(s+prof)	1524.03	12.50	0.00
26	psi1(.),psi2(.),gamma(),p(s+f+ts+prof)	1525.60	14.07	0.00
27	psi1(tri)=psi2(tri),gamma(),p(s+prof)	1525.68	14.15	0.00
28	psi1(.),psi2(.),gamma(),p(s+ts+prof)	1525.95	14.42	0.00
29	psi1(.),psi2(.),gamma(),p(s)	1527.08	15.55	0.00
30	psi1(.),psi2(.),gamma(),p(s+f)	1527.62	16.09	0.00
31	psi1(.),psi2(.),gamma(),p(s+ts)	1529.07	17.54	0.00
32	psi1(.),psi2(.),gamma(),p(s+f+ts)	1529.59	18.06	0.00
33	psi1(.),psi2(.),gamma(),p(prof)	1536.85	25.32	0.00
34	psi1(.),psi2(.),gamma(),p()	1541.94	30.41	0.00
35	psi1=psi2,gamma(),p()	1545.55	34.02	0.00

Models that did not converge

psi1(alt+alt_sq),psi2(alt+alt_sq+migrh+lspop),gamma(),p(s+a+f+prof)

psi1(alt+alt_sq+tri+ndvi),psi2(alt+alt_sq+tri+ndvi),gamma(),p(s+a+f+prof)

psi1(alt+alt_sq+tri),psi2(alt+alt_sq+tri+migrh+lspop),gamma(),p(s+a+f+prof)

psi1(alt+tri),psi2(alt+tri+migrh+lspop),gamma(),p(s+a+f+prof)

psi1(alt+tri),psi2(alt+tri+migrh),gamma(),p(s+a+f+prof)

psi1(alt+alt_sq)=psi2(alt+alt_sq),gamma(),p(s+a+f+prof)

psi1(tri),psi2(tri+migrh+lspop),gamma(),p(s+a+f+prof)

psi1(.),psi2(migrh+lspop),gamma(),p(s+a+f+prof)

psi1(alt+alt_sq+tri)=psi2(alt+alt_sq+tri),gamma(),p(s+a+f+prof)

psi1(alt+alt_sq+tri)=psi2(alt+alt_sq+tri),gamma(),p(s+a+prof)

psi1(alt),psi2(alt+migrh+lspop),gamma(),p(s+a+f+prof)

psi1(alt+tri+ndvi),psi2(alt+tri+ndvi+migrh+lspop),gamma(),p(s+a+f+prof)

psi1(alt+alt_sq+tri+ndvi),psi2(alt+alt_sq+tri+ndvi+migrh+lspop),gamma(), p(s+a+f+prof)

psi1(alt+alt_sq+tri)=psi2(alt+alt_sq+tri),gamma(),p(s+a)

Sl. No	Models	AIC	Delta AIC	AIC weight
	psi1(ndvi),psi2(ndvi+migrh+lspop),gamma(),p(s+a+f+prof)			
	psi1(tri)=psi2(tri),gamma(),p(s)			
	psi1(alt+alt_sq+migrh) = psi2(alt+alt_sq+migrh),gamma(),p(s+a+f+prof)			
	psi1(migrh) = psi2(migrh),gamma(),p(s+a+f+prof)			
	psi1(alt+tri+migrh) = psi2(alt+tri+migrh),gamma(),p(s+a+f+prof)			

Blue sheep

Sl.No	Models	AIC	Delta AIC	AIC weight
1	psi1(alt+migrh) = psi2(alt+migrh),gamma(),p(s+a+prof)	726.23	0	0.50
2	psi1(alt+migrh), psi2(alt+migrh),gamma(),p(s+a+prof)	727.92	1.69	0.22
3	psi1(alt+tri+migrh) = psi2(alt+tri+migrh),gamma(),p(s+a+prof)	728.22	1.99	0.19
4	psi1(alt+tri+migrh), psi2(alt+tri+migrh),gamma(),p(s+a+prof)	729.63	3.4	0.09
5	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+a+prof)	743.45	17.22	0.00
6	psi1(alt+alt_sq+tri)=psi2(alt+alt_sq+tri),gamma(),p(s+a+prof)	744.74	18.51	0.00
7	psi1(alt+tri),psi2(alt+tri),gamma(),p(s+a+prof)	745.36	19.13	0.00
8	psi1(alt+alt_sq+tri),psi2(alt+alt_sq+tri),gamma(),p(s+a+prof)	746.26	20.03	0.00
9	psi1(tri),psi2(tri),gamma(),p(s+a+prof)	747.09	20.86	0.00
10	psi1(alt+tri+ndvi),psi2(alt+tri+ndvi),gamma(),p(s+a+prof)	747.23	21	0.00
11	psi1(alt+alt_sq+tri+ndvi),psi2(alt+alt_sq+tri+ndvi),gamma(),p(s+a+prof)	747.93	21.7	0.00
12	psi1(.),psi2(.),gamma(),p(s+a+prof)	749.69	23.46	0.00
13	psi1(.),psi2(.),gamma(),p(s+a+ts+prof)	750.94	24.71	0.00
14	psi1(alt),psi2(alt),gamma(),p(s+a+prof)	751.56	25.33	0.00
15	psi1(ndvi),psi2(ndvi),gamma(),p(s+a+prof)	751.68	25.45	0.00
16	psi1(.),psi2(.),gamma(),p(s+a+f+prof)	751.69	25.46	0.00
17	psi1(.),psi2(.),gamma(),p(s+a+f+ts+prof)	752.94	26.71	0.00
18	psi1(alt+alt_sq),psi2(alt+alt_sq),gamma(),p(s+a+prof)	753.29	27.06	0.00
19	psi1(.),psi2(.),gamma(),p(s+f+prof)	756.21	29.98	0.00
20	psi1(.),psi2(.),gamma(),p(s+ts+f+prof)	758.14	31.91	0.00
21	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+prof)	759.2	32.97	0.00
22	psi1(alt+alt_sq+tri)=psi2(alt+alt_sq+tri),gamma(),p(s+prof)	760.71	34.48	0.00
23	psi1(.),psi2(.),gamma(),p(s+prof)	765.52	39.29	0.00
24	psi1(.),psi2(.),gamma(),p(s+ts+prof)	767.51	41.28	0.00
25	psi1(alt+tri)=psi2(alt+tri),gamma(),p(s+a)	768.5	42.27	0.00
26	psi1(alt+alt_sq+tri)=psi2(alt+alt_sq+tri),gamma(),p(s+a)	770.09	43.86	0.00
27	psi1(.),psi2(.),gamma(),p(s+a)	774.8	48.57	0.00
28	psi1(.),psi2(.),gamma(),p(s+a+ts)	776.07	49.84	0.00
29	psi1(.),psi2(.),gamma(),p(s+a+f)	776.75	50.52	0.00

Sl.No	Models	AIC	Delta AIC	AIC weight
30	psi1(.),psi2(.),gamma(),p(s+a+f+ts)	778.05	51.82	0.00
31	psi1(.),psi2(.),gamma(),p(s+f)	778.51	52.28	0.00
32	psi1(.),psi2(.),gamma(),p(s+f+ts)	780.35	54.12	0.00
33	psi1(.),psi2(.),gamma(),p(s)	785.14	58.91	0.00
34	psi1(.),psi2(.),gamma(),p(s+ts)	787.14	60.91	0.00
35	psi1(.),psi2(.),gamma(),p(prof)	796.22	69.99	0.00
36	psi1=psi2,gamma(),p()	813.73	87.5	0.00
37	psi1(.),psi2(.),gamma(),p()	814.43	88.2	0.00

Models that did not converge

psi1(.)=psi2(migrh),gamma(),p(s+a+prof)
psi1(.),psi2(migrh),gamma(),p(s+a+prof)
psi1(alt),psi2(alt+migrh),gamma(),p(s+a+prof)
psi1(tri),psi2(tri+migrh+lspop),gamma(),p(s+a+prof)
psi1(alt+alt_sq+tri),psi2(alt+alt_sq+tri+migrh+lspop),gamma(),p(s+a+prof)
psi1(alt+alt_sq),psi2(alt+alt_sq+migrh+lspop),gamma(),p(s+a+prof)
psi1(.)=psi2(migrh),gamma(),p(s+prof)
psi1(.)=psi2(migrh),gamma(),p(s+a)
psi1(tri),psi2(tri+migrh),gamma(),p(s+a+prof)
psi1(alt+tri),psi2(alt+tri+migrh),gamma(),p(s+a+prof)
psi1(ndvi),psi2(ndvi+migrh+lspop),gamma(),p(s+a+prof)
psi1(.),psi2(lspop),gamma(),p(s+a+prof)
psi1(alt),psi2(alt+migrh+lspop),gamma(),p(s+a+prof)
psi1(.),psi2(migrh+lspop),gamma(),p(s+a+prof)
psi1(alt+alt_sq+tri),psi2(alt+alt_sq+tri+migrh),gamma(),p(s+a+prof)
psi1(alt+tri),psi2(alt+tri+migrh+lspop),gamma(),p(s+a+prof)
psi1(alt+tri+ndvi),psi2(alt+tri+ndvi+migrh+lspop),gamma(),p(s+a+prof)
psi1(alt+alt_sq+tri+ndvi),psi2(alt+alt_sq+tri+ndvi+migrh+lspop),gamma(),
p(s+a+prof)
psi1(alt+alt_sq),psi2(alt+alt_sq+migrh),gamma(),p(s+a+prof)

Asiatic ibex

Sl.No	Models	AIC	Delta AIC	AIC weight
1	psi1(migrh) = psi2(migrh),gamma(),p(s+f)	983.42	0	0.68
2	psi1(alt+migrh) = psi2(alt+migrh),gamma(),p(s+f)	984.97	1.55	0.32
4	psi1(.)=psi2(.),gamma(),p(s+f)	1012.17	28.75	0
5	psi1(ndvi)=psi2(ndvi),gamma(),p(s+f)	1013.60	30.18	0

Sl.No	Models	AIC	Delta AIC	AIC weight
6	psi1(.), psi2(.),gamma(),p(s+f)	1014.17	30.75	0
7	psi1(ndvi), psi2(ndvi),gamma(),p(s+f)	1015.58	32.16	0
8	psi1(.), psi2(.),gamma(),p(s+a+f)	1015.73	32.31	0
9	psi1(tri), psi2(tri),gamma(),p(s+f)	1015.79	32.37	0
10	psi1(.), psi2(.),gamma(),p(s+f+ts)	1016.07	32.65	0
11	psi1(alt), psi2(alt),gamma(),p(s+f)	1016.13	32.71	0
12	psi1(.), psi2(.),gamma(),p(s+a+f+ts)	1017.63	34.21	0
13	psi1(alt+tri), psi2(alt+tri),gamma(),p(s+f)	1017.66	34.24	0
14	psi1(.), psi2(.),gamma(),p(s+f+prof)	1018.05	34.63	0
15	psi1(.), psi2(.),gamma(),p(s+a)	1018.40	34.98	0
16	psi1(alt+tri+ndvi), psi2(alt+tri+ndvi),gamma(),p(s+f)	1018.58	35.16	0
17	psi1(.), psi2(.),gamma(),p(s+a+f+prof)	1019.60	36.18	0
18	psi1(.), psi2(.),gamma(),p(s+f+ts+prof)	1019.89	36.47	0
19	psi1(.), psi2(.),gamma(),p(s+a+ts)	1019.99	36.57	0
20	psi1(.), psi2(.),gamma(),p(s+a+f+ts+prof)	1021.42	38	0
21	psi1(.), psi2(.),gamma(),p(s+a+prof)	1022.05	38.63	0
22	psi1(alt+alt_sq+tri+ndvi), psi2(alt+alt_sq+tri+ndvi+migrh+lspop),gamma(),p(s+f)	1022.58	39.16	0
23	psi1(.), psi2(.),gamma(),p(s+a+ts+prof)	1023.38	39.96	0
24	psi1(alt+tri), psi2(alt+tri+migrh+lspop),gamma(),p(s+f)	1023.96	40.54	0
25	psi1(.)=psi2(.),gamma(),p(s)	1027.70	44.28	0
26	psi1(ndvi)=psi2(ndvi),gamma(),p(s)	1029.02	45.6	0
27	psi1(.), psi2(.),gamma(),p(s)	1029.69	46.27	0
28	psi1(.), psi2(.),gamma(),p(s+ts)	1029.89	46.47	0
29	psi1(.), psi2(.),gamma(),p(s+ts+prof)	1032.52	49.1	0
30	psi1(.), psi2(.),gamma(),p(s+prof)	1033.02	49.6	0
31	psi1(.), psi2(.),gamma(),p()	1077.96	94.54	0
32	psi1(.), psi2(.),gamma(),p(prof)	1081.22	97.8	0
33	psi1=psi2,gamma(),p()	1083.12	99.7	0

Models that did not converge

psi1(alt), psi2(alt+migrh+lspop),gamma(),p(s+f)

psi1(alt+tri+ndvi)psi2(alt+tri+ndvi+migrh+Lspop)gamma(.)p(s+f)

psi1(alt+alt_sq+tri+ndvi)psi2(alt+alt_sq+tri+ndvi)gamma(.)p(s+f)

psi1(alt+alt_sq+tri)psi2(alt+alt_sq+tri)gamma(.)p(s+f)

psi1(alt+alt_sq)psi2(alt+alt_sq)gamma(.)p(s+f)

psi1(.)psi2(migrh+lspop)gamma(.)p(s+f)

psi1(.)psi2(migrh)gamma(.)p(s+f)

psi1(.)psi2(lspop)gamma(.)p(s+f)

psi1(alt+alt_sq+tri)psi2(alt+alt_sq+tri+migrh+Lspop)gamma(.)p(s+f)

Sl.No	Models	AIC	Delta AIC	AIC weight
	psi1(alt+alt_sq)psi2(alt+alt_sq+migrh+Lspop)gamma(.)p(s+f)			
	psi1(alt)psi2(alt+migrh+lspop)gamma(.)p(s+f)			
	psi1(tri)psi2(tri+migrh+lspop)gamma(.)p(s+f)			
	psi1(ndvi)psi2(ndvi+migrh+lspop)gamma(.)p(s+f)			
	psi1(alt+alt_sq+tri)psi2(alt+alt_sq+tri+migrh)gamma(.)p(s+f)			
	psi1(alt+tri)psi2(alt+tri+migrh)gamma(.)p(s+f)			
	psi1(alt+alt_sq)psi2(alt+alt_sq+migrh)gamma(.)p(s+f)			
	psi1(alt)psi2(alt+migrh)gamma(.)p(s+f)			
	psi1(tri)psi2(tri+migrh)gamma(.)p(s+f)			
	psi1(tri+migrh)=psi2(tri+migrh)gamma(.)p(s+f)			
	psi1(alt+alt_sq+migrh)=psi2(alt+alt_sq+migrh)gamma(.)p(s+f)			
	psi1(alt+tri+migrh)=psi2(alt+tri+migrh)gamma(.)p(s+f)			
	psi1(alt+migrh), psi2(alt+migrh),gamma(),p(s+f)			

*Psi1 – past occupancy; psi2 – recent occupancy; gamma – probability of distribution expansion; p – detection probability; Site covariates: alt – mean of altitude in a grid; alt_sq – altitude squared (quadratic function); tri – proportion of rugged area in a grid derived from terrain ruggedness index; ndvi – proportion of vegetated area in a grid derived from Normalized Difference Vegetation Index; migrh – presence/absence of migratory livestock grazing in a grid; lspop –relative abundance of livestock in a grid; survey covariates: s – time lapse/seasonality; a – age of a respondent; f – respondents' familiarity of area of knowledge; ts – time spent by a respondent in area of knowledge per year; prof – categories of profession of respondents, prof1 denotes sedentary profession (e.g. office worker), prof2 denotes sedentary and partially outdoor profession (e.g. forest guard) and prof3 denotes completely outdoor profession (e.g. herder, hunter).

Supplementary Figure S4

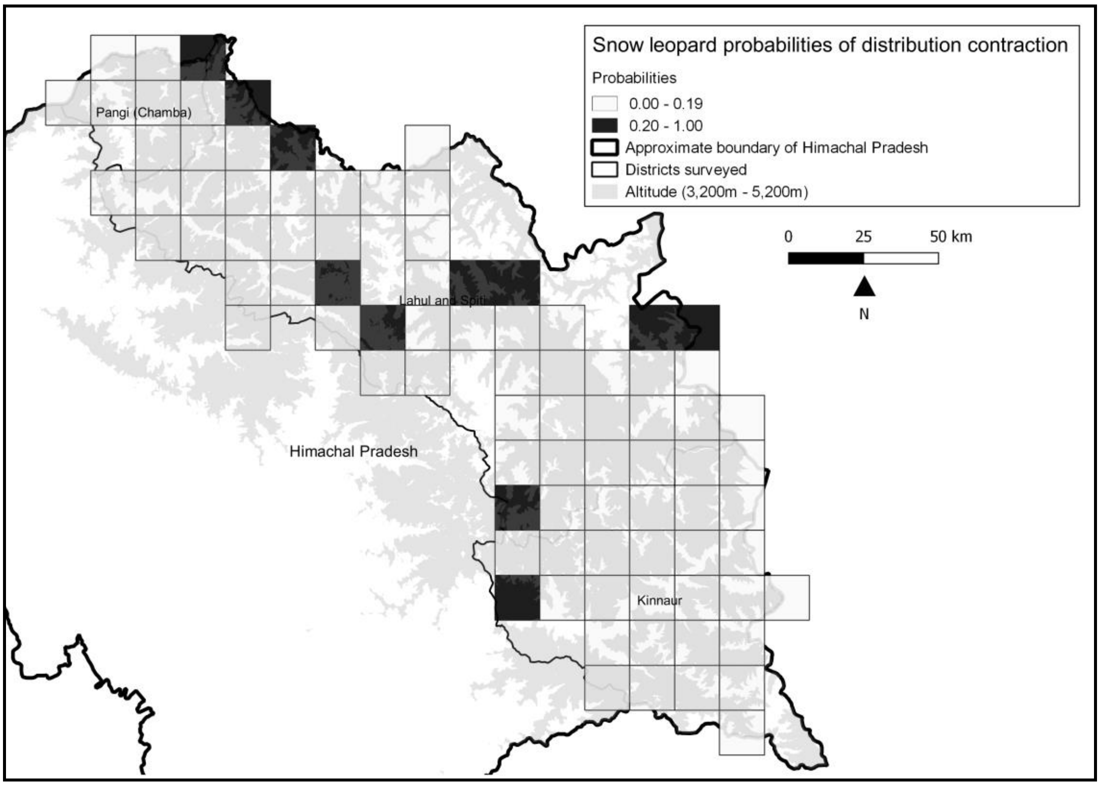


Figure S4a: Map showing probability of distribution contraction of snow leopard in the Greater and Trans-Himalayan mountains of Himachal Pradesh, India.

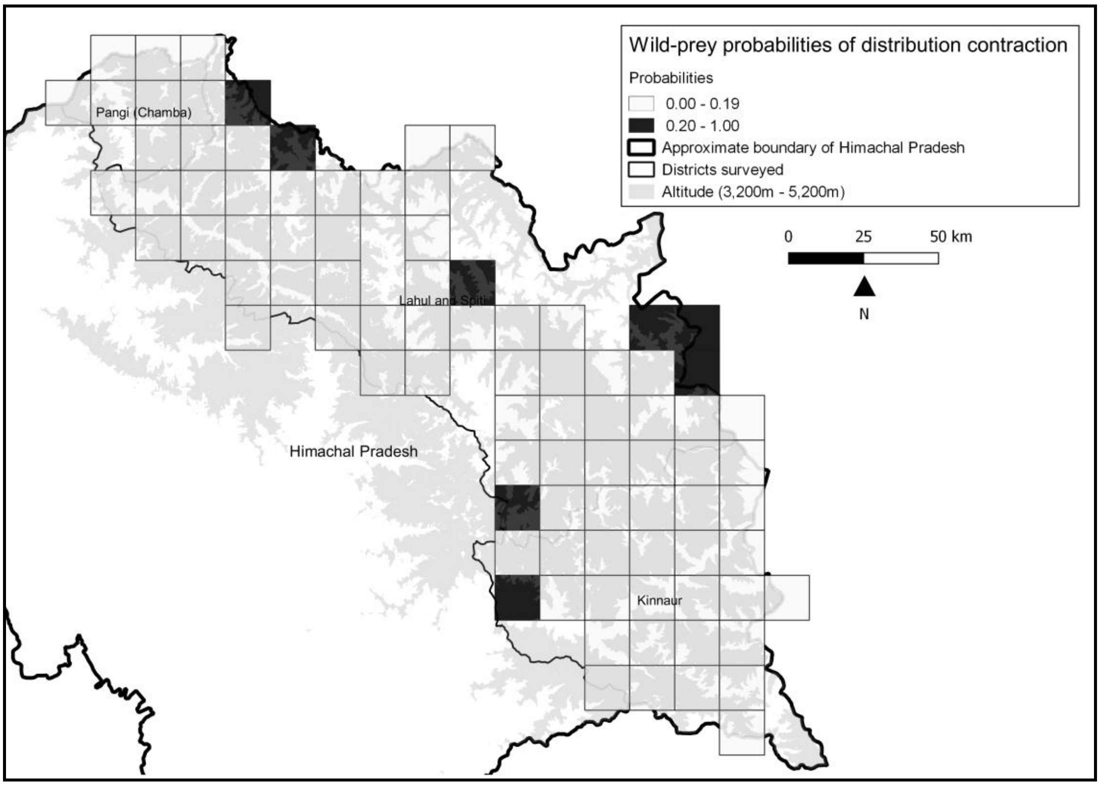


Figure S4b: Map showing probability of distribution contraction of wild-prey in the Greater and Trans-Himalayan mountains of Himachal Pradesh, India.

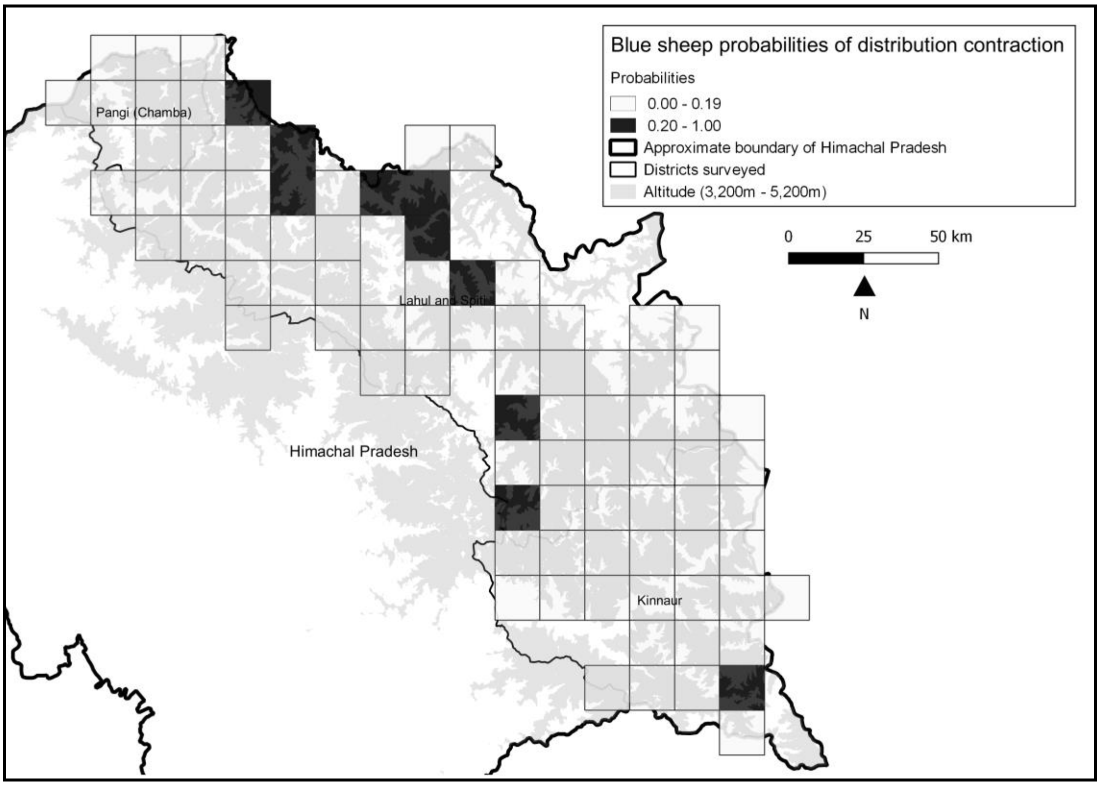


Figure S4c: Map showing probability of distribution contraction of blue sheep in the Greater and Trans-Himalayan mountains of Himachal Pradesh, India.

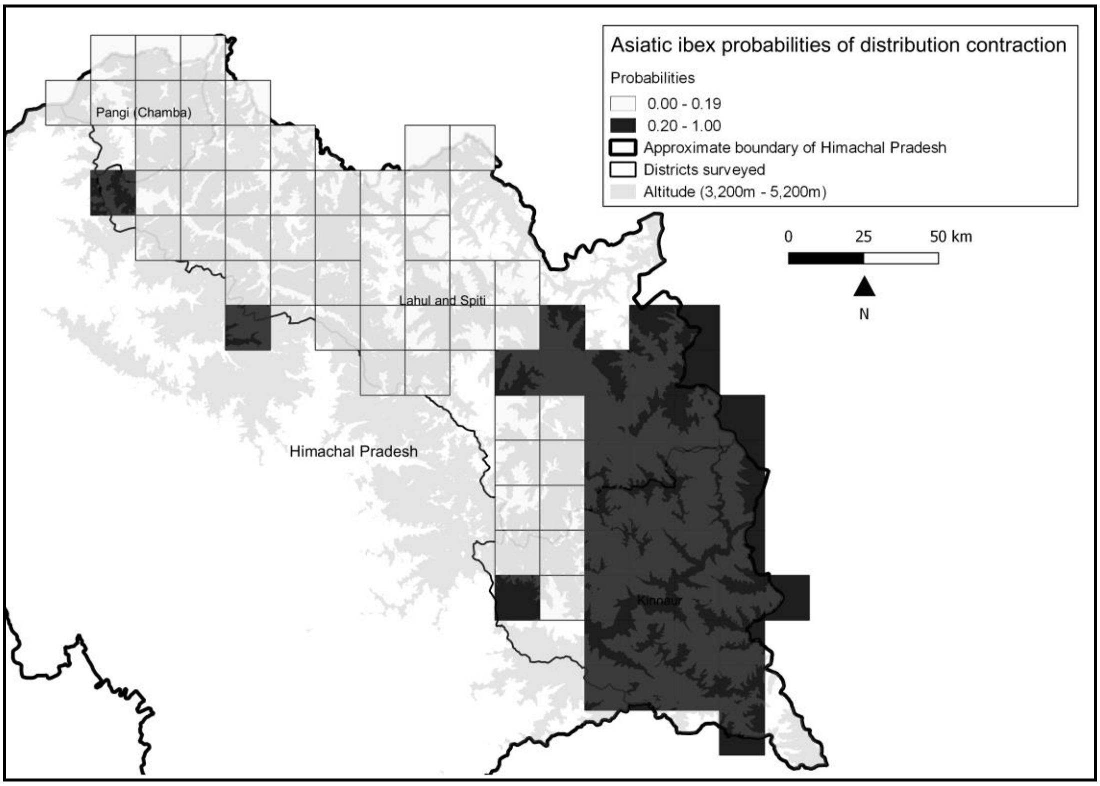


Figure S4d: Map showing probability of distribution contraction of Asiatic ibex in the Greater and Trans-Himalayan mountains of Himachal Pradesh, India.

Supplementary material S5: Semi-structured questionnaire to document changes in migratory grazing practice, perception of migratory herders on changes in pasture quality and diversification potential of livestock products.

Questions for herders

Respondent ID

Grazing practice information

Years into migratory grazing:

Are you the owner of stock or an employee?

Herd size (no. of sheep and goat):

Number of accompanying persons:

Relations with accompanying persons:

Catchments used (duration of time spent):

1.

2.

3.

Duration of time spend in Lahaul/Spiti (months):

Has there been any change in livestock herd sizes over the past 10 years?

Yes / No

If yes, has there been an increase / decrease?

If increase, why?

1. Increasing family size
2. Increasing market demand for livestock products
3. Including livestock herds from other Gaddis
4. All the above
5. Other reason(s) (please specify)

If decrease, why?

1. Lack of man power
2. Alternate source of income
3. Decreasing market demand
4. All the above
5. Other reason(s) (please specify)

Has there been any change in livestock composition over the last 10 years?

Yes / No

If yes, what changes have happened?

1. Increase in goat
2. Increase in sheep
3. Both have increased
4. Decrease in goat
5. Decrease in sheep
6. Both have decreased

Why so?

Grazing fee to village panchayat (Rupees/in kinds):

Grazing fee paid to forest dept. (Rupees/in kinds):

Pasture quality

Is pasture quality changing?

Yes / No

If yes, perception on pasture quality:

1. Drastic degradation
2. Gradual degradation
3. Gradual improvement
4. Drastic improvement

Indicators of pasture quality/degradation:

1.
2.
3.
4.
5.

Why is pasture quality improving?

1.
2.
3.
4.
5.

Why is pasture quality degrading?

1.
2.
3.
4.
5.

Will you continue with migratory lifestyle for the next 10 years?

Yes / No

If yes, why?

If no, why?

If yes, will you increase/decrease/maintain livestock herd size? (check the appropriate option)

If increase, why so?

1. Increasing market demand
2. Increasing family demand
3. Increasing availability of pastures
4. Addition of livestock from retiring herders
5. Availability of man-power (non-native laborers)
6. Availability of man-power (native laborers)
7. Other (please specify)

If decrease, why so?

1. Decreasing market demand
2. Decreasing family demand
3. Decreasing availability of pastures
4. Decreasing availability of man-power (non-native laborers)
5. Decreasing availability of man-power (native laborers)
6. Other (please specify)

Have you ever thought of quitting migratory lifestyle?

1. Yes
2. No

If yes, under what conditions/circumstances? (open ended; rank the conditions / circumstances in the space below)

1.

2.

3.

4.

5.

Income/property information

Total income from grazing (give best approximation):

While in Lahaul-Spiti Rest of the year

Income from wool:

While in Lahaul-Spiti Rest of the year

Income from other wool products (if any):

While in Lahaul-Spiti Rest of the year

Income from meat (sale of animals):

While in Lahaul-Spiti Rest of the year

Income from milk:

While in Lahaul-Spiti Rest of the year

Income from other milk products (e.g. ghee, yoghurt):

While in Lahaul-Spiti Rest of the year

Other income sources (If any, please specify):

	In Lahaul-Spiti	Amount (Rs.)	Rest of the year	Amount (Rs.)
1.				
2.				
3.				

Total annual family income:

Total income from land/agriculture:

Agricultural area: Crops cultivated:

Market information

Market locations (names of places in order of sale from herders to middlemen to dealers) for:

Wool Other wool products Meat Milk Other milk products

1.

2.

3.

4.

5.

Current market price for 1 kg raw wool:

While in Lahaul-Spiti Rest of the year

Current market price for 1 kg refined wool:

While in Lahaul-Spiti Rest of the year

Current market price for 1 kg meat:

While in Lahaul-Spiti Rest of the year

Current market price for 1 litre milk:

While in Lahaul-Spiti Rest of the year

Current market price for 1 kg/litre milk-products:

While in Lahaul-Spiti Rest of the year

Trend of market price for raw wool over the last 10 years:

Increasing / Decreasing / Fluctuating / No change

Trend of market price for refined wool over the last 10 years:

Increasing / Decreasing / Fluctuating / No change

Trend of market price for livestock meat over the last 10 years:

Increasing / Decreasing / Fluctuating / No change

Trend of market price for milk over the last 10 years:

Increasing / Decreasing / Fluctuating / No change

Trend of market price for milk products over the last 10 years:

Increasing / Decreasing / Fluctuating / No change

Market price for 1 kg raw wool 5-10 years ago:

While in Lahaul-Spiti Rest of the year

Market price for 1 kg refined wool 5-10 years ago:

While in Lahaul-Spiti Rest of the year

Market price for 1 kg meat 5-10 years ago:

While in Lahaul-Spiti Rest of the year

Market price for 1 litre milk 5-10 years ago:

While in Lahaul-Spiti Rest of the year

Market price for 1 kg/litre milk-products 5-10 years ago:

While in Lahaul-Spiti Rest of the year

Market demand for wool/wool products – stable/increasing/decreasing

Market demand for meat – stable/increasing/decreasing

Market demand for milk/milk products – stable/increasing/decreasing

Demographic information

Age Town/village District Highest education

Family size Number of adults Number of minors

Number of earning members

Occupation of other earning members

1.

2.

3.

Supplementary material S6: Semi-structured questionnaire to document perception of local community toward impacts of migratory livestock grazing practice in Pin Valley National Park, Himachal Pradesh.

Participants' occupation/role (up to 5 participants, e.g. village council members, herder, etc)

1.
2.
3.
4.
5.

What are the indicators of pasture quality?

1. Grass/fodder
2. Fuel-wood
3. Medicinal plant
4. Soil moisture
5. Wild herbivore
6. All the above
7. Any particular species of plant (Names)

8. Others (please specify)

How would you define pasture degradation? / When will you say a pasture is degraded?

1. Inadequate grass/fodder
2. Inadequate fuel wood
3. Inadequate medicinal plant
4. Drying of soil
5. Low/absence of wild herbivore population
6. All the above
7. Any particular species of plant (Names)

8. Others (please specify)

Have you ever thought of leasing unused pastures to others (Gaddis)?

Yes/No

If yes,

Based on what rationale?

1. Benefit from dung (Amount)
2. Financial incentive (Species and age-wise amount; any other fee)
3. Benefits in kind (milk, milk products, meat etc details)
4. All the above
5. Others (please specify)

Do you think migratory livestock grazing, being inherently at high density, affects pastures?

Yes/No

If yes, in which way(s)?

1. Heavy/rapid degradation
2. Mild/gradual degradation
3. No effects
4. Mild/gradual improvement
5. Sharp/Rapid improvement

If degradation, in which way(s)?

1. Inadequate grass/fodder
2. Inadequate fuel wood
3. Inadequate medicinal plant
4. Drying of soil
5. Low/absence of wild herbivore population
6. All the above
7. Any particular species of plant (Names)

8. Others (please specify)