

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Prey, predator, human and climate change  
interactions in the Himalaya, Nepal**

**Achyut Aryal**

**2013**

**Prey, predator, human and climate change  
interactions in the Himalaya, Nepal**

**A thesis presented in partial fulfilment of the requirements for the degree of**

**Doctor of Philosophy**

**In**

**Conservation Biology**

**at Massey University, Auckland,**

**New Zealand**

**Achyut Aryal**

**2013**

## Acknowledgement

My deepest gratitude and the sincerest thanks go to my supervisors Prof. Dr. Dianne Brunton, Prof. Dr. David Raubenheimer, and Dr. Weihong Ji for all your support, insight, and guidance which made this PhD research possible. I am highly appreciative that you all always put me on right track for good science “THANK YOU VERY MUCH”. I specially thank to Prof. David, who taught me in the field to undertaken research and to set up my project. I still remember the day when the “dog bit you” in upper Mustang but you never gave up with the situation and you continued to searching for snow leopards and blue sheep in the Himalayas. I am inspired by your way of working, teaching, and guiding. Thanks also to Dr. Shanta Raj Jnawali and Dr. S. Sathyakumar for their advisory, logistic, and administrative support to conduct research in Nepal.

Thanks to the Ministry of Forests and Soil Conservation/Department of National ParkWildlife Conservation-Government of Nepal, and the National Trust for Nature Conservation/Annapurna Conservation Area for granting permission to conduct this study; Specially Dr. Shanta Raj Jnawali, Dr. Udaya Raj Sharma, Gopal Prasad Upadhyaya, Krishna Prasad Acharya, Kamal Jung Kuwar, Bishnu Thapaliya, Dr. Maheshwor Dhakal, Hari Bhadra Acharya deserve special thanks for their support for obtaining permission and for their support during the study period.

The study has been made possible by financial support from the Institute of Natural and Mathematical Sciences (INMS), Massey University Doctoral Hardship Bursary, Institute of Natural Sciences Scholarship, Massey University Research Fund, Rufford Small Grant Foundation, Alteris Netherland, and KNCF Japan. Special thanks to Prof. Dr. Gaven Martin for arranging tuition support and a scholarship from INMS and for all your support to complete this study.

I also acknowledge the assistance provided by Bikash Adhikari, Shambhu Paudel, Madan Mohan Acharya, Funjok Gurung, Sonam Gurung, Tasi Bista, Indra Gurung, Dhoma Gurung, Pema Gurung, Maya Bista, and others all local for their support in field.

Thank you due to Institute of Forestry, Tribhuvan University, Pokhara, Nepal for their support to provide lab facilities: Assoc. Prof. Raj Kumar Koirala and Assoc. Prof. Hari Prasad Tripathi who supported the lab work for this project; and Dibesh Karmacharya and his team (Center for Molecular Dynamic, Kathmandu, Nepal) for their support in Genetic analysis. Thank you to Campus Chief and faculty of IOF for giving me the opportunity to learn and for involving me in the teaching and guiding of students during my stay in Nepal.

Thank you to all: Dr. Roberta Benicini, Dr Kevin Parker, Brigitte Kreigenhofer, Dr Manuela Barry, Mark Delaney, Christophe Amiot, Narendra Lama, Lal Prasad Gurung, Nirjana Dhungana, Santosh Serchan, Hemanta Kumar Yadav, Purshotam Pandey, Naresh Subedi, Harka Man Lama, Tirtha Lama, Tej Kumar Shrestha, Bhupendra Yadav, Saroj Panthi, Daya Nithi Gautam, Santosh Bhandari, Sunil Pandey and Ramesh Lal for your support.

Many thanks to my parents, sister, and brother for their support and motivation. I would like to especially thank my wife “Hari” and son “Arpeet”. You are my source of motivation and your support was incredible and allowed me to complete my PhD work- thank you very much.

THANK YOU ALL

Achyut Aryal

June, 2013

## Abstract

This thesis evaluates prey-predator, climate change, and human-wildlife interactions in the Nepalese Himalayas and contains 12 scientific papers which were prepared from 2009-2012 to explain these interactions. The content of this thesis is categorised into four broad **themes**; wildlife ecology, human-wildlife conflict, the influence of climate change on human-wildlife interactions, and recommendations for developing strategies to balance wildlife conservation and human needs in Nepal. The findings summarized below based on their relevant themes.

- ❖ In the study of human wildlife conflict in the upper Mustang region, Nepal, I recorded a total of 1,347 km<sup>2</sup> of pasture land utilised by the local people from six village development committees, 706 livestock animals were killed during the study period by predators (equivalent to US\$44,213 every two years), and 75% of the total livestock predation was attributed to snow leopards. I also found that the movement of livestock drives the snow leopards to lower elevations and into closer proximity to villages.
- ❖ Rangelands are considered to be critical ecosystems in the Nepalese Himalayas and provide multiple ecosystem services that support local livelihoods. This study analyses the conflict over the use of rangeland by two villages in Mustang, Nepal. The conflict suggests that excessive demand for limited rangelands motivates local villagers to gain absolute control of the resources. In such contexts, external support should focus on enhancing the management and production of local foraging resources, which requires the establishment of local common property institutions to facilitate sustainable rangeland management.
- ❖ The northern Barandabhar Forest Corridor (BFC) in southern Nepal, which consists of 10,644 ha with 15 community forestry (3,184 ha) that connects Chitwan National Park to the Mahabharat range, was studied. BFC has the potential to contribute to the improvement of Nepal's ecological integrity. We propose that the northern BFC should be managed via a

new participatory scheme, the Barandabhar Forest Management Council, to foster ecological integrity of the area while providing forest products to communities.

- ❖ The presence of brown bears in the Manasalu Conservation Area and Annapurna Conservation Area of Nepal, was confirmed. Results showed that brown bears are potentially distributed between 3800 m and 5500 m in the high mountainous region of Nepal, across an area of 4037 km<sup>2</sup>. Small mammals were the preferred prey of brown bears (75%) with marmots (*Marmota himalayana*; 46%) being the largest contributor to brown bear diet. Finally, a three stage brown bear conservation programme is recommended: (a) detailed research activities both inside and outside protected areas of Nepal (b) livelihood and conservation awareness support at local and national level (c) strengthening of the local capacity and a reduction in human-wildlife conflict in the region.
- ❖ The Nepalese Himalayas provide habitat for the endangered snow leopard (*Panthera uncia*) and its principal prey species, the blue sheep (*Pseudois nayaur*). A total of 939 Blue sheep were recorded at altitudes ranging from 3209 to 5498 m on slopes with gradients of 16–60° and aspects of 40°NE to 140°SE. The upper Mustang had the lowest population density of blue sheep recorded within their distribution range in Nepal (0.86 blue sheep/km<sup>2</sup>). It is estimated that the existing blue sheep population biomass of approximately 38,925 kg in the upper Mustang region could support approximately 19 snow leopards (1.6 snow leopards/100 km<sup>2</sup>).
- ❖ Habitat suitability analyses of snow leopards in Annapurna Conservation Area (ACA), Nepal indicated that an area of 3248 km<sup>2</sup> was suitable for snow leopards. Genetics analysis of the collected scats were successfully genotyped (62%) using 6 microsatellite markers, and identified as having originated from five different individuals and suggested minimum home ranges of 89.4 km<sup>2</sup> (male) and 59.3 km<sup>2</sup> (female). Microhistological analysis of scats (n=248)

revealed that blue sheep are the primary prey species (63%) and that livestock contributed 18% of the snow leopard diet.

- ❖ The Hispid hare (*Caprolagus hispidus*) is one of the least studied endangered small mammal species in the world. The diet and habitat use of the hispid hare was studied at Shuklaphanta Wildlife Reserve (SWR), Nepal. The population density of the hispid hare was 5.76 individuals/km<sup>2</sup>. Hispid hares mostly prefer grasses (*Saccharum spontaneum* and *Imperata cylindrica*) and more than nineteen plants were identified in their pellets.
- ❖ The Himalayan marmot (*Marmota himalayana*) was found to inhabit warmer valleys close to water resources in areas between 3200m and 5300m above sea level. Plant diversity was higher in the marmot habitat. Seventeen plants were recorded in marmots' scats over three seasons (summer, autumn and spring). Soil pH, organic matter and organic carbon were not significantly different in habitat occupied by marmots compared to area where marmots were absent. Phosphorus (P<sub>2</sub>O<sub>5</sub>) levels were significantly higher and potash (K<sub>2</sub>O) levels significantly lower in marmot burrow habitat.
- ❖ I found that the average annual temperature in the upper Mustang region has increased by 0.13 °C per year over the last 23 years. A predictive model suggested that the mean annual temperature will double by 2161 to reach 20 °C in the upper Mustang region. A reduction in suitable agricultural, grassland, and forest land was recorded. Furthermore, grasses and many shrub species are no longer found in abundance at higher elevations and consequently blue sheep move to forage at lower elevations which attracts snow leopard (*Panthera uncia*) from their higher elevation habitats to lower sites, where they encounter and depredate livestock. Increased crop raiding by blue sheep and depredations of livestock by snow leopards have adversely impacted the livelihood of local people.

## Table of Contents

Acknowledgement .....	2
Abstract.....	4
Preface.....	15
Thesis Outline .....	18
Thesis Structure .....	20
<b>Chapter One</b> .....	<b>21</b>
Summary.....	21
Paper I: Snow Leopard-Human Conflict in the Upper Mustang Region of Nepal: Ecological and Economic Implications of Snow Leopard Predation of Livestock .....	23
Abstract.....	23
Introduction.....	24
Methods and Material .....	25
Results.....	28
Pasture lands .....	28
Livestock holding and density .....	29
Livestock depredation in the upper Mustang.....	30
Economic value of livestock depredation .....	32
Seasonal livestock depredation .....	33
Livestock movement patterns and approximate distance of depredation from villages and seasonally used pastures .....	33
Discussion.....	35
References.....	39
Paper II: Rangelands, conflicts and society in Upper Mustang Nepal: Status, rights, and traditional management strategies.....	44
Abstract.....	44
Introduction.....	44
Material and Methods .....	46

Results.....	48
Rangelands in Chhoser and Chhunup VDCs, Mustang District .....	48
History of Rangeland Use in Chhoser and Chhunup VDCs .....	50
Traditional Conflict Resolution System.....	53
People’s Perceptions on Conflict and Conflict Resolutions .....	53
Discussion .....	55
Conclusions.....	58
Acknowledgments.....	59
References .....	59
<b>Paper III: Biological diversity and management regimes of the northern Barandabhar Forest Corridor: an essential habitat for ecological connectivity in Nepal .....</b>	<b>64</b>
Abstract.....	64
Introduction.....	65
Methods.....	67
Results.....	70
Extent and current use of the northern BFC .....	70
Vegetation and biodiversity .....	72
Discussion .....	76
Implications for conservation .....	81
References.....	82
<b>Chapter Two.....</b>	<b>86</b>
Ecology and conservation of brown bears .....	86
Summary .....	86
<b>Paper I:Current status of brown bears in the Manasalu Conservation Area, Nepal .....</b>	<b>88</b>
Abstract.....	88
Introduction.....	88
Method and Materials .....	90

Results.....	93
Presence and absence survey .....	93
Brown bears and human conflict .....	95
Discussion.....	96
Literature Cited .....	98
Paper II: Distribution and diet of brown bears in the upper Mustang region, Nepal.....	100
Abstract.....	100
Introduction.....	100
Method and Materils .....	103
Study area.....	103
Results.....	105
Brown bear sign .....	105
Dietary analysis.....	108
Brown bear depredations .....	109
Discussion.....	110
Literature cited.....	111
Abstract.....	114
Introduction.....	115
Mehtod and Materials .....	117
Results.....	122
Brown Bear Distribution in Nepal .....	122
Habitat Use by Brown Bears in Upper Mustang .....	123
Vegetation in Brown Bear Habitat in Upper Mustang.....	125
Habitat Overlap with Blue Sheep and Domestic Livestock.....	127
Brown Bear Research and Studies throughout Nepal.....	128
Habitat Monitoring and the Need for Habitat Restoration.....	128
A need for Anti-Poaching Operations.....	129

Reduction in Human-Brown Bear Conflict .....	129
Strengthening of Local Capacity .....	130
Support for Local People to improve their Livelihoods .....	131
Discussion .....	133
References .....	137
<b>Chapter Three</b> .....	142
Conservation and ecology of snow leopards and their main prey species (blue sheep) .....	142
Summary .....	142
Paper I: Food habits, movements and habitat preference of the snow leopard in an area of Central Himalaya .....	145
Abstract .....	145
Introduction .....	146
Methods .....	148
Study area .....	148
Survey methods .....	149
Snow leopard occupancy, habitat use and availability in upper Mustang .....	149
Snow Leopard Information Monitoring System (SLIMS) habitat surveys and scat collection..	151
Non-invasive genetics analyses .....	151
DNA Extraction .....	152
Species identification .....	152
Sex identification .....	152
Individual identification by PCR assay .....	153
Movement pattern analysis .....	154
Diet analysis .....	154
Results .....	155
Status of snow leopards .....	155
Habitat types .....	157

Genetic analysis of snow leopard scats.....	160
Movement pattern and population density.....	161
Diet composition of snow leopard.....	161
Discussion.....	164
Habitat use and availability.....	165
Diet and non-invasive analysis.....	167
References.....	169
Abstract.....	177
Introduction.....	177
Method and Materials.....	179
Results.....	186
Habitat use of blue sheep.....	186
Plant species diversity and the importance value index in the blue sheep habitat.....	191
Blue sheep population.....	195
Carrying capacity of the upper Mustang for snow leopards.....	197
Discussion.....	198
Conclusion.....	202
References.....	203
Paper III:Habitat assessment for blue sheep translocation to maintain a viable snow leopard population in the Mt Everest Region, Nepal.....	208
Abstract.....	208
Introduction.....	209
Material and Methods.....	211
Results.....	216
Distribution and connectivity for blue sheep in the Himalayas.....	216
Current blue sheep distribution.....	218
Habitat preferences of blue sheep.....	218

Possibilities for translocation of blue sheep to the Sagarmatha NP and biophysical comparisons	222
Discussion .....	226
References .....	232
<b>Chapter Four</b> .....	247
Small mammals and their distribution and ecology .....	247
Summary .....	247
Paper I: Habitat Characteristics of the Himalayan Marmot ( <i>Marmota himalayana</i> ) in upper Mustang, Nepal .....	249
Abstract .....	249
Introduction .....	250
Materials and Methods .....	252
Results .....	257
Marmot distribution .....	257
Soil nutrient in marmot habitats .....	261
Temperature and precipitation pattern in marmot habitat .....	262
Foods identified in the scat of marmot .....	264
Discussion .....	267
References .....	270
Paper II: Diet and Habitat Use of Hispid Hare <i>Caprolagus hispidus</i> in Shuklaphanta Wildlife Reserve, Nepal .....	278
Abstract .....	278
Introduction .....	279
Method and Materials .....	280
Results .....	286
Distribution and habitat use .....	286
Population and pellet density .....	289
Diet composition .....	289
Discussion .....	290

References.....	294
<b>Chapter Five</b> .....	298
Climate change impact on an ecosystem .....	298
Abstract.....	300
Introduction.....	301
Materials and Methods.....	302
Study Area .....	302
Current and Future Climate Change Modeling through the Analysis of Temperature and Rainfall Data from 1987–2009 .....	304
Local Inhabitants’ Perceptions of Climate.....	305
Assessment of Land Cover Changes between 1979 and 2009 .....	308
Results.....	310
Temperature Trends.....	310
Seasonal Maximum and Minimum Temperature Trends .....	312
Precipitation Trends.....	313
Seasonally based rainfall trends.....	315
Impacts of Climate Change on Prey, Predators, and Local Livelihood.....	316
Demands of the Local People of Samjung Village and Dhey Village.....	318
Land Cover Changes and Tree Line Shifts in Mustang District.....	319
Discussion.....	321
Rainfall and Temperature Trends and Impacts.....	321
Land Cover Changes.....	324
Conclusions.....	327
Acknowledgments.....	328
<b>Chapter Six</b> .....	334
Perspectives and conclusions.....	334
Human-Wildlife conflict and management strategy.....	334

Snow leopard-human conflict.....	334
Rangelands and Society-Rangeland use conflict .....	335
Involvement of local people in the management of the northern Barandabhar Forest Corridor	337
Predators: brown bear ecology and conservation strategy.....	338
The conservation and ecology of snow leopards and its main prey species, the blue sheep .....	339
Small mammals and their distribution and ecology.....	340
Marmot ecology, distribution, and diet.....	340
Hispid hare diet and distribution.....	341
Climate change impacts on Ecosystems .....	342
References.....	343

## Preface

The Himalayas boast an immense biodiversity, and yet many of the ecosystems in these ranges are fragile and threatened (Christensen & Heilmann-Clausen 2009). A region of particular interest in this regard is the Annapurna Conservation Area in Nepal (ACA). ACA is a remote, low to high altitude Trans-Himalayan desert ecosystem which is home to several endangered species (Spitiri and Nepal 2008), including the iconic snow leopard (*Panthera uncia*) and its principle prey species, the blue sheep or bharal (*Pseudois nayaur*). The blue sheep is a keystone prey species in this ecosystem, sustaining not only the snow leopard but also other endangered predators, namely the brown bear, wolf and lynx. In addition, ACA is an important area for human habitation and cultural heritage and supports a population of approximately 120,000 people representing a range of ethnic and cultural groups (Spitiri and Nepal 2008). Owing to its inaccessibility, extensive areas within ACA remain largely isolated and host some of the most authentic remaining examples of traditional cultures. The inaccessibility of this area means that this critical ecosystem remains poorly understood.

Recognising the need to balance wildlife conservation with cultural and development imperatives, in 1986 the Nepalese government implemented a project in this region to test a new concept in protected area management, aimed at integrating conservation and community needs (Baral et al. 2007). This project, the Annapurna Conservation Area Project (ACAP), is based on the principle of incentive based programmes (IBP), in which stewardship by local communities is fostered by linking tangible benefits to the conservation of biodiversity (Spitiri and Nepal 2008). While there is evidence that this approach has delivered benefits to biodiversity conservation (Bajracharya et al. 2005), considerable challenges remain. Principle among these is that economic returns, which dominate in incentive based approaches like ACAP (Baral et al. 2007), are not equally derived from conserving all species. In particular, the conservation of

many of the large, ecologically important, and/or conservation critical species produces no direct economic benefits to communities, and might even constitute an economic burden (e.g. Oli et al. 1994). Further, the high market value commanded by pelts and other derivatives of these animals provides an incentive for poaching. There is thus potential for conflict between communities practicing incentive based conservation programmes and key components of the biodiversity. Indeed, there already is conflict between humans and wildlife in the region because of livestock degradation (Jackson et al. 1996, Mishra 1997, Hussain 2003), a problem that exists throughout the world (Mech 1981, Oli et al. 1994, Cozza et al.1996, Pedersen 1999, Graham et al. 2004, Namgail et al. 2007, Aryal et al. 2012a, Aryal et al. 2012b).

An example of the impacts of this human wildlife conflict is found in the snow leopard and blue sheep relationships in northern Mustang and Manang districts of ACA. Human communities in this region are largely based on an agro-pastoral system, cultivating crops in the fertile river valleys and grazing livestock on surrounding mountainous rangelands. Productive rangeland is, however, scarce and crop production is severely limited by low rainfall, a lack of irrigation systems, and low temperatures (Pokharel 2005). Snow leopards have long been perceived as a significant threat to the livelihoods of these communities. Shrestha and Wegge (2008a) show that there is appreciable overlap between grazing preferences of blue sheep and livestock, which can lead to ecological competition between these species (Shrestha and Wegge 2008b). This competition is exacerbated by overgrazing (Pokharel 2005). Therefore, the conflict management strategies were adapted differently for specific prey and predators based on the type of animals involved, landscape, socio-economic status of the people, level of conflict, and the culture of the area (Oli et al. 1994, Cozza et al. 1996, Naughton-Treves 1997, Sekhar 1998, Siex and Struhsaker 1999, Butler 2001, Imam et al. 2002, Zang and Wang 2003, Mishra et al. 2003, Patterson et al. 2004, Nyhus and Tilson 2004 b & a).

As the ACAP is a model of participatory resource management and adheres to a strategy of human-wildlife conflict mitigation, it has been used as a baseline for developing a conservation model and strategy to reduce human wildlife conflict in another sensitive area in Nepal, the Barandabhar Forest Corridor (BFC) (see Chapter one; *Paper III*). The BFC which links the Chitwan National Park (CNP) to the Mahabharat range (Dhakal et al. 2011, Bhattarai and Basnet 2004, Bhattarai 2003) and then connecting the landscape from CNP to ACA, allowing the movement of one-horned rhinoceros (*Rhinoceros unicornis*) and Royal Bengal tiger (*Panthera tigris tigris*) into higher altitudes during monsoon seasons (Tiwari et al. 2007) in lowland.

As mentioned above, however, there are potential problems for the conservation of prey and predators under the IBP approach implemented in ACAP (and more recently BFC). A further challenge, is that the currently changing climate, warming temperature, and change in precipitation pattern has influenced the management strategy of resource use and human livelihood (Locky and Mackey 2009, IPCC 2001). Both low and high altitude areas of Nepal are among the most vulnerable ecosystems to these climatic changes (Christensen and Heilmann-Clausen 2009, Xu et al. 2009, Dong et al. 2009, Sharma and Tsering 2009, Aryal et al. 2012 a, b & c). Furthermore, despite a lack of information specifically related to these high altitude ecosystems and their human inhabitants, it is probable that climate change will reduce productivity and threaten human occupation of the region by reducing the effectiveness of the cultural adaptations that have historically enabled human inhabitants to persist in these marginal habitats (Bagchi et al. 2004, Berkes 1999, Cruikshak 2001, Nuttal 2001, Riedlinger and Berkes 2001, Fox 2002).

The study reported in this thesis evaluates human-wildlife interactions in ACA and other sensitive parts of Nepal, with a view towards contributing to strategies for balancing the needs of wildlife conservation and human subsistence and development. Further, the sensitivity of the

human-wildlife interactions to climate change necessitated this being taken into account in the study. The study encompasses a range of species that represent human-wildlife conflict in Nepal, including blue sheep, marmots, snow leopards and brown bears, as well ecologically important relationships among these species. Marmot and blue sheep are the main prey species of snow leopard and brown bear, and the presence of these prey is a strong indicator of the presence of snow leopard and brown bear. In addition this study has examined an endangered lowland species, the hispid hare, and developed participatory management strategies for corridors to assist movements of lowland species of Nepal. (References citation details for this section are in the chapter six).

## **Thesis Outline**

The contents of this thesis can be partitioned into four broad **themes**: wildlife ecology, human-wildlife conflict, the influence of climate change on human-wildlife conflict, and recommendations for developing strategies to balance wildlife conservation and human needs in Nepal.

From the perspective of wildlife ecology, it documents the distribution, diet of three prey species blue sheep (*Pseudois nayaur*), the Himalayan marmot (*Marmota himalayana*) from high mountain region, and the hispid hare from the lowlands of Nepal, and also describes the ecology and distribution of two predator species, snow leopard (*Panthera uncia*) and brown bears (*Ursus arctos*). In the first study of its kind being undertaken in Nepal, I investigate the home range of snow leopards and their population status using non-invasive genetic techniques, and also determine the feeding ecology of the snow leopard and its distribution in the Himalayan region of Nepal. These data are used to estimate the carrying capacity for snow leopards in the upper Mustang region of Nepal.

As the second theme, this thesis examines the issues of conflict between humans and wildlife, and between the local communities in the Himalayas of Nepal, and investigates the livestock depredation by snow leopards and brown bears in the region. The study also documents the causes of wildlife damage with wild prey and predator species.

The third theme concerns the effects of climate change on human-wildlife ecosystem interactions in the Mustang district of the Trans-Himalaya region, the highest altitude permanent human settlement (>3800m) in Nepal. Climate change is one of the significant issues in the Himalayas in relation to conservation of biodiversity. There is ongoing debate about the impact of climate change on local ecosystems, endangered wildlife, and human society.

Fourth, the aim of the study was to understand the issues outlined above, but above all to contribute to effective management strategies for human-wildlife conflict in Nepal. Results of the thesis have already been used in the design of two conservation strategies in Nepal; for the brown bear of the Nepalese Himalayas and for lowland corridor management.

## **Thesis Structure**

The thesis is based on 12 scientific papers prepared between 2009 and 2012. These papers are synthesized in six chapters based on their relevant theme. Of the papers included in this thesis, nine papers are published in peer reviewed journals, two papers are under review and one is in the process of submission to the Journal.

My supervisors, Dianne Brunton, David Raubenheimer, and Weihong Ji, are co-authors on all published, accepted and submitted papers. Their support and contributions to all stages of research activities, from experiment design to the field work, and from the logistic to the funding and analysis are noteworthy.

The structure of **this thesis is as follows:** Chapters one to five based on research themes and findings; and the final chapter: six describes overall conclusion and perspectives of the study.

# Chapter One

## Human-wildlife resource use conflict and management strategy

### Summary

This chapter encompasses three papers which present the overall human-wildlife conflicting issues and resource use. Human communities in the Trans-Himalayan region depend on the dynamics of an agro-pastoral system for their livelihood. Humans, livestock, and wild predators share common resources in the region. This leads to human-wildlife interactions which potentially threaten the viability of this fragile ecosystem and may impact the local economy. I explore the interactions between livestock and predators in the upper Mustang region of Nepal in terms of economic impacts (paper *I* below).

In addition, this chapter includes a description of current rangeland resource use and existing conflict in the region. Rangelands are considered to be critical ecosystems in the Nepalese Himalayas and, provide multiple ecosystem services to support local livelihoods. However, these rangelands are under threat from various anthropogenic and natural sources. The results show how a change in international policy influences the local use of common property resources. In addition, the study concludes that if national policies are not updated accordingly, local conflict over the use of resources may arise (paper *II* below).

The final component of this chapter describes the role that connectivity plays in wildlife movement from the lowlands of Nepal. We proposed a participatory scheme to manage the northern Barandabhar Forest Corridor (BFC), establishing the Barandabhar Forest Management Council, to foster the ecological integrity of the area while providing forest products to local communities. This component has been published in the *Tropical Conservation Science* (Vol. 5 (1):38-49; paper *III* below) and is co-authored with my PhD supervisors, an official from the

Government of Nepal (Yam Bahadur Thapa, Deputy Director of the Department of Forests), and other experts. It outlines the management strategy for the Barandabhar Corridor Forest and the plan has been adopted by the Department of Forests/Government of Nepal for implementation. A similar model could be implemented to manage wildlife in the Himalayan region of Nepal.

*The three papers contained in this chapter are:*

- I. Aryal, A., D. Raubenheimer, W. Ji, R.K. Barraclough and D. Brunton. **(Submitted)**. Snow leopard-human conflict in the upper Mustang region of Nepal: Ecological and economic implications of snow leopard predation of livestock.
- II. Aryal, A., D. Brunton, R. Pandit, R. Rai, U. B. Shrestha, N. Lama, D. Raubenheimer. **(2013)**. Rangelands and Society: status, rights, conflicts and indigenous conflict management strategies in rangeland of Nepal. *Mountain Research and Development* 33 (1): 11-18.
- III. Aryal, A., D. Brunton, T K Shrestha, R. K. Koirala, J. Lord, Y. B. Thapa, B. Adhikari, W. Ji, D. Raubenheimer. 2012. Biological diversity and management regimes of the northern Barandabhar Forest Corridor: an essential habitat for ecological connectivity in Nepal. *Tropical Conservation Sciences* 5 (1):38-49.

# **Paper I: Snow Leopard-Human Conflict in the Upper Mustang Region of Nepal: Ecological and Economic Implications of Snow Leopard Predation of Livestock**

## **Abstract**

Human communities in the Trans-Himalayan region depend on the dynamics of an agro-pastoral system for survival. Humans, livestock and wild predators share common resources in the region, and this leads to human-wildlife interactions which have the potential to threaten the continued viability of this fragile ecosystem and impact the local economy. This study explored the interaction between livestock and predators in the upper Mustang region of Nepal in terms of economic impact and habitat.

A total of 1,347 km<sup>2</sup> of pasture land was used by the local people from six village development committees of the upper Mustang region and was grazed by 30,217 livestock. A total of 706 livestock were killed during the study periods by predators, and 75% of total livestock predation was attributed to snow leopards. Thereby an estimated US\$44,213 was lost between two year (October 2009 to June 2011) due to livestock predation. It was found that the seasonal movement patterns of livestock, from higher to lower elevations (closer to villages) coincided with elevation movements of wild ungulate prey and snow leopards into this smaller land area. In addition to predation, a minimum of 82 livestock also died due to disease/parasites

Findings will be useful to mitigate human-wildlife conflict in upper Mustang region, and giving insight to do further study on disease transmission between livestock, prey and predators.

Keys words: Conflicts, ecosystem, depredation, movement patterns, parasites

## Introduction

The livelihoods of the communities in the Trans-Himalayan region of Nepal are largely dependent on an agro-pastoral system, involving the cultivation of crops in the fertile river valleys and the grazing of livestock on the surrounding mountainous rangelands (Mishra 2001, Namgail et al. 2007, Aryal et al. 2012a, b & c). Productive rangelands are however scarce and crop production in river valleys is severely limited by low rainfall, a lack of irrigation systems and low temperatures (Aryal et al. *Chapter five-paper I*, Pokharel 2005). Rangelands are also shared by both livestock and wildlife, and studies show that in the Himalayas, livestock depredation is increasing (Jackson et al. 1996, Mishra 1997, Hussain 2003). Since livestock predation is inevitably the main source of conflict between humans and wildlife throughout the world (Mech 1981, Oli et al. 1994, Cozza et al. 1996, Pedersen 1999, Mazzoli 2002, Graham et al. 2004, Namgail et al. 2007, Aryal et al. 2012b & c).

Conflict between humans and predators can be a product of socio-economic and political conditions, fundamentally arising from the competition that exists between wildlife and humans for shared and limited resources (Aryal et al. 2012c, Thirgood et al. 2000, Graham et al. 2005). As such, snow leopards (*Panthera uncia*) have long been perceived as a significant threat to the livelihoods of the Trans-Himalayan communities (Aryal et al. 2012a). For instance, in monetary terms, Oli et al. (1994) found that in a two year period in the Manang district, the number of livestock lost to predation by snow leopards amounted to almost 25% of the average per capita income in Nepal. Therefore it is not surprising that villagers hold strongly negative attitudes towards snow leopards and other predators, and the majority advocate their complete elimination (Aryal et al. 2012Aa). It is also not surprising that the economic losses from livestock depredation generally lead to the retaliatory killing of the predators by agro-pastoralists (Oli et al. 1994, Graham et al. 2007). Moreover, this conflict is likely to escalate in regions where effective conservation laws may help to increase the number of predators, particularly where

natural prey species are not abundant (Namgail et al. 2007). Therefore these issues are likely to become increasingly serious in the future.

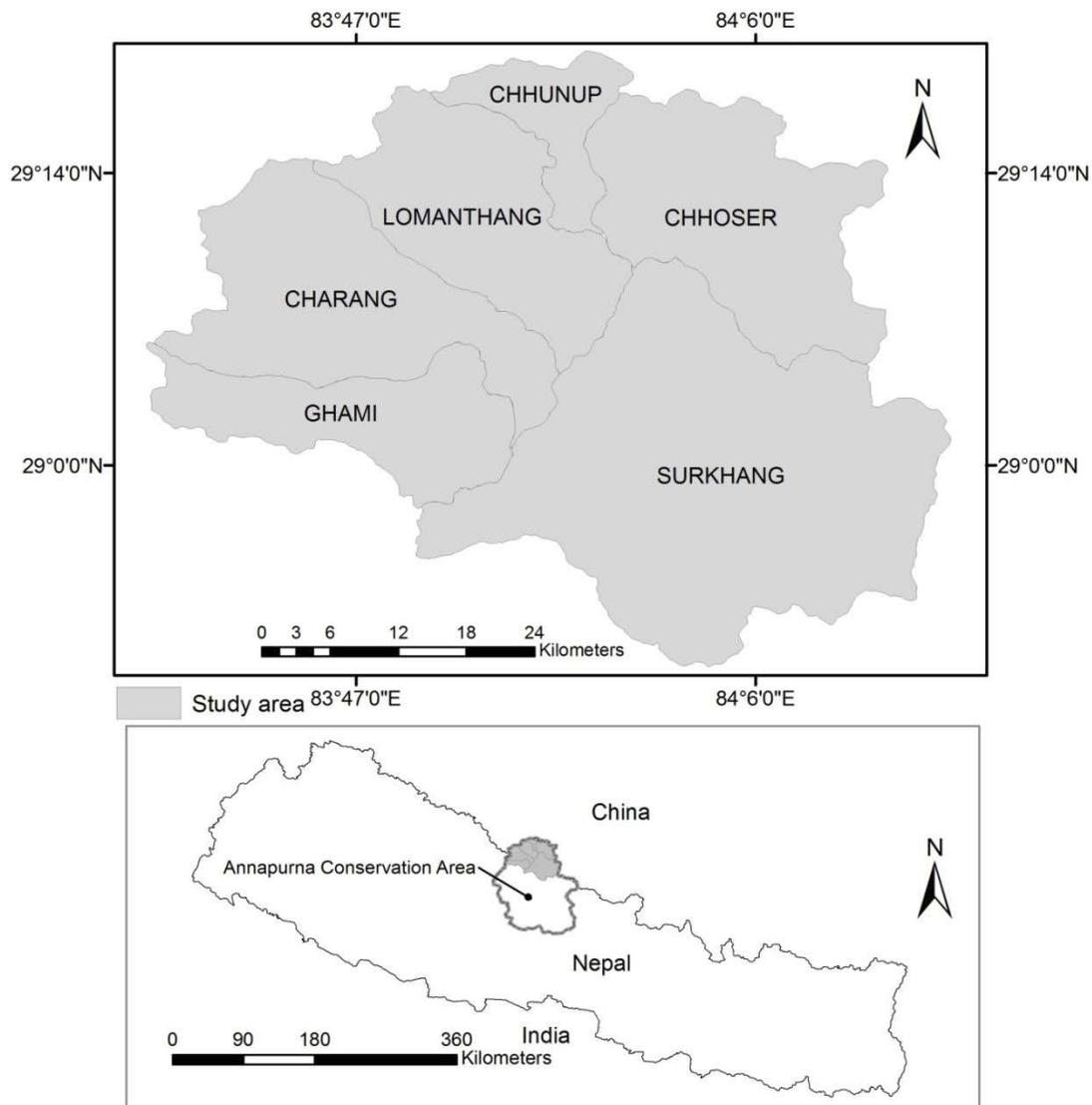
The specialist knowledge of human-wildlife interactions and livestock-predator dynamics, which is of primary importance in the management of human-wildlife conflicts elsewhere in the world, is largely lacking in the Himalayas (Oli et al. 1994, Mishra 1997, Graham et al. 2004, Conover 2002, Namgail et al. 2007, Aryal et al. 2010, Aryal et al. 2012b & c). Snow leopards are the main carnivores within the upper Mustang region, and local people frequently complain about livestock depredation by these predators. However, although several studies of livestock depredation were conducted in the 1990s in the Manang district of the Annapurna Conservation Area (ACA) region of Nepal (Oli et al. 1994) and recently Wegge et al. (2012) examined snow leopard predation on livestock and other prey in Phu valley of Manang district, such information is lacking from the upper Mustang. Therefore, we aim to establish baseline depredation data upon which we can begin to base future strategies for sustainable pastoral and wildlife management.

Our study therefore addresses two key aspects of snow leopard-livestock interactions, ecological and economic impact. The main aims were: a) to investigate the rate of livestock depredation by wild predators and how the seasons and livestock movement patterns affect the depredation rate and the economic losses suffered; and The findings of this study will be of benefit to the management of human-wildlife conflicts in the Trans-Himalayan region.

## **Methods and Material**

This study was conducted in six village development committees (VDCs) (Ghami, Surkhang, Charang, Lomanthang, Chhoser, and Chhunup) in the upper Mustang region of the Annapurna Conservation Area (ACA), Nepal (Fig. 1). This region lies in the northern part of the Mustang district, at approximately 83° 45' to 84° E and 29° 04' 12" to 29° 18' N. The area can be

characterized as a cold desert, desiccated by strong winds and intense solar radiation (Aryal et al. 2012a, b & c)). The climate is sub-alpine, and average maximum and minimum temperatures of 26.8°C -5.8 °C. The total annual rainfall is less than 200mm, and more than half of the total precipitation falls as snow during the winter months (Aryal et al. 2012a, b & c).



**Figure 1.** Location of study area

## Data collection

## Pasture land delineation

Topographic maps (1:50000) and vector layers for vegetation were obtained from the Department of Survey, Nepal and ICIMOD (<http://geoportal.icimod.org>) and used in this study. Pasture lands that are both used and available for the local people were delineated in the field. In each VDC, pasture land was identified with the help of the local people and by the use of topographic maps. Furthermore, participatory resource maps for each VDC which indicate livestock grazing areas and pasture areas were prepared. These data were also used for GIS analysis. Pasture land boundaries were also delineated from vantage points and marked on topographic maps. Local people (n=611) were interviewed to gather data on livestock grazing patterns and on how far livestock are moved from the villages during the four climatic seasons (winter, spring, summer, and autumn). Local interviewers were selected base only who had livestock and those whose livestock killed by predators, beside that we asked exact number of livestock of their neighbours or friend if they have information. Data were analyzed in Arc GIS (version 9.3, ESRI Inc., Redlands, California, USA) using vegetation and elevation vector layers of the study site for reference. The area of pasture land in each VDC was calculated.

### **Household survey**

Six hundred and eleven local people from the six VDCs of the upper Mustang region were interviewed between December 2010 and June 2011, to determine all livestock deaths between October 2009 and June 2011. For each VDC, the total number of livestock, the number of livestock lost to predation, the species of carnivore that was thought to have killed the livestock, the season of the attack, and any identifying details of the depredation event were recorded. Information regarding the seasonal use of pasture lands, and the distance from the pasture lands to the villages was also recorded. Every effort was made to contact all livestock owners. However, when owners could not be located, their relatives, herder men, or the nearest neighbors were interviewed. As some pastoralists have a propensity to exaggerate the numbers of livestock killed by predators, perhaps in the hope of compensation from the government or concerned

authorities (Bhatnagar et al. 1999, Namgail et al. 2007, Aryal et al. 2010), the responses of the individual herders/owners were verified by independently interviewing family members or other people from the area. The number of livestock deaths in each VDC resulting from disease was also recorded.

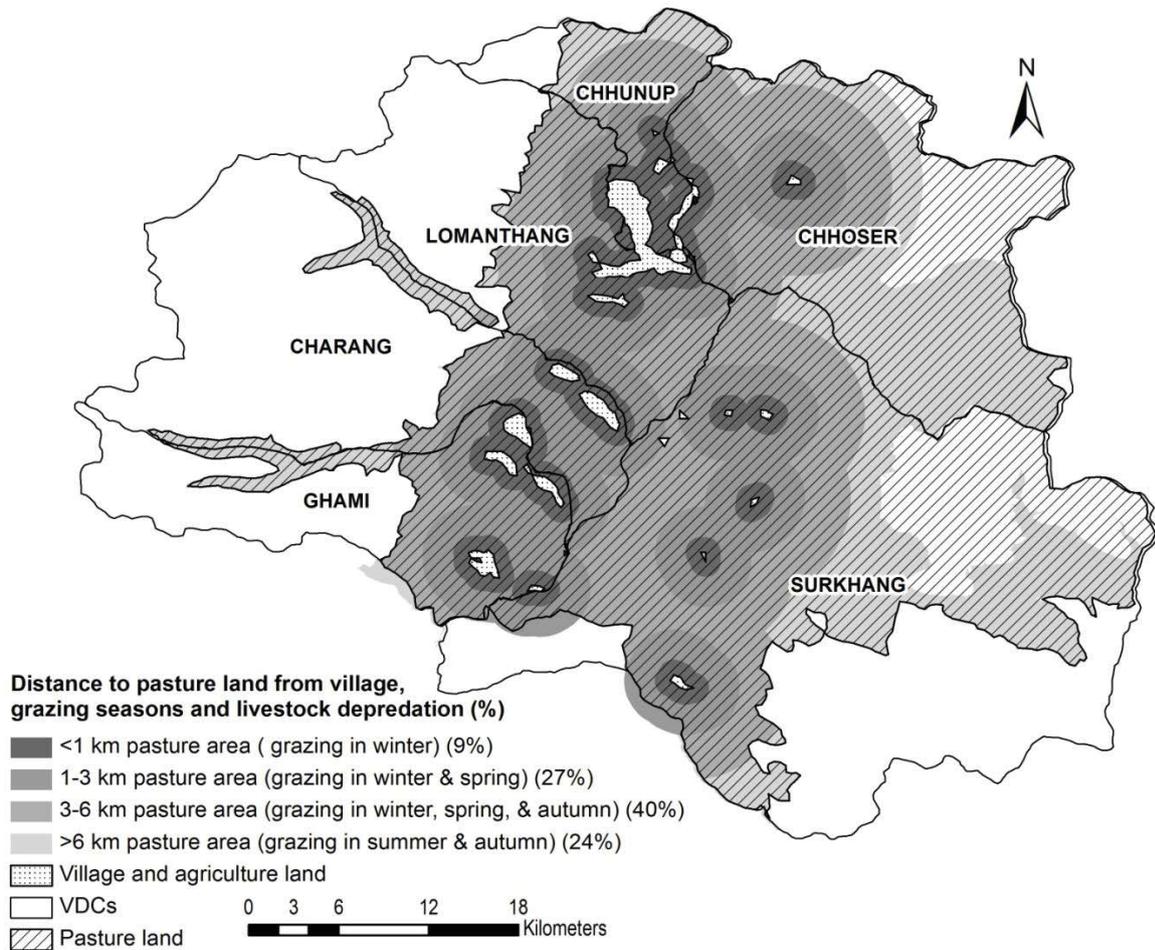
Locals were asked how they knew that their livestock had been killed by specific predators (snow leopards, wolves, jackals, feral dogs); in reply, they claimed that wolves attack the hindquarters and that snow leopards attack the neck or throat of livestock. Other predators are not thought to have specific strategies for killing livestock, however local people claim that jackals, foxes, and feral dogs kill their livestock during the evenings. The prevailing market value for each type of livestock was estimated by interviewing herders and on the basis of local selling and buying rates.

SPSS (16.0 version) software was used for further data analysis and a chi-square test was used to test for significant differences in factors such as seasonal pasture land use and in livestock depredation patterns.

## **Results**

### **Pasture lands**

Currently, 1,347 km<sup>2</sup> of pasture land are used by the local people for livestock grazing. There were not significant differences in pasture land distribution between the different VDCs of the upper Mustang ( $\chi^2 = 3.5$ ,  $df=5$   $P=0.62$ ). (Table 1, Fig. 2). Surkhang VDC has the largest area of pasture land, 552 km<sup>2</sup> or 41% of total pasture land, followed by Chhoser (25%), Lomangthang (12%), Ghami (9%), Charang (7%) and Chhunup (6%).



**Figure 2.** Livestock depredation by predator according to seasons and distance to pasture land from the villages

### Livestock holding and density

A total of 30,217 livestock were recorded in the study area. Goats were significantly more abundant than other types of livestock in the upper Mustang region ( $\chi^2 = 80.4$ ,  $df=7$ ,  $P<0.05$ ) (Table 1). The number of goats recorded was 20,767 (68.7%), whereas sheep accounted for 4,378 (14.5%), and donkeys 122 (<1 %) (Table 1). The highest number of livestock were recorded in the Surkhang VDC ( $n=8,555$ ) followed by Chhoser, Chhunup, Ghami, and Charang. However, although there were no significant differences in the number of different types of livestock among the VDCs ( $\chi^2 = 10.4$ ,  $df = 5$ ,  $p=0.062$ ) (Table 1). Livestock density was the highest in the Chhunup VDC (56 livestock/km<sup>2</sup>), followed by Ghami VDC (40 livestock/km<sup>2</sup>).

The lowest livestock density was found in the Surkhang VDC (15 livestock/km<sup>2</sup>) ( $\chi^2 = 3.8$ , df=5, p=0.56) (Table 1). The overall livestock density in the upper Mustang region was 22.42 livestock per km<sup>2</sup>.

**Table 1:** Livestock holding, pasture land area and livestock density in upper mustang region.

	VDCs							Total	Percentage
	Chhunup	Chhoser	Ghemi	Lo Manthang	Surkhang	Charang			
<b>Yak</b> ( <i>Bos grunniens</i> )	592	76	108	136	318	241	1471	4.87	
<b>Jhoppa</b> ( <i>Bos indicus</i> )	97	31	173	42	103	92	538	1.78	
<b>Cow/ox/Lulu</b> ( <i>Bos spp</i> )	381	246	258	216	194	216	1511	5.00	
<b>Donkey</b> ( <i>Equus asinus</i> )	19	26	41	19	17		122	0.40	
<b>Mule</b> (Cross between <i>Equus asinus</i> and <i>Equus caballus</i> )			34	28	29		91	0.30	
<b>Goat</b> ( <i>Capra spp</i> )	2,857	3,961	3,128	1,652	6,496	2,673	20767	68.73	
<b>Sheep</b> ( <i>Ovis spp</i> )	427	574	761	739	1183	694	4378	14.49	
<b>Horse</b> ( <i>Equus caballus</i> )	238	192	275	282	215	137	1339	4.43	
<b>Total number of livestock</b>	4,611	5,106	4,778	3,114	8,555	4,053	30217	100	
<b>Pasture land area in km<sup>2</sup></b>	82.09	338.8	117.9	163	552.91	92.9	1347		
<b>Livestock density per km<sup>2</sup></b>	56.17	15.07	40.53	19.10	15.47	43.63	22.42		
<b>Total area of each VDCs (km<sup>2</sup>)</b>	98.78	345.56	209.6	280.46	791.541	348.64	2074.6		

### Livestock depredation in the upper Mustang

A total of 706 domestic animals, the majority of which were goats (n=438), were killed by predators during the study period in the upper Mustang region. A minimum of 526 livestock (75%) were killed by snow leopards and the remaining (25%) were killed by other predators such as wolves, jackals, lynx, and red foxes (Table 2). It can be seen that snow leopards killed a significantly higher number of livestock when compared to other predators in the upper Mustang region ( $\chi^2 = 11.8$ , df =5, p=0.03) (Table 2). Snow leopards killed a significantly higher number

of goats (312) when compared to other livestock in the upper Mustang region ( $\chi^2 = 16.7$ ,  $df = 5$ ,  $p = 0.005$ ). Those concluded that the snow leopard killed significantly more goats than other livestock in the region. Based on the local interview; livestock depredation was reported to mainly occur during the day (48%) followed by night (28%) and evening (25%).

Livestock depredation trends did not vary significantly across the different VDCs of the upper Mustang ( $\chi^2 = 1.02$ ,  $df = 5$ ,  $p = 0.96$ ). The proportion of predation events was largely proportional to the size of the VDC's, except that the most densely grazed regions (Ghami, Chhunup, and Charang) experienced slightly greater proportion of depredation events than may be expected based on size: Surkhang ( $n = 217$ ; 31%), followed by Chhoser ( $n = 148$ ; 21%); Ghami ( $n = 105$ ; 15%), Chhunup ( $n = 87$ ; 12%); Charang ( $n = 80$ ; 11%) and Lomanthang ( $n = 69$ ; 10%).

**Table 2:** Livestock depredation by predators in upper mustang region

Livestock	Predators					Total
	Snow leopard	Wolf	Jackal	Red fox	Lynx	
<b>Goat</b>	312	39	21	42	24	438
<b>Sheep</b>	111	12	22	7	3	155
<b>Yak</b>	56	8	0	1	1	66
<b>Cow/ox/lulu</b>	8	0	0	0	0	8
<b>Jhoppa</b>	22	0	0	0	0	22
<b>Horse</b>	17	0	0	0	0	17
<b>Total</b>	526	59	43	50	28	706
<b>Percentage</b>	74.5	8.4	6.1	7	4.0	

### Economic value of livestock depredation

An estimated US\$ 44,213.33 was lost during the study period (two years) in the upper mustang region due to livestock predation (Table 3). Over two years (October 2009 to June 2011) monetary loss was approximately \$14,600 for goats, \$17,600 for yaks, \$4,133 for sheep, and \$160 for cattle (Table 3). Most of the monetary losses were caused by snow leopards (US\$ 36173) followed by wolves, jackals, red foxes, and lynx (Table 4).

**Table 3.** Economic loss due to livestock depredation in each VDCs

Economic loss by predator in different VDC s								
Type of Livestock	Lomanthang	Chhoser	Charang	Surkhang	Ghami	Chhunup	Total in amount in USD	Average price per livestock (NRs)*
Goat	1533	2533	1667	4833	2433	1600	14600	Goat 2500
Sheep	293	880	453	1147	613	747	4133	Sheep 2000
Yak	1867	4533	2400	5067	2400	1333	17600	Yak 20000
Cow/ox/lulu	20	60	0	40	0	40	160	cow 1500
Jhoppa	0	840	280	467	0	467	2053	Jhoppa 7000
Horse	1333	2000	333	1000	0	1000	5667	horse 25000
<b>Total in US\$</b>	<b>5047</b>	<b>10847</b>	<b>5133</b>	<b>12553</b>	<b>5447</b>	<b>5187</b>	<b>44213</b>	

\*1 US\$ equivalent to 75 Nepali Rupees (NRs).

**Table 4.** Economic loss caused by different predators

	snow leopard	Wolf	Jackal	Red fox	Lynx	Total in USD
Goat	10400	1300	700	1400	800	14600
Sheep	2960	320	587	187	80	4133
Yak	14933	2133	0	267	267	17600
Cow/ox/lulu	160	0	0	0	0	160
Jhoppa	2053	0	0	0	0	2053
Horse	5667	0	0	0	0	5667

<b>Total in USD</b>	36173	3753	1287	1854	1147	44213
---------------------	-------	------	------	------	------	-------

### Seasonal livestock depredation

Livestock depredation was greatest during winter (42%), followed by spring (23%), autumn (19%), and then summer (15%) (Table 5). However, the differences in livestock predation patterns across these seasons was not statistically significant (Kruskal Wallis  $\chi^2 = 3$  df=3 p<0.39) (Table 5, Fig. 2).

**Table 5:** Seasonal livestock depredation trend in upper Mustang

Seasons	livestock killed	%
winter (Dec-March)	297.00	42.07
Spring (April 1-June 30)	165.00	23.37
Summer (July 1 to August 31)	108.00	15.30
Autumn (September 1 to November 30)	136.00	19.26

### Livestock movement patterns and approximate distance of depredation from villages and seasonally used pastures

This study tested the hypothesis that the greater the distance to the pastures used (as determined by the season), the greater the propensity for livestock losses to decrease (that is, the season and the distance of the pasture from a village influences the livestock losses experienced). Livestock were reared in different locations of the pasture lands in different seasons. In winter, livestock were kept in the pastures nearest to the village and in summer they were taken longer distances from the villages for grazing. For nearly one month in December, when conditions were extreme, livestock were kept less than 1 km from the village, where they grazed on approximately 110 km<sup>2</sup> of land. The livestock grazing land were equally used (in term of area

from approximate distance from the village) during the different season ( $\chi^2 = 1.6$  df=3; p=0.64, Table 6, Fig. 2). However livestock depredation were significantly higher in winter, spring, and autumn compare to summer (Fig. 2, Table 6). The grazing pattern area and distance from the village was based on season, in winter it is close to village and summer far from the village (fig. 2). The predators killed 65 livestock (9%) in the nearest pastures (1 km from the villages). From February to April, livestock were moved further away for grazing but within 3 km of the villages, and 363 km<sup>2</sup> of pasture land (26%) were grazed in this period. 189 livestock (27%) were killed in these areas. The greatest amount of pasture land (562 km<sup>2</sup>; 41%) 3-6 km from the villages was used from May to July and during September. Livestock spent most of the year in these areas, and these areas had the highest level of depredations (n=285; 40%). From July to November, livestock were moved to higher elevations >6km from the villages. These pasture lands covered 312 km<sup>2</sup> of land (23%). In these areas, 167 livestock (24%) were killed by predators (Table 6, Fig. 2).

Therefore the rate of livestock depredation is effected by seasonal livestock distribution patterns. In cold seasons, livestock are moved to lower elevation zones, close to the villages. During cold periods wild prey and snow leopards also move to lower elevation zones. This seasonal shift increases the encounter rate between snow leopard and livestock and causing higher livestock predation.

**Table 6.** Livestock depredation with respect to season, distance from the village and pasture land used area during the seasons

Distance from Village to Pasture land	Livestock grazing seasons	Number of livestock killed by	%	Pasture area use respect to season and distance from the village	%
---------------------------------------	---------------------------	-------------------------------	---	--	---

		predators	in km <sup>2</sup>		
<1000 meters	Winter	65	9.21	110	8.17
1001-3000 meters	Winter+Spring	189	26.77	363	26.95
3001-6000 meters	Spring+Autumn+Winter	285	40.37	562	41.72
>6000 meters	Summer + Autumn	167	23.65	312	23.16

### **Livestock depredation due to disease**

The snow leopard was the main predator of livestock in the upper Mustang region over this study period. However, a minimum of 82 livestock also died during the survey period from disease (0.13 livestock /household). If these data are representative of general mortality rates in this region, at least 57 goats 19 sheep, 4 yak, 12 cows/oxen and 4 horses die as a result of disease in the upper Mustang region each year.

## **Discussion**

### **Pasture land and livestock density**

A total land area of 2,074.58 km<sup>2</sup> is incorporated by the six adjoining VDCs in the upper Mustang region, and 64% of this area is used as pasture lands for grazing. Local herders and nomads mostly follow a rotational grazing system which accords with the seasons. Livestock graze in pastures at lower elevations and closer to the villages in the winter months and are moved to higher elevations and further away from the villages during the summer. In winter, most of the area is covered with snow, and this makes foraging more difficult. For this reason, livestock are moved closer to the villages to be fed with the remnant and redundant bi-products from agriculture. Over-grazing throughout the years has caused a reduction in grassland productivity in the upper Mustang region (Pokharel 2006). Further studies on the carrying

capacity of rangelands are necessary so that the maximum number of livestock that can be sustainably grazed in the upper Mustang region can be accurately ascertained.

### **Livestock depredation and economic loss**

As reported in the results, an average of 2.3% of the total livestock in the upper Mustang region was killed by carnivores each year. Snow leopards contribute the highest of livestock depredation followed by wolves, jackals, lynx, red foxes and feral dogs. The study has concluded that the snow leopard killed significantly higher goats in the region, the reason was this likely to be due to there being more of an overlap in habitat preference of goats and snow leopards (e.g. SN favouring steep rugged terrain, as per the McCarthy et al. 2003). The annual loss is higher than that reported by some studies (Graham et al. 2005, Kolowski and Holecamp 2006) but is similar to the rates found in the Manang region of 2.6% loss per household (Oli et al. 1994) The possible reason for the increased incidence of attacks on domestic livestock is that a decrease in the numbers of natural prey may be occurring as carnivore density increases (Sagor et al. 1997, Stahl et al. 2001, Stoddart et al. 2001).

The loss of livestock to snow leopards and other predators leads to higher levels of conflict with humans and retaliatory killings, and this in turn may significantly affect the viability of predator populations in this region. Retaliatory killing is occurring in the upper Mustang region through the use of poisons, traps, and sometimes guns. One retaliatory killing of a predator was recorded during the study period (a lynx in the Samar area of the upper Mustang region in November 2009) and local people (>83%) expressed a dislike for predators such as snow leopards, lynx, and wolves. Although the effects of these retaliatory killing actions on predator populations remain unknown, an urgent investigation into options for management of human-predator conflict is necessary, especially those conflicts involving snow leopards in the upper Mustang.

The annual loss per household from depredation cannot be ignored. It stands at USD \$72.00, and of this, about 81% of the economic loss in the upper Mustang region of Nepal is caused by snow leopards. These losses are higher than the monetary losses recorded in the Manang region of ACA of USD \$47.00 to \$49.00 per household (Oli et al. 1994), and lower than that in India (USD \$128/household) (Mishra 1997). However, total economic losses are significantly higher in the upper Mustang region (USD \$44,213.00 per two year) due to the higher market value of horses and yaks when compared to goats.

### **Seasonality in depredation and distance from settlements**

Seasons are the main factor determining livestock movement. In the winter season, livestock remain at lower elevations, and they are then led to higher elevations during summer before descending in autumn. As a result of the colder conditions and because most of the higher elevation areas are covered with snow, the snow leopard's natural wild prey animals also move to lower elevations. Snow leopards, following the movement of their natural prey also descend to areas of lower elevation. These lower elevation regions cover a smaller land area and include the locations of villages along water ways and in valleys. This synchronized movement of predators, wild prey and livestock into a smaller available land area inevitably increases encounter rates between predators and livestock and this is likely to explain the higher number of livestock killings recorded during winter. Furthermore, some natural prey animals, such as Himalayan marmots, hibernate in winter, and this would encourage their predators to supplement their diet with livestock when these are encountered. In summer, natural prey species are more widely available and all potential prey (livestock and wild prey) are distributed over a wider area, which may explain the lower rate of livestock depredation.

### **Implication: Human-wildlife conflict management strategies for the upper Mustang**

Some practices have been implemented to mitigate human-wildlife conflicts throughout the world, and the techniques used differ depending on the level of conflict, types of wildlife, and the local economic and cultural value of the area (Oli et al. 1994, Cozza et al. 1996, Naughton-Treves 1997, Sekhar 1998, Siex and Struhsaker 1999, Butler 2000, Imam et al. 2002, Vijayan and Pati 2002, Zang and Wang 2003, Mishra et al. 2003, Patterson et al. 2004, Nyhus and Tilson 2004b & a). Unresolved human-wildlife conflicts may lead to the local extinction of the target wildlife species (Ogada et al. 2003). The local economy in the upper Mustang region mostly depends upon livestock production and is directly associated with rangeland productivity. In the upper Mustang, apart from livestock depredation, crop raiding by blue sheep presents a problem. Therefore, region-specific conservation mitigation measurements should be implemented. Two approaches can be used to mitigate the conflict and generate alternative income and provide conservation education opportunities at the local level. Mitigation measures were discussed with local people (n=611) and the majority of them (>87%) recommended a compensation programme. I also canvassed the possibility of a livestock insurance programme and over 45% of respondents supported the concept for such a programme. It is recommended that, as a start, a livestock insurance scheme be piloted in a small village (Chhoser village) and a compensation programme be tested in Yara and Ghara villages. On the basis of the impact and success of the pilot programs, management authorities may extend them to other areas of the upper Mustang. In addition, predator proof corrals and livestock guards should be improved to reduced depredation. A conservation education programme should also be implemented to raise the awareness of the role of ecosystem health in wild predators.

## **Acknowledgement**

We thank the National Trust for Nature Conservation/Annapurna Conservation Area Project for providing permission and necessary support to conduct this research. We thank Mr. R. K. Koirala, Dr. S.R. Jnawali, Mr. R. Lamsal, Mr. L.B. Gurung ; Mr. N. Lama, and Niranjana Dhungana, and all upper Mustang Unit Conservation office's staffs for their support. We thank Massey University Research Fund for providing financial support for the project. We thank Mr. G. Gurung, D. C. Gurung, F. Gurung, S. Gurung, Mr. S. Paudel and Mr. B. Adhikari for their support in field survey. We thank to Brigitte Kreigenhofer for her first edit, comments and suggestion on the paper.

## **References**

- Aryal, A., S. Sathyakumar, C.C. Schwartz. (2010). Current status of the brown bear in Manasalu Conservation Area Nepal. *Ursus* 21(1):109-114. doi: 10.2192/09GR029.1
- Aryal, A., D. Raubenheimer, W. Ji and D. Brunton. (2012a). Blue sheep in the Annapurna Conservation Area, Nepal: habitat use, population biomass and their contribution to the carrying capacity of snow leopards. *Integrative Zoology*. In press (DOI: 10.1111/1749-4877.12004).
- Aryal A., D. Raubenheimer, S. Sathyakumar, B.S. Poudel, W. Ji, K.J. Kunwar, J. Kok , S. Kohshima and D. Brunton. 2012b. Conservation strategy for brown bear and its habitat in Nepal. *Diversity* 2012, 4,(3): 301-317.
- Aryal, A., J. Hopkins, W. Ji, D. Raubenheimer and D. Brunton. 2012c. Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (2): 231-236
- Aryal, A., D. Brunton, R. Pandit, R. Rai, U. B. Shrestha, N. Lama, D. Raubenheimer. (2013). Rangelands and Society: Status, Rights, Conflicts and Indigenous Conflict Management Strategies in Rangeland of Nepal. *Mountain Research and Development* 33 (1), In press.

- Bhatnagar Y. V., R. Wangchuk, R. Jackson. 1999. A survey of depredation and related wildlife-human conflicts in Hemis National Park, Ladakh, Jammu & Kashmir, India. International Snow Leopard Trust, Seattle, WA
- Butler, J. (2000). The economic costs of wildlife predation on livestock in Gokwe communal land, Zimbabwe. *African Journal of Ecology* 38 (1): 23-30.
- Conover, M.2002. Resolving Human–Wildlife Conflicts: The Science of Wildlife Damage Management. Lewis, Florida.
- Cozza K., R.Fico, L. Battistini . E. Rogers. (1996). The damage- conservation interface illustrated by predation on domestic livestock in central Italy. *Biological Conservation* 78 (3): 329-337.
- Graham K, A.P Beckerman, S. Thirgood. (2005). Human-predator–prey conflicts: ecological correlates, prey losses and patterns of management. *Biological Conservation* 122: 159–171.
- Hewson R. (1990). Victim of myth: Predation upon lambs byfoxes in the absence of control. League Against Cruel Sports. Department of Zoology, University of Aberdeen
- Houston D. (1977). The effect of hooded crow on hill sheep farming in Argyll, Scotland. *Journal of Applied Ecology*. 14:1-15.
- Hussain S. (2003). The status of snow leopard in Pakistan and its conflict with local farmer livelihoods. *Oryx* 37:26–33
- Imam E., H. Yahya,I. Malik.(2002). A successful mass translocation of commensal rhesus monkeys *Macaca mulatta* in Vrindaban, India. *Oryx* 36 (1): 87-93.
- Jackson R.M., G. Ahlborn, M. Gurung, S. Ale. (1996). Reducing livestock depredation losses in the Nepalese Himalaya. In R. M. Timm, A. C. Crabb (eds), Proceedings of the 17th Vertebrate Pest Conference. University of California, Davis, CA, pp 241–47

- Joshi B.R., L.M. Gibbons, D.E.Jacobs. (1997). *Ostertagia nianqingtangulaensis* K'ung & Li, 1965 (Nematoda: Trichostongyloidea) from sheep and goats at high altitudes in Nepal. *Journal of Helminthology* 71: 21-27.
- Kolowski, J.M., K.E. Holekamp. (2006). Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. *Biological Conservation* 128: 529-541.
- Mazzoli M, Graipel M.E, Dunstone N. (2002). Mountain lion depredation in southern Brazil. *Biological Conservation* 105 (1): 43–51.
- McCarthy T.M., R.K. Fuller, B. Munkhtsog .(2005). Movements and activities of snow leopards in Southwestern Mongolia. *Biological Conservation* 124: 527-537.
- Mech L.D. (1981). *The Wolf: The Ecology and Behaviour of an Endangered Species*. Doubleday, New York.
- Mishra C. (1997). Livestock depredation by large carnivores in the Indian Trans-Himalaya: conflict perceptions and conservation prospects. *Environmental Conservation* 24:338–343
- Mishra C, P. Allen, T. McCarthy M. Madhusudan, A. Bayarjargal, H. Prins. (2003). The role of incentive programs in conserving the Snow Leopard. *Conservation Biology* 17 (6): 1512-1520
- Namgail T., J.L.Fox Y. V. Bhatnagar. (2007). Carnivore-Caused Livestock Mortality in Trans-Himalaya. *Environment Management* 39:490-496
- Naughton-Treves L.(1997). Farming the forest edge: Vulnerable places and people around Kibale National Park, Uganda. *Geographical Review* 87 (1): 27-46.
- Nyhus PJ and R.Tilson. (2004). Characterizing human-tiger conflict in Sumatra, Indonesia: implications for conservation. *Oryx* 38 (1): 68-74.

- Oli M K, I.R. Taylor, M.E. Rogers. (1994). Snow leopard *Panthera uncia* predation of livestock: an assessment of local perceptions in the Annapurna Conservation Area, Nepal. *Biological Conservation* 68:63–68
- Ogada M., R.Woodroffe, N. Oguge. Frank.(2003). Limiting Depredation by African Carnivores: the Role of Livestock Husbandry. *Conservation Biology* 17 (6): 1521-1530.
- Patterson B.D., S.M. Kasiki, E. Selempo R.W. Kays.(2004). Livestock predation by lions (*Panthera leo*) and other carnivores on ranches neighboring Tsavo National ParkS, Kenya. *Biological Conservation* 199 (4): 507-516.
- Polisar J., I. Maxit, D. Scognamillo, L. Farrell, M.E. Sunkist, J.F. Eisenberg. (2003). Jaguars, pumas, their prey base and cattle ranching: ecological interpretations of a management problem. *Biological Conservation* 109: 297–310.
- Sagor J.T., J.E. Swenson, E. Roskaft. (1997). Compatibility of brown bear *Ursus arctos* and free-ranging sheep in Norway. *Biological Conservation* 81: 91–95.
- Sekhar N.U. (1998). Crop and livestock depredation caused by wild animals in protected areas: the case of Sariska Tiger Reserve, Rajasthan, India. *Environmental Conservation* 25 (2): 160-171.
- Siex K.S. T.T. Struhsaker. (1999). Colobus monkeys and coconuts: a study of perceived human–wildlife conflicts. *Journal of Applied Ecology* 36 (6): 1009-1020.
- Stahl P., J.M. Vandel, V. Herrenschmidt, P. Migot. (2001). Predation on livestock by an expanding reintroduced lynx population; long-term trend and spatial variability. *Journal of Applied Ecology* 38: 674–687.
- Thirgood S.J., S.M. Redpath, D.T. Haydon, P. Rothery , I. Newton, P.J. Hudson.(2000). Habitat loss and raptor predation: disentangling long- and short-term causes of red grouse declines. *Proceedings of the Royal Society of London B* 267: 651–656.

Thorel M.F., C. Karoui, A. Varnerot, C. Fleury, V. Vincent. (1998). Isolation of *Mycobacterium bovis* from baboons, leopards and a sea-lion. *Veterinary Research* 29: 207-212.

Zhang L. N. Wang. (2003). An initial study on habitat conservation of Asian elephant (*Elephas maximus*), with a focus on human elephant conflict in Simao, China. *Biological Conservation* 112 (3): 453-459.

Wegge P., R. Shrestha , Q. Flagstad. (2012). Snow leopard *Panthera uncia* predation on livestock and wild prey in a mountain valley in northern Nepal: implications for conservation management. *Wildlife Biology* 18: 131-141.

## **Paper II: Rangelands, conflicts and society in Upper Mustang Nepal: Status, rights, and traditional management strategies**

### **Abstract**

Rangelands are considered critical ecosystems in the Nepal Himalayas and provide multiple ecosystem services that support local livelihoods. However, these rangelands are under threat from various anthropogenic stresses. This study presents an example of conflict over the use of rangeland, involving two villages in the Mustang district of Nepal. This prolonged conflict over the use of rangeland rests on how use rights are defined by the parties; whether they are based on traditional use or property ownership. Traditionally, such conflicts in remote areas were managed under the *Mukhiya* (Village Chief) system, but this became dysfunctional after the political change of 1990. The continuing conflict suggests that excessive pressure on limited rangelands motivates local villagers to gain absolute control of the resources. In such contexts, external support should focus on enhancing the production of forage resources locally, which requires the establishment of local common property institutions to facilitate sustainable rangeland management.

**Key words:** rangelands, conflict, traditional use, use rights.

### **Introduction**

Rangelands are considered critical ecosystems in the Himalayas. They occupy about 60% of the Himalayan landscape (Yi and Sharma 2009, ICIMOD 2012). Most of the rangelands in the Nepal Himalayas are at high elevations and in relatively dry regions. These rangelands provide various ecosystem services that support the livelihoods of local people and environmental benefits such as watershed protection, biodiversity conservation and eco-tourism promotion

(ICIMOD 2012). Livestock ranching and medicinal plant collection in rangelands are major livelihood support strategies for rural people (Miller 1997, Dong et al. 2009). In addition, rangelands support many plant and animal species that are integral components of the Himalayan ecosystem as they provide ecosystem services and maintain sustainability of the region (ICIMOD 2012).

Despite the significant role of rangelands in Nepal, they are under threat from various anthropogenic stresses, including overgrazing and overexploitation of medicinal plants (Dong et al. 2009). Additionally, the looming impacts of climatic change in the subalpine and alpine regions of the Himalayas are omnipresent (Sharma and Tsering 2009). The climatic change can adversely impact the rangeland ecosystems and their economic potential and ecological sustainability (ICIMOD 2012).

In Nepal, rangelands are generally treated as common pool resources (CPR). The existing mode of overuse and overgrazing of rangelands may lead to their depletion and ultimately push rangelands beyond the limits of sustainable yields (Blomquist and Ostrom 1985, Wade 1987). This depletion of CPR occurs due to either the lack of appropriate institutions for management or conflicting claims over rangeland resources (Adams et al. 2002). Different modes of conflicts over rangeland use, such as conflicts between local communities and with government agencies, have been observed (Wily 2008, Bedunach and Angerer 2012). Usually, conflict between communities over property rights poses serious challenges to the sustainable management of rangeland resources. These challenges could be the potential sources of free riding on rangeland use leading to the tragedy of commons (Hardin 1968). Occasionally, violent conflicts between local and non-local villagers have been observed in the rangelands of the high mountains in Nepal, claiming several lives in the search of high value resources such as Yarsagumba (*Ophicordyceps sinensis*). Therefore, these socio-political dimensions are critical for the sustainable management of rangeland resources. However, studies on rangelands have focused

primarily on their natural dimensions (Lehmkuhl et al. 1988, Carpenter and Klein 1995, Katrina 1997, Dong et al. 2009,), while the equally important social dimensions have been generally overlooked (Richard et al. 2000, Chhetri and Gurung 2004).

In order to motivate and complement the policy dialogue on sustainable management of rangeland resources in the mountainous regions of Nepal, this study examines rangeland management issues at a local level. Specifically, we use a case study approach to examine and discuss traditional rangeland use rights, conflicts, indigenous conflict management strategies and other historical and social aspects from Mustang district of Nepal. We conclude by offering some policy relevant recommendations to strengthen the sustainable management of rangelands in the high Himalayan region of Nepal, and possibly elsewhere.

## **Material and Methods**

### *Case Study Area*

Nepal is located on the southern slopes of the central-Himalayan range, extending about 885 km east-west and 145-241 km north-south. Physiographically, it is divided into five parallel zones running east-west: High-Mountain, Middle-Mountain, Hill, Siwalik and Terai (Fig. 1). Our case studies are from Mustang district, located in the High-Mountain zone in central Nepal, where rangelands extend northward onto the Tibetan plateau. The district is sparsely populated, with the lowest population density ( $4.1/\text{km}^2$ ) in the country. Historically, agriculture and animal husbandry are the two major economic activities of the traditional people in Mustang district (NBS 2002). However, the district is characterized by low agricultural productivity because of low annual rainfall, lack of proper irrigation facilities, low temperature and a single growing season (Chhetri and Gurung 2004). Due to the limited amount of land suitable for cultivation in this zone ( $2500 \text{ km}^2$ ), and environmental constraints, animal husbandry is the primary source of

income for people in the region (Aryal et al. 2012, Aryal et al. 2012a). A long tradition of goat and sheep trading from Mustang to China reflects the social-cultural value of animal husbandry in the district (Chhetri and Gurung 2004, Pokharel et al. 2006, Aryal et al. 2012, Aryal et al. 2012a).

Two Village Development Committees (VDCs<sup>1</sup>), namely Chhoser and Chhunup of Mustang district, were selected for this study. Both of the VDCs are situated in the northern part of the Annapurna Conservation Area (ACA) bordering Tibet, China. Bista and Gurung are the two dominant ethnic groups in these VDCs, and the dominant culture and religion (Buddism) are similar in many aspects to Tibetan culture and tradition (NTNC 2008).

#### *Data Collection*

We used participatory rural appraisal (PRA), community meetings, visual observations and a questionnaire survey to gather information on rangeland use and management in Chhoser and Chhunup VDCs. The PRA method was used to document resource use patterns, property rights, conflicts and traditional conflict management strategies. Two community and stakeholder meetings were organized separately for each VDC between October 2010 and June 2011, with key people that included VDCs members, local leaders, local non-governmental organization (NGOs) representatives and Annapurna Conservation Area Project (ACAP) representatives. In addition, 120 local residents aged 40 years and over (64 from Chhoser and 56 from Chhunup VDC), who had used rangelands in the past and knew their history, were randomly selected as survey respondents for a questionnaire survey. These respondents were interviewed in November 2010 (Chhoser) and June 2011 (Chhunup) to collect information on the underlying causes of rangeland conflicts and to explore potential solutions. Eighty percent of the

---

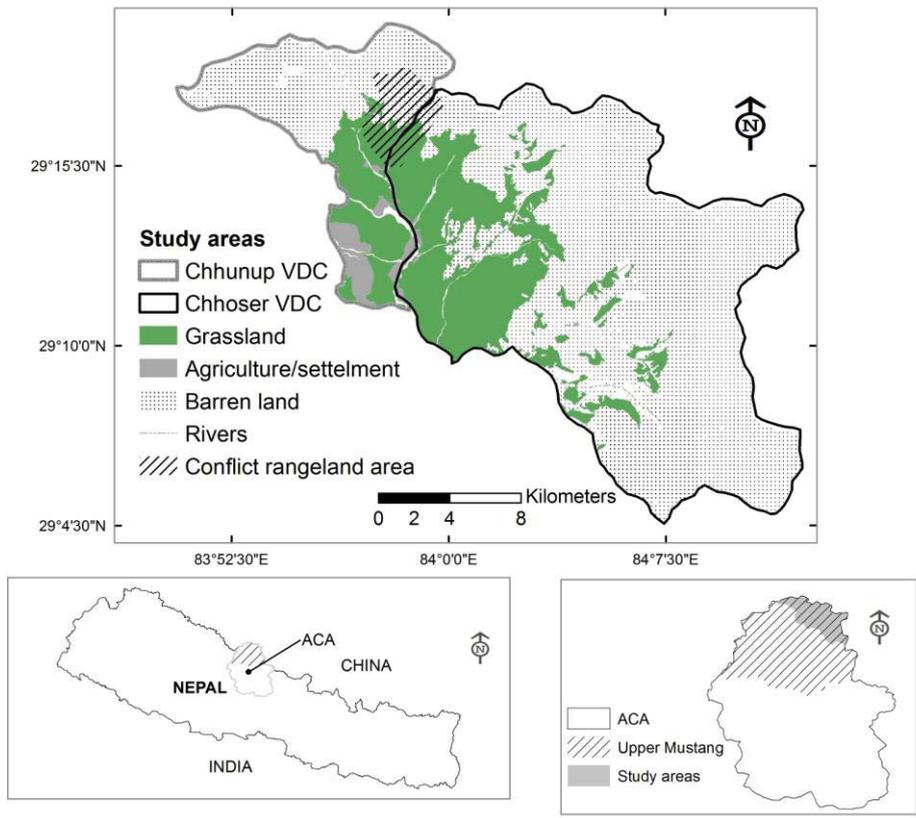
<sup>1</sup> Village development committee (VDC) is the lowest administrative level of the Local Development Ministry of Nepal, which is rural based.

respondents were male and a high percentage of respondents (85%) were illiterate. In addition, direct observations of the rangelands were made to delineate the disputed area identified during the meetings and PRA. A group of 12 local people from each VDC (total 24) were selected in consultation with local agencies to verify disputed boundaries during the field visits. Two seasonal field visits (summer and winter) were made to the disputed rangeland with the representatives of each village on separate occasions to understand their views of the location of the boundaries. We then calculated the area of each VDC and estimated the disputed rangeland area from a land use map developed by the Department of Survey, Government of Nepal, and the area of each VDC using ArcGIS 9.3.

## **Results**

### **Rangelands in Chhoser and Chhunup VDCs, Mustang District**

Our study was focussed on rangeland conflicts between Chhoser and Chhunup VDCs of Mustang district. Both VDCs include agricultural land, grassland, barren land, sandy areas and cliffs (Table 1, Fig. 1). There are only 147 households in Chhoser VDC, which covers an area of about 347 km<sup>2</sup>, including 95 km<sup>2</sup> (28%) of grassland and a small percentage of agricultural land (0.3%). In comparison, Chhunup VDC has 197 households located within an area of 98 km<sup>2</sup>, making it relatively more densely populated than Chhoser VDC. About 32 km<sup>2</sup> (33%) of the Chhunup VDC is covered by grassland and only about 8.69 km<sup>2</sup> (9%) is agricultural land (DDC 2009). In both of these VDCs, there are several patches of rangeland used for seasonal grazing, including Kyungchhyu and Tuhpang, the region's two largest rangelands. Other rangelands, such as Terahthang and Dihring Bhoto, are smaller in area and lack water sources. The Chhoser VDC has both summer and winter grazing pastures, while the Chhunup VDC has limited summer and winter pasture. Therefore, the people of Chhunup are fully dependent upon the summer pasture for livestock grazing.



**Figure 1.** Land cover in Chhoser and Chhunup VDCs, Mustang district

**Table 1.** Land cover of Chhunup and Chhoser VDCs

Land cover	Area in Chhunup (km <sup>2</sup> )	Area in Chhoser (km <sup>2</sup> )
Cliff	0.25	0.18
Agriculture	8.69	1.02
Rangeland (Grassland)	32.09	95.50
Sandy area	3.15	3.31
Barren land	54.12	245.55
<b>Total</b>	<b>98.30</b>	<b>345.56</b>

## History of Rangeland Use in Chhoser and Chhunup VDCs

Historically, people in the Chhoser and Chhunup VDCs had their own system for livestock grazing. The traditional grazing practices have the following characteristics:

- No grazing tax for herders of the same VDC.
- Decisions about grazing schedules and grazing sites are made by village leaders (*Mukhiya*<sup>2</sup>) in consultation with villagers and herders.
- Livestock from other VDCs are strictly prohibited because of inadequate size of the pastures.
- Due to the insufficiency of pasture in winter, herders use the grazing land of the adjacent VDC (Lomanthang VDC) during the winter by paying a grazing tax to the *Mukhiya*.

The area of the disputed rangeland was 16.61 km<sup>2</sup>. It was located on the western border of Chhoser VDC and the eastern border of Chhunup VDC and included parts of rangelands within Khukyu, Kyungchhyu and Nahma Dhongtong areas (Fig. 1). The estimated disputed rangeland area is more than half of the total rangeland area of Chhunup and one-sixth of the total rangeland area of Chhoser. In the past, the disputed land was a common grazing land used by local herders of both VDCs during summer to graze yak, goat and sheep. As these villages practice transhumance, during winter the grazing land is left unused for grazing and herds are taken back to their respective villages because of the cold weather. Residents in these VDCs use livestock dung, grasses and shrubs for cooking and heating, as they generally lack fuel wood as there is limited woody vegetation in the area. The residents of Chhoser VDC used to collect livestock dung from the disputed area throughout the year.

---

<sup>2</sup> *Mukhiya* is the village chief nominated by the local community. The *Mukhiyas* are powerful as they regulate the economic, social and justice systems in the villages.

Conflicts between the two VDCs over the use of rangelands arose in 1985 as both claimed ownership over the same piece of land (Fig. 1). The Chhunup VDC considered the rangeland to be under its administrative jurisdiction, whereas Chhoser VDC considered that they had a long history of using the land and claimed it based on traditional use rights (Fig. 1). The conflict continued without resolution and lately became violent as the claim over the land intensified from both sides. The chronology of the conflict is reported in Table 2.

**Table 2. History and timeline of rangeland conflict between Chhoser and Chhunup VDCs upper Mustang region of Nepal**

Conflicts Date	Conflict situation	Conflict resolution strategy
1985	Members of Garphu of Chhoser VDC constructed sheds for herders on the Nahma Dhongtong pasture (Fig 2). The sheds were destroyed by the locals of Namdo of Chhonup VDC claiming that the land belonged to them.	The ruling king of Mustang at that time, Jigme Parbal Bista, resolved the dispute and gave a resolution paper ( <i>Mialpatra</i> ) to both conflicting parties. As per the agreement, the areas from Dhongtong to Lhehka Siji are not permitted to Chhoser communities for use. The Chhoser communities denied accepting the agreement by claiming the agreement paper is a fake document.
2005	The ACAP supported the construction of an improved shed at Namdohngdhong through	The conflict was resolved through the initiatives of NTNC-ACAP,

community mobilization of Chhoser VDC. Lomanthang, with the decision that After its completion the people of Chhonup the herders from both Chhoser and again destroyed the shed claiming their Chhonup can equally use the rights over the land. constructed sheds.

**April 2009**

Direct confrontation arose between the people of Chhoser VDC and Nyamdo village of Chhunup VDC when the people of Chhoser collected stone from the banks of the river along the side of Nyamdo. Two local people from Nyamdo were seriously injured during the violent clash. The settlement of the conflict was done at village level with the provision of compensation of NRs 15,000 to each of injured people by the communities of Chhoser VDC.

**August 2009**

The most violent conflict happened between the Chhoser and Chhunup VDCs. This clash turned Balley pasture into a battle field, resulting in serious injuries to many people many of the participants. NTNC-ACAP immediately initiated a negotiation process by mobilizing the representatives of both sides, as well as the police. Five persons of each VDC took part in the meeting and the meeting unanimously imposed a ban on communal confrontation and decided to seek a support from the chief district office (CDO) of Mustang for a permanent solution to resolve the conflict.

---

**September/October 2009** As per the decision to seek support from the Chief District Office (CDO) of Mustang, two meetings were called in the presence of Mustangi King Jigme Parbal Bista. However, the 2<sup>nd</sup> meeting could not be held due to absence of representatives of Chhoser VDC.

---

### **Traditional Conflict Resolution System**

Several attempts to resolve this conflict at village and district levels have proven unsuccessful. Villagers of Chhunup claim ownership over the disputed rangeland on the basis of an agreement prepared in 1985. However, Chhoser villagers claim that the document was fake and legally void. During (2011) a meeting at NTNC-ACAP (Natural Trust for Nature Conservation-Annapurna Conservation Area Project), a proposal to tax Chhoser villagers for the use of rangeland was discussed. The proposal was refused by the Chhunup villagers, stating that they did not allow outsiders to use the rangelands within their VDC territory. On the other hand, the Chhoser villagers continue to claim their use rights based on having used the rangeland for over 150 years.

### **People's Perceptions on Conflict and Conflict Resolutions**

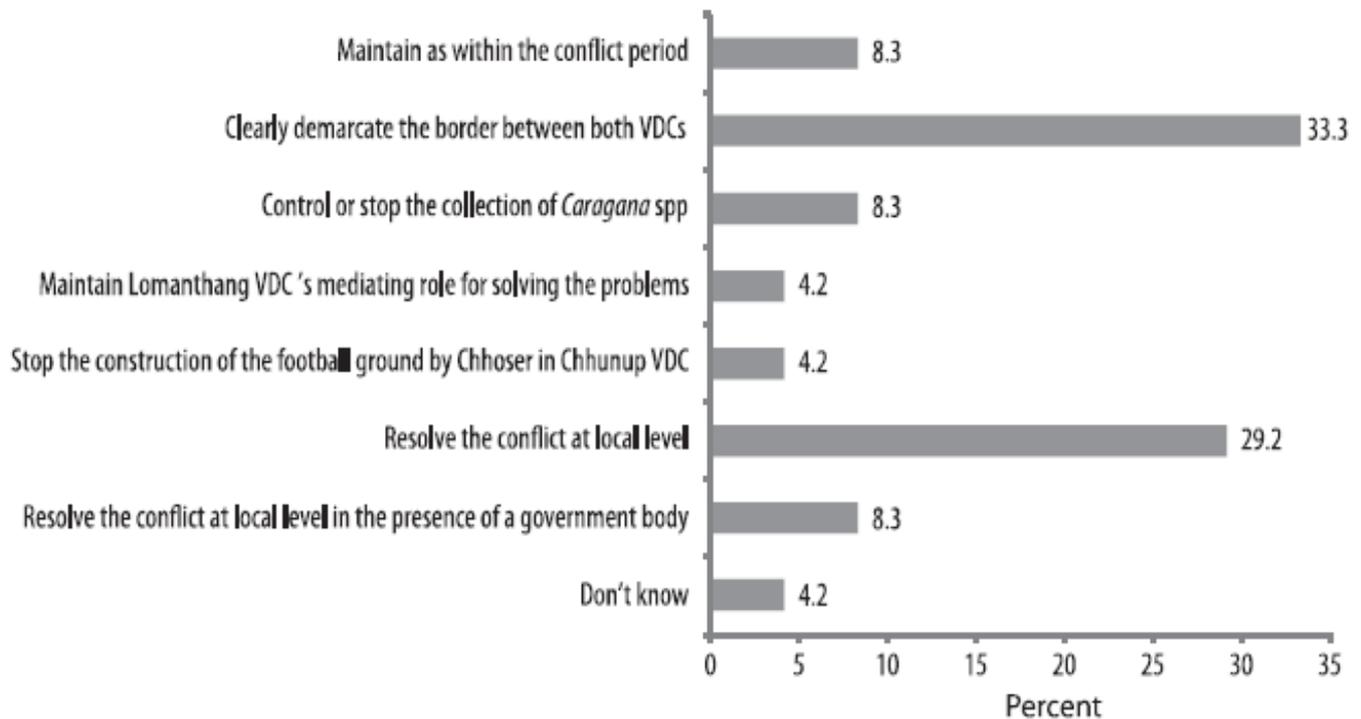
In a questionnaire survey we asked the respondents, ordinary villagers, about their perceptions of existing conflicts and possible resolution strategies. The majority of the villagers were aware of the conflicts; 75% were well informed about the rangeland boundary dispute, while 25% had no knowledge of the conflict. About 83% of the respondents agreed that the disputed area of

rangeland belong to Chhunup VDC legally, but supported the idea of allowing equal access to people from Chhoser VDC. In contrast, 17% of the respondents thought that the rangeland should belong to both VDCs, with equal access rights.

The majority of respondents (75%) suggested that resource use was the main cause of conflict. They cited three main incidents that added to the prolonged conflict between the two VDCs: (i) collection of *Caragana* by locals of Chhunup in the area belonging to Chhoser, (ii) destruction of improved sheds by Chhunup locals in the area belonging to Chhoser and (iii) construction of a football field by locals of Chhoser VDC in the area belonging to Chhunup VDC. Ten percent of the respondents believed that the increasing commercial importance of trade around Ngichung village could be the cause of the conflict. Only five percent suggested increased pressure on the rangeland as the main cause of the conflict.

Respondents were asked about the consequences of the conflict. A large number of respondents (45%) stated that the conflict had impacted on inter-communal social relationships and was deterring marriages between members of the two VDCs, which had been a traditional practice in the past. Twenty-five percent of the respondents thought that the conflict had threatened social security; 15% thought that it could break long-standing economic relationships; and the remaining 15% responded that it had created difficulties for people wanting to migrate from one VDC to another.

The perception of respondents about the possible solutions of the conflict also differed. Most of the respondents suggested two or three probable solutions (Fig. 2). One-third of the respondents thought that a clear demarcation of a border around the disputed area could solve the conflicts. Only 8% thought that regulating *Caragana* collection could reduce the conflict because villagers of both VDCs collect this grass from the disputed land (Fig. 2).



**Figure 2.** Perceptions of local people on conflict resolutions

## Discussion

This case study highlights the significance of rangelands in the livelihoods of mountain communities. However, unclear rangeland policies and the remote location of these rangelands are major barriers for their proper management in Nepal. The prolonged dispute identified in this case study clearly indicates the need for an institutionalized intervention in rangeland management from local to national governments. This view is supported by some previous findings. Pariyar (1998) stated that the rangeland sector in Nepal has not yet been addressed by the Government because of the lack of a definite government body, even at national level, which means that there is an ambiguity in responsibility between governmental authorities for the management of rangelands. Legally, rangelands are considered 'forests' and thus are under the jurisdiction of the Ministry of Forests and Soil Conservation (MoFSC). However, in practice the Pasture Development and Livestock Improvement Services of the Ministry of Agriculture has been working to improve rangelands in Nepal. Therefore, local people implicitly associate the responsibility for rangeland

management with the Ministry of Agriculture (NBS 2002).

In Nepal's mid-hills, forest areas outside protected areas, which include rangelands near settlements, have for over 30 years been managed by local communities through community forestry (CF) programs (Pandit and Bevilacqua 2011). This program has not been widely adopted in high mountains, where rangeland ecosystems are more prevalent. Furthermore, local people depend more on high mountain rangelands than those in the mid-hills. In high mountains, rangelands and forest areas are still managed under traditional systems without formal management plans.

Rangelands supply 36% of the total feed requirement for livestock in the country. However, the estimated forage demand at high mountains exceeds the potential supply (Miller 1993, Rajbhandari and Shah 1981), and there is therefore a high dependency and pressure on rangelands in high mountains to provide livelihood support to local communities. This may partly explain why Chhunup villagers denied access to Chhoser villagers to a particular rangeland. In addition, a small fraction of people also admitted that there is an increasing pressure on the rangelands and exclusion of individuals from another village could be a strategic move by Chhunup villagers to reduce this pressure. Therefore, rangeland management programs should try to maintain a balance between local demand and carrying capacity of the rangelands, while addressing social complexities. However, livestock development planners, who generally ignore the complexities of rangeland systems, often prescribe the “improved” grazing systems as a solution to livestock development programs (Miller 1993, Pokharel et al. 2006).

Most rangelands in Nepal are located in the north bordering China (Tibet) and their use is still based on a traditional management system. After the political change in Tibet in 1959, China and Nepal established some agreements regulating livestock grazing in border areas. A significant change was made in 1988 when both governments agreed to stop animal migration between Nepal and Tibet (Pariyar 2008, NBS 2002). This meant that Nepalese herders now had to

rely only on native pastures. In response, the High Altitude Pasture Development Project, funded by FAO/UNDP (Pariyar 2008), took steps during 1985-1990 to improve pastures, but their efforts failed to reduce the gap between forage production and local demand.

As we observed in this case study, local dependence on rangelands can lead to serious conflict between neighbouring villages in search of foraging resources for livestock. This conflict was exacerbated as the neighbouring VDCs based their rights to the rangelands on two different systems: legal rights based on administrative boundaries and traditional use rights based on social norms and historical practices.

Usually, when demand exceeds supply, conflicts increase over the use of limited common pool resources (CPR) such as rangelands (Blomquist and Ostrom 1985, Wade 1987). This has raised the issue of defining rights over the use of CPR. Defining rights based on traditional use or administrative boundaries are both competing issues (Dong et al. 2007, Lehmkuhl et al. 1988, Carpenter and Klein 1995, Katrina 1997). In community forest management systems, access to forest resources based on traditional use is well established. However, in the case of rangelands it is more complex, as it involves a large geographic domain because of migratory grazing practices. Our analysis in this case study supports the idea that social dimensions are important drivers to ensure resource governance in rangelands (Richard et al. 2000, Chhetri and Gurung 2004).

In the context of this case study, traditional governing systems, i.e. *Mukhiya* system, had been historically effective for resolving local affairs involving resource management. However, there were no written rules; it is in fact a despotic practice. Decisions were largely based on the subjective judgment of a single person and local stakeholders were excluded from the decision-making process. After the reinstatement of parliamentary democracy in Nepal during 1990, such traditional governing systems have become dysfunctional (NBS 2002, NTNC 2008, Pariyar

2008). However, new rules and regulations that came into effect after the political change could not be implemented equally across the country, particularly in remote mountainous areas, primarily because the government did not acknowledge the role of traditional institutions in resource governance. In the absence of authority, Nepal's rangelands were viewed as CPR and their open access status resulted in excessive overuse. Once local communities realized that dwindling rangeland resources were affecting their livelihoods, they attempted to gain control over their use. This became the source of conflicts in many resource governance cases across rural Nepal, including the one described here.

## **Conclusions**

In this case study, historical evidence and local perception indicated that conflicts over the use of rangelands became more complex due to increased pressure on their use. Lack of clearly defined national and local rangeland policies has created insecurity among villagers about the availability of sufficient forage to meet their needs. As the villages have limited rangelands, they refused to acknowledge the traditional rangeland use practices of neighboring villagers. Given the lack of a proper policy, it is almost impossible to secure traditional use rights for villagers if they were considered outsiders based on political jurisdiction.

We propose two possible ways to manage conflicts in our study context, which may have relevance to many other areas in Nepal and mountainous regions elsewhere. First, the conflict we observed was related to the use of summer rangeland and the VDCs could share the use of seasonal rangelands in a fair manner. For example, Chhunup had political rights and boundary control over the disputed area, but limited winter grazing lands, while Chhoser possessed traditional use rights to the disputed area and has winter grazing lands. Hence, Chhunup could provide Chhoser's villagers summer access to the disputed area in exchange for being allowed to use their winter grazing lands. Second, there should be an external authority focused on

enhancing the management and production of livestock forage on both private and public rangelands. The solution strategies should ensure that by allowing Chhoser villagers to use the rangeland, Chhunup villagers are not compromised in their usage of it. Furthermore, it must be widely understood that the continuation of conflicts over rangeland use not only threatens traditional social institutions, but it also leads to the degradation of this common pool resource. Hence, we believe that it is imperative that the rangeland management authority adopt the positive outcomes learned from Nepal's community forestry programs and apply them to sustainably manage rangelands in mountainous areas of the country.

### **Acknowledgments**

We thank the National Trust for Nature Conservation/Annapurna Conservation Area Project for providing the support necessary to conduct this research, and all staff at the upper Mustang Unit Conservation Office for their support. Finally, we thank Massey University Research Fund (New Zealand) for providing financial support.

### **References**

- Adams WM, Brockington D, Dyson J, Vira B. 2002. Analytical framework for dialogue on common pool resource management. Department of Geography, University of Cambridge, Cambridge.
- Aryal A, Hipkins J, Ji W, Raubenheimer D, Brunton D. 2012. Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23(2), (in press).
- Aryal A, Raubenheimer D, Sathyakumar S, Poudel BS, Ji W, Kunwar KJ, Kok J, Kohshima S, Brunton D. 2012a. Conservation Strategy for Brown Bear and Its Habitat in Nepal. *Diversity* 4: 301-317.

- Bedunah DJ, Angerer JP. 2012. Rangeland Degradation, Poverty, and Conflict: How Can Rangeland Scientists Contribute to Effective Responses and Solutions? *Rangeland Ecology Management* 65:606-612.
- Blomquist W, Ostrom E. 1985. Institutional capacity and the resolution of a commons dilemma. *Policy Studies Review* 5(2): 383-393.
- Carpenter C, Klein J. 1995. Plant Species Diversity in Relation to Grazing Pressure in Three Alpine Pasture, Shey Phoksundo National Parks, Dolpa District, Nepal. WWF Nepal Program Report Series No. 20. WWF Nepal Program, Kathmandu, Nepal.
- Chetri M, Gurung CR. 2004. Vegetation Composition, species performance and its relationship among livestock and wildlife in the grassland of Upper Mustang, Nepal. In: Jincheng Z, Xiangdong Z, Jianlin H, Zhihua C. (Eds.), *Yak Production in Central Asian Highlands, Proceeding of the Fourth International Congress on Yak*. Sichuan Publishing Group, Sichuan Publication House of Science and Technology: 235–244. Chicago Press.
- DDC. 2009. The Mustang District Profile. District Development Committee (DDC), Mustang district office, Government of Nepal.
- Dong S, Lassoie J, Shrestha KK, Yan Z, Sharma K, Pariya D. 2009. Institutional development for sustainable rangeland resource and ecosystem management in mountainous areas of northern Nepal. *Journal of Environmental Management* 90: 994–1003.
- Hardin G. 1968. The Tragedy of the Commons. *Science New series* 162 (3859): 1243-1248
- ICIMOD. 2012. Rangeland. ICIMOD, Kathmandu, Nepal. Available at <http://www.icimod.org/?q=1277>[accessed on 7 March 2012]

- Katrina B. 1997. Plain tales from the grasslands: extraction, value, and utilization of biomass in Royal Bardia National Park, Nepal. *Biodiversity and Conservation* 6 (1): 59–74.
- Lehmkuhl JF, Upreti RK, Sharma UR. 1988. National parks and local development: grasses and people in Royal Chitwan National Park, Nepal. *Environmental Conservation* 15 (2): 143–148.
- Miller D. 1997. Conservation biodiversity in the HKH rangelands. ICIMOD Newsletter 27 (Spring), 8–11.
- Miller DJ. 1993. Grazing lands in the Nepal Himalaya: present and Potential Economic Returns to Range livestock Production in High Elevation Areas. Draft Final Report. USAID, Kathmandu, Nepal.
- NBS. 2002. Nepal Biodiversity Strategy (NBS). His Majesty's Government of Nepal, Ministry of Forest and Soil Conservation Nepal/GEF/UNDP.
- NTNC. 2008. Sustainable development plan Mustang (2008—2013). National Trust for Nature Conservation (NTNC), Kathmandu, Nepal.
- Pariyar D. 2008. Country Pasture/Forage Resource Profiles. FAO. Available at <http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Nepal.pdf>, accessed on 29 March 2012.
- Pandit R, Bevilacqua E. 2011. Forest users and environmental impacts of community forestry in the hills of Nepal. *Forest Policy and Economics* 13:345-352.
- Pariyar D. 1998. Rangeland resource biodiversity and some options for their improvements. National Biodiversity Action Plan. Kathmandu.

- Pokharel A, Chhetri M, Upadhyaya C. 2006. Effects of grazing on plant species diversity and above ground biomass in a Trans- Himalayan Rangeland. *Banko Janakari* 17(1): 25-31.
- Rajbhandari HB, Shah SG. 1981. Trend and projections of livestock development. Proceedings of the Seminar on Nepal's Experiences in Hill Agricultural Development, Kathmandu HMG, Ministry of food and Agriculture, Kathmandu, Nepal.
- Richard C, Basnet K, Sah JP, Raut Y. 2000. Grassland Ecology and Management in Protected Areas of Nepal, Mountain Parks, vol. III. ICIMOD, Kathmandu.
- Sharma E, Tsering K. 2009 Climate change in the Himalayas: The vulnerability of biodiversity. *Sustainable Mountain Development* 55: 10-12.
- Shrestha UB, Shrestha S, Chaudhary, Chaudhary RP. 2010. How Representative is the Protected Areas System of Nepal?. *Mountain Research and Development* 30(3):282-294. 2010.
- Wade R. 1987. The management of Common property resources: Collective action as an alternative to privatization or state regulation. *Cambridge Journal of Economics* 11: 95-106.
- Wily LA. 2008. Whose land is it? Commons and conflict states: Why the Ownership of the Commons Matters in Making and Keeping Peace. [http://www.rightsandresources.org/documents/files/doc\\_853.pdf](http://www.rightsandresources.org/documents/files/doc_853.pdf). Accessed on 3 Dec 2012.
- Yi, S, Sharma E. 2009. Climate change and the Hindu Kush-Himalayan rangelands. Information Sheet # 8/09, ICIMOD, Kathmandu, Nepal. Available at [http://books.icimod.org/uploads/tmp/icimod-climate\\_change\\_and\\_the\\_hindu\\_kush-himalayan\\_rangelands.pdf](http://books.icimod.org/uploads/tmp/icimod-climate_change_and_the_hindu_kush-himalayan_rangelands.pdf), accessed on 7 March 2012.



**Paper III: Biological diversity and management regimes of the northern  
Barandabhar Forest Corridor: an essential habitat for ecological connectivity  
in Nepal**

**Abstract**

Despite the development of progressive policies in forestry and wildlife management sectors in Nepal, over the last ten years it has become clear that protected areas in the country lack the landscape connectivity required to support viable populations of endangered species such as rhino (*Rhinoceros unicornis*) and tiger (*Panthera tigris tigris*). Forests, which provide essential habitat for a diverse array of species and forest products to many human populations, continue to decline. The present study, focusing on the northern Barandabhar Forest Corridor (BFC), aimed to begin to address these problems by establishing preliminary data concerning the extent of the forest, the associated biological diversity, and the resources available for local communities, in order to promote a community-based management strategy. Results established that the northern BFC covers an area of 10,644 ha between the East-West Mahendra highway and the Mahabharat range, incorporating 15 community forestry areas (3,184 ha). It was found to support a number of IUCN listed threatened and endangered species including rhino and tiger; and contains suitable habitat for a number of other endangered species. Owing to its connectivity, linking Chitwan National Park with the Mahabharat range, BFC has the potential to make an important contribution to improving the ecological integrity in Nepal. Different institutions and governance structures currently exist to manage the northern BFC. Although these institutions differ in resource utilization and benefit sharing mechanisms, they are united to safeguard the habitat of key wildlife species including rhino and tiger. We propose that the northern BFC should be

managed through a new participatory scheme, the Barandabhar Forest Management Council, to foster ecological integrity of the area while providing forest products to communities.

**Keywords:** *connectivity, corridor, Barandabhar forest, community forestry, Asian rhino, tiger.*

## **Introduction**

The Barandabhar Forest Corridor (BFC) lies between Chitwan National Park (CNP) and the Mahabharat range within the Terai Arc Landscape of Nepal (Fig. 1). Approximately 75% of this landscape was previously forested, supporting a rich diversity of flora and fauna (Joshi 2002, Bennet 2004). Since 1950's, however, the area has been subject to deforestation. This is largely due to an influx of people attracted by the fertile soils, the launch of the Rapti Doon Development Programme, which encouraged deforestation for agriculture and the conversion of private forest to national forest (Ojha 1983, Shrestha 2001, MOPE 2002, Satyal 2006, Panta 2008). Consequently, the BFC is likely now the only remaining natural forest that connects the CNP and Chure Siwalik range with the Mahabharat range (Bhattarai 2003, Bhattarai and Basnet 2004, Dhakal et al. 2011), allowing the endangered one-horned rhinoceros (*Rhinoceros unicornis* hereafter 'rhino') and Royal Bengal tiger (*Panthera tigris tigris* hereafter 'tiger') access to refuge at higher altitudes during monsoon seasons (Tiwari et al. 2007). The retention and restoration of such ecological corridors, linking protected areas, is considered essential in maintaining and restoring wildlife populations across south and central Asia (Tiwari et al. 2007). Despite the potential importance of the BFC for protected species, including rhino and tiger, there is currently a dearth in published literature with respect to the biodiversity of the area and the use of the corridor by these keystone species. Indeed, even baseline information including the extent of the northern BFC and its boundaries is lacking.

In addition to a lack of ecological data for the area, two further issues have been reported to currently restrict the potential to manage the BFC as a functioning ecological corridor (Bhattarai

2003, Bhattarai and Basnet 2004, Dhakal et al. 2011). Firstly, the East-West Mahendra Highway bisects the BFC and due to volume and speed of traffic, may pose a barrier to wildlife movement (Graner 199, Bhattarai 2003, Bhattarai and Basnet 2004, Dhakal et al. 2011). Secondly, the BFC to the south of the highway is included within the CNP buffer zone, managed by the Buffer Zone Development Council, whereas the northern extent is in the Department of Forests ownership, and therefore management regimes for the two areas of forest are currently inconsistent (Bhattarai 2003, Bhattarai and Basnet 2004, Dhakal et al. 2011, Tiwari et al. 2007).

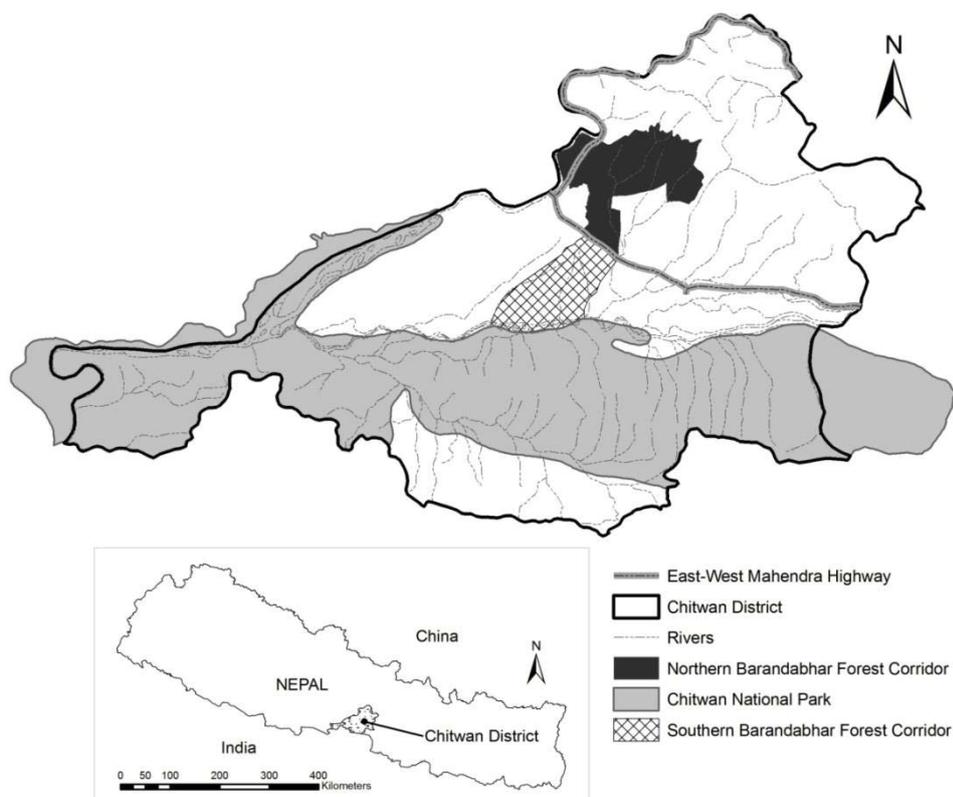
In order to begin to resolve these issues, the aim of the current study was to determine the exact area of the northern BFC and undertake preliminary surveys of its biological diversity and resources available for local communities. This data will be used to inform how to optimally manage the area in respect of its ecological, economical and cultural resources, through a management plan that will engage and involve local stakeholders.

In Nepal, forests are considered a “social space”. As such, a community-based conservation approach to forest management has been promoted since the early 1980’s (Graner 1999, Mehta and Heinen 2001). This approach has had a positive impact on forest cover in other areas, slowed rates of deforestation, restored denuded mountain landscapes and has been shown to be favored by local communities, compared with traditional parks and reserve management (Heinen 1993, Forest Act 1999, Mehta and Heinen 2001, Shrestha and Narayan 2010). A community-based approach to management of the northern BFC is therefore proposed in this paper, with particular emphasis on conservation of rhino and tiger. It is envisaged that by employing participatory forest management in the northern BFC, government agencies (for instance, the Department of Forests and the Department of National Parks and Wildlife Conservation) will be able to engage local stakeholders, including forest dependent communities, to prevent internal and external threats to the conservation of the entire BFC.

## Methods

### *Study site*

The northern BFC is located at around 27°39' N latitude and 84°28' E longitude, within the Chitwan Valley of Nepal (Fig. 1). It lies approximately 50 km west of Kathmandu, 2 km east of the city of Bharatpur and 6 km north of the CNP. The two major settlements, Bharatpur to the west and Jutpani to the east, support approximately 109,316 people in the vicinity of the BFC, including Tharus and other ethnic groups (Bhattarai 2003, Bhattarai and Basnet 2004, Tiwari et al. 2007). The area has a sub-tropical climate with average annual temperatures of 25°C, but it can reach up to 43°C during the summer months. The monsoon season is between June and September and the average annual rainfall is 2000mm groups (Bhattarai 2003, Bhattarai and Basnet 2004, Tiwari et al. 2007). The flora of the BFC is dominated mainly by *Sal* forest and riverine grasslands (Dhaka et al. 2011).



**Figure 1.** Location of the study area, residing to the north of Chitwan National Park, Chitwan, Nepal.

#### *Survey of the northern Barandabhar Forest Corridor*

In order to confirm the extent of the northern BFC, which lies to the north of the East-West Mahendra Highway, the survey team with the support of the District Forest Office undertook field investigations between December 2009 and July 2010.

A total of 1,853 reference points on the ground were recorded using GPS in order to establish the boundary of the northern BFC. The boundaries were confirmed through discussion with technical experts, local stakeholders, the District Forest Office personnel and the surrounding Community Forest User Groups (CFUGs). A map illustrating the extent of the northern BFC was prepared using ArcMap 9.3 (ESRI) based on GPS data to compute the area of the forest.

#### *Vegetation and biodiversity survey*

During field investigations, data on forest type and structure, biomass, growing stock and current resource use (such as grass, fuel wood and non-timber forest products) was documented according to the Community Forest Inventory Guidelines 2004 (Department of Forest, Government of Nepal, 2004).

A total of 389 sample plots of 20m x 20m were surveyed at intervals ranging from 200m to 500m along 49 transects through the forest from west to east. The width of each transect was 50m and the length ranged from 1km to 10km, depending on the distance between the west and east forest boundaries. Locations of plots were recorded with GPS. The surveys distinguished between the following forest types: *Sal*, mixed, Padke (*Albizia lucida*) and Khair-Sissoo (*Acacia catechu* and *Dalbergia sissoo*) as detailed within the Community Forest Inventory Guidelines (Department of Forest, Government of Nepal, 2004). Within each plot, plants were identified

either on site or after further examination at the National Herbarium and Plant Laboratories in Kathmandu. The height and DBH (diameter at breast height) of trees (>30cm DBH) in each sample plot were recorded. In each sample plot, the number of poles (10-29.9cm DBH), saplings (>1m height and <9.9cm DBH) and seedlings (<1m height) were counted using smaller plots of size 10m x 10m, 5m x 5m and 1m x 1m respectively. The Community Forest Inventory Guidelines 2004 (Department of Forest, Government of Nepal, 2004). were followed to calculate frequency, density and volume of trees in each sample plot i.e.  $\text{Volume} = 3.14 \times 1/4\text{DBH}^2 \times \text{form factor} (0.5) \times \text{tree quality index}$  (Department of Forest, Government of Nepal, 2004).

The location and extent of wetland and grassland areas inside the BFC were also recorded using GPS. A preliminary survey of wildlife present within the forest and associated wetland and grassland habitats consisted of recording direct sightings of bird and mammal species along each transect. In addition, a pugmark, dung, scat and pellet survey was undertaken along each transect, in order to establish evidence for the presence of mammals, in particular rhino and tiger. As supplementary evidence, local people (N=274) from different communities adjacent to the forest were interviewed to better understand the number and circumstances of rhino and tiger sightings in the area.

#### *Interaction with local stakeholders*

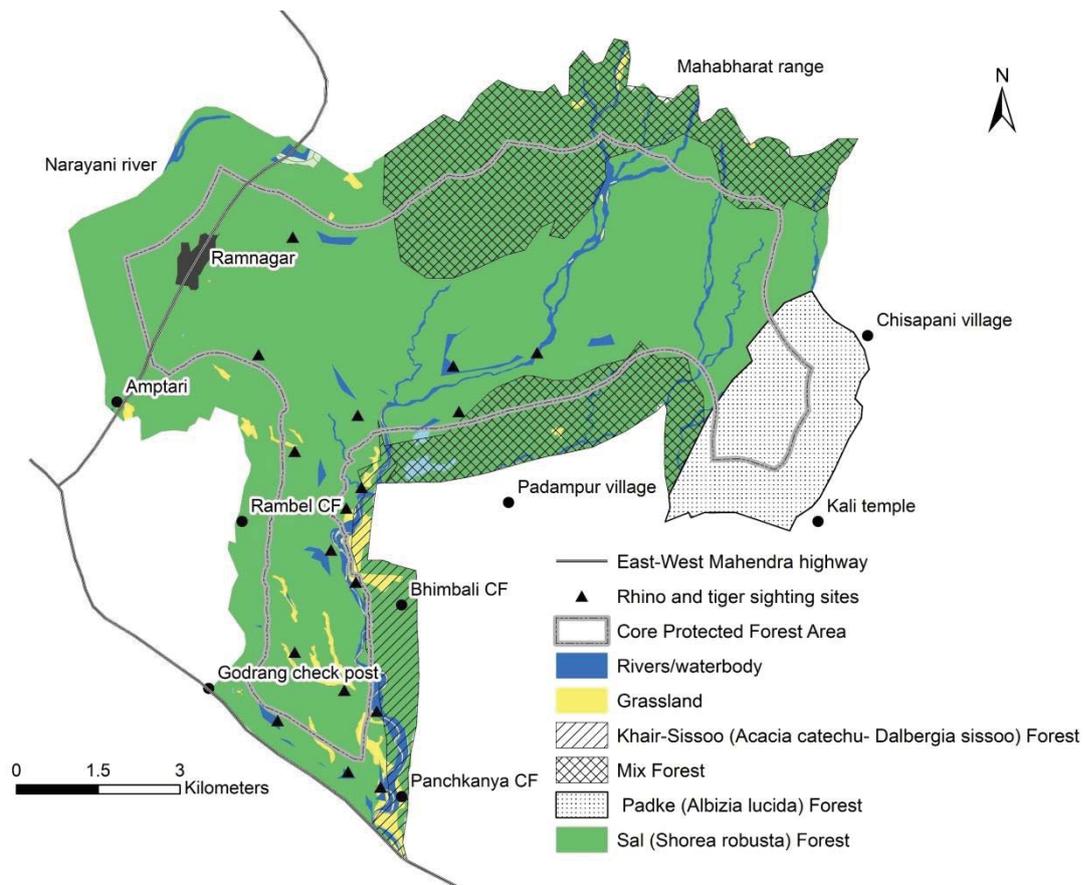
In each local community (N=6), a one day workshop was organized to understand the local people's knowledge and experience on traditional wildlife management approaches and their perception of wildlife management in general. Management options were devised following consultation with the concerned stakeholders (Community Forest User Group, Leasehold User Group, concerned Government Departments, and NGOs) through a series of discussion workshops based on findings of the survey. Management options aimed at internalizing and minimizing any future resource use issues that could be encountered in the next 5 years.

Available literatures was also reviewed to prepare the management plan of the study area (Panta et al 2008, Satyal 2006, MOPE 2002, Dhakal et al. 2011, Bhattarai 2003, Bhattarai and Basnet 2004, Tiwari et al. 2007, Graner 1999, Mehta and Heinen 2001, Ramsar Convention Secretariat 2010).

## **Results**

### Extent and current use of the northern BFC

The northern BFC, to the north of the East-West Mahendra Highway, covers approximately 10,466 ha, meeting the Mahabharat range to the north. The western side of the forest is bounded by the Narayani river and coincides with the Chitwan district boundary. Amptari, Jakhadi Mai and Godrang checkpost also demarcate this boundary. The southern boundary is formed by the East-West Highway and the eastern boundary is marked by Khagadi Khola to the boundaries of Panchakanya community forest and Bhimbali community forest followed by Jutpani Road, Kali temple, Padampur village, Chisapani village, and Mangaldevi community forest to the Mahabharat range (Fig. 2).



**Figure 2.** Map illustrating the extent of the northern BFC. Dominant habitat types, core protected areas, and rhino and tiger sightings recorded within the northern BFC are also illustrated.

Out of the total 10,466 ha of the forest land, 3,184 ha, adjacent to residential areas has been handed over to 15 community forest user groups. In addition, 350 ha has been set aside as leasehold forests to be handed over to 65 different user groups and 10 ha of forest is to be allocated as religious forest. It has been proposed that the remaining core zone of 6,922 ha is designated as a core protected forest area for wildlife, specifically rhino and tiger (Fig. 2). This core area includes 2,673 ha in the upper Mahabharat range and 4,249 ha in lower regions, including several riverine areas. Designation as a protected area will ensure that the connectivity of intact natural habitats at a range of altitudes will be managed to foster biodiversity conservation.

In the eastern part of BFC boundary the forest connectivity was observed to be interrupted for an area of approximately 1km in width by 8km in length, due to human settlement and agricultural land uses at Shaktikhor VDC (Fig. 3).

#### *Vegetation and biodiversity*

Based on the field data, it was estimated that the northern BFC can support 11,985 and 1,455 seedlings and samplings respectively per ha. There were approximately 322 poles and 196 mature trees per ha with respective growing stocks of 824 m<sup>3</sup> and 1092.3 m<sup>3</sup> per ha. The highest tree density was recorded in the *Sal* forest (93 tree/ha and 373.6 volume m<sup>3</sup> /ha) followed by Sisso- Khair forest (60/ha), mixed forest (30/ha) and lastly Padke forest (21/ha) (Table 1).

**Table 1. Details of timber resources (trees and poles) within the dominant forest types of the northern BFC**

Forest types	Area (ha)	Tree number/ha	Timber volume (m <sup>3</sup> )	Flue wood (m <sup>3</sup> )	Total volume (m <sup>3</sup> )	Pole /ha	Stem volume (m <sup>3</sup> )
Sal ( <i>Shorea robusta</i> ) forest block	5447.12	85	157.2	131.4	373.6	98	483
Padke ( <i>Albizia lucida</i> ) forest block	984.33	21	58.5	109.6	189.1	50	98
Khair-Sissoo ( <i>Acacia</i> )	601.58	60	62.6	103	225.6	98	67

---

*catechu-*

*Dalbergia sissoo*) forest

block

Mix forest block	759.99	30	94	180	304	76	176
Total Trees (>30cm DBH)		196	372.3	524	1092.3		
Total Poles (10cm -30cm DBH)						322	824

---

At least 13 grassland areas, ranging from 10ha to 230ha in size, covering approximately 4% of the northern BFC were recorded (Fig. 2). Grassland flora consisted of a combination of wetland herbs and moist grass species. The most abundant grass species were: *Imperata cylindrical*, *Cyperus papyrus*, *Digitaria ciliaris*, *Bulbostylis barabata*, *Eragrostis tentella*, *Cyperus rotundus*, *Polygonum sp.*, *Ageratum conyzoides*, *Smithia sensitive*, *Centella asiatica*, *Cyperus species*, *Narenga porphyrocoma*, *Hemarthria compressa*, *Saccharum spontaneum*, *Cyperus rotundus*, *Desmostachya bipinata*, *Saccharum munja*, *Misconthes nepalensis*, *Corex vesicularosa*, *Ricinus Commonis*, *Botrichola globara*.

Seventeen wetlands were recorded in the study area, including all the water bodies that are defined under the wetland criteria . Amongst these, the most prominent are Nawagrithi Ghol, Gaida Ahal, Swami Ghol, Lama Ghol, Pyauli ghol, Rhino Tal of Rambel CF (Fig. 2).

We recorded 233 plant species in the northern BFC. Twenty five species of mammal, excluding those belonging to the Rodentia and Chiroptera, were recorded in the forest and associated habitats (Table 2). These included 5 species designated by IUCN as vulnerable species (gaur, *Bos gaurus*; sambar deer, *Cervus unicolor*; Indian smooth coated otter, *Lutrogale perspicillata*; sloth bear, *Melursus ursinus*); 2 designated as near threatened species (common leopard,

*Panthera pardus*; large Indian civet, *Viverra zibetha*), and 2 as endangered species (rhino and tiger). The area also supports a great diversity on bird species. 96 bird species were recorded, including 2 IUCN listed vulnerable species (cinereous vulture, *Aegypius monachus*; darter, *Anhinga melanogaster*), one endangered Egyptian vulture (*Neophron percnopterus*) and one critically endangered white rumped vulture (*Gypes bengalensis*).

Based on the pugmark survey, interviews with local people and forest office personnel (N=274), it was established that 3 tigers were frequently using the northern BFC. In addition, five rhinos were directly observed in the northern BFC by the survey team. Rhino Lake had the highest sightings of rhino in the BFC. Panchakanya CF, NawJagruti CF, Bhimbali CF and southern boundary of Indreni CF, Pandpur CF and its associated lakes and wetland areas were the frequently used places by rhino and tiger within the northern BFC. Potential sites for rhino within the northern BFC include Rhino Tal of Rambel CF, Ghol between Panchankaya and Chaturmuki CF, Nawagruti Ghol, Bhimabali CF, Dhamile khola, Gundremandre, northern boundary of Pandampur CF (Fig. 2).

**Table 2:** Mammals recorded in the northern BFC during the survey period (taxonomy according to IUCN (2011)).

Common name	Scientific name	Common name	Scientific name
Bengal tiger	<i>Panthera tigris</i>	One horn rhino	<i>Rhinoceros unicornis</i>
Common leopard	<i>Panthera pardus</i>	Small Indian mongoose	<i>Herpestes auropunctatus</i>
Large indian civet	<i>Viverra zibetha</i>	Hanuman langur	<i>Semenopithecus</i>

			<i>entellus</i>
Bison/Gaur	<i>Bos gaurus</i>	Rhesus macaque	<i>Macaca mulatta</i>
Small indicant civet	<i>Vivericula indica</i>	Sambar deer	<i>Cervus unicolor</i>
Asiatic golden jackal	<i>Canis aureus</i>	Spotted deer	<i>Axis axis</i>
India fox	<i>Vulpes bengalensis</i>	Barking deer	<i>Muntiacus</i> <i>muntjac</i>
Yellow throated marten	<i>Martes flavigula</i>	Wild boar	<i>Sus scrofa</i>
Common hare	<i>Lepus nigricollis</i>	Jungle cat	<i>Felis chaus</i>
Palm squirrel	<i>Funambulus pennanti</i>	Indian smooth coated otter	<i>Leutrogale</i> <i>perspicillata</i>
Sloth bear	<i>Melursus ursinus</i>	Eurasian Otter	<i>Lutra lutra</i>
Common mongoose	<i>Herpestes edwardsi</i>	Dolphin**+	<i>Platanista</i> <i>gangetica</i>
Asiantic black bear*+	<i>Ursus thibetanus</i>		

---

\* *In the northern boundary of northern BFC (Mahabharat range).*

+ *Based on public interview.*

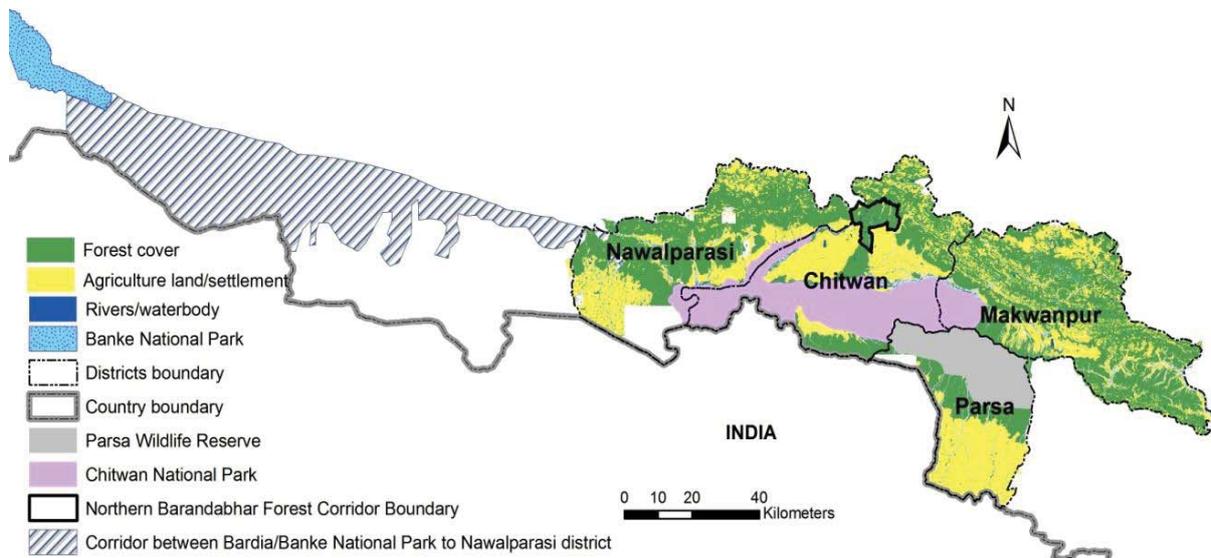
\*\* *In the Narayani river (Western boundary of northern BFC)*

## **Discussion**

The current study provides baseline ecological data for the northern extent of the BFC, which has previously received little attention from practitioners and scientific communities. It is anticipated that this study will form a basis for further research to help connect the CNP with the Mahabharat range in the north for biodiversity conservation, through engaging with local communities in Chitwan valley.

The preliminary surveys conducted during this study have demonstrated that the northern BFC supports a rich diversity of flora and fauna, including endangered species such as rhino and tiger. The northern BFC therefore is likely an essential part of the ecological network in Nepal, contributing to the habitat required to sustain populations of large mammals. For this reason, the retention and restoration of this corridor is advocated.

Although the northern BFC is shown to have a high growing stock that can provide basic forest products (i.e. timber, fuel wood) to local people along with providing natural habitat for wildlife, this study has identified a risk of habitat loss due to expanding settlements on the edges of the northern BFC. To avert the negative ecological impacts of such expansion, we propose the establishment of additional forest in areas of agricultural land to outside the east and west of the northern BFC boundaries. This is anticipated to eventually provide continuous intact forest to the east and west boundaries where it is currently fragmented. Establishing these small strips of forest would play a significant role in facilitating the movement of animals in the Terai Arc Landscape from the west to the east of the country (Fig. 3). The preservation and management of this connectivity will also ensure the continuity of natural habitats from the south of the country to the Mahabharat range in the north, providing an altitudinal gradient.

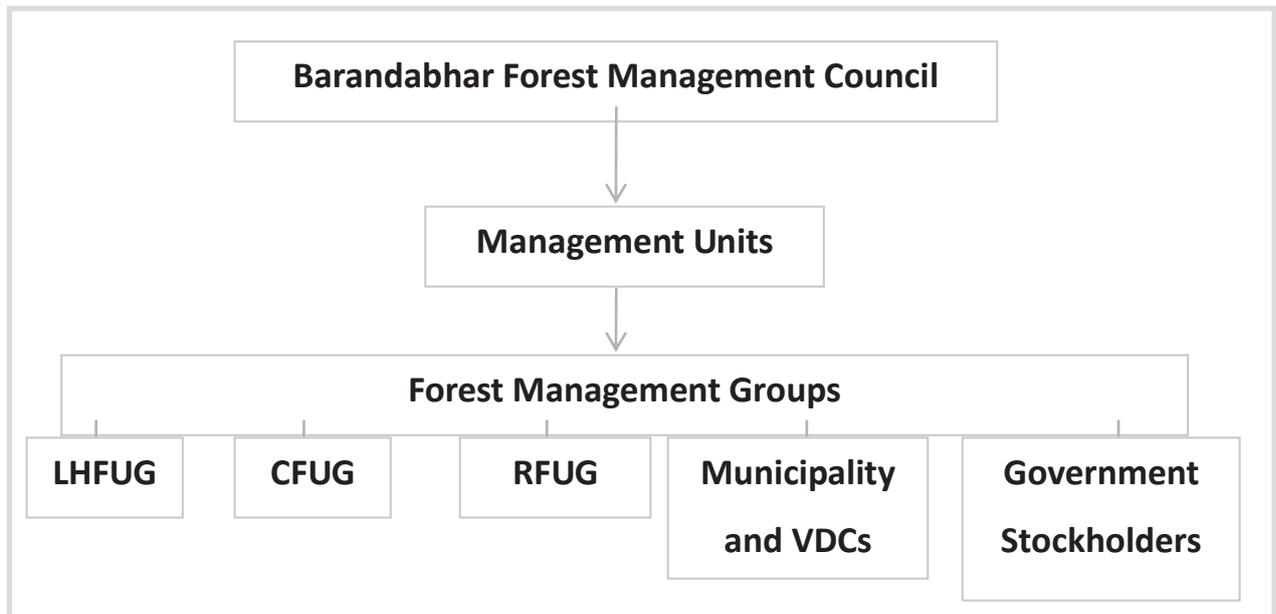


**Figure 3.** Location of the northern BFC with respect to the protected areas of Chitwan National Park, Parsa Wildlife Reserve and Banke National Park within the Terai Arc Landscape. The map demonstrates the connectivity provided by the corridor between higher and lower altitudes and across the landscape from east to west.

### *Proposed management strategy*

Social and cultural divisions exist within Nepalese societies, and in respect of forest management in particular, the social sub-ordination of women and marginalization of lower caste people continue to inhibit the democratization process (Tiwari et al. 2007, Dhakal et al. 2011, Pandit and Bevilacqua 2011). Acknowledgement of the effects of this issue has resulted in the promotion of new incentives aimed at poverty alleviation and community involvement (Bhattarai 2003, Bhattarai and Basnet 2004, Dhakal et al. 2011). These programs, including new management regimes, often tend to emanate from state initiatives, however, and are therefore usually implemented using a top-down approach (Ostrom 1990, Bray et al. 2003). They are relatively inflexible and unable, or unwilling, to adapt to changing social or biophysical conditions that require modification to appropriate management practices (Ostrom 1990). To

facilitate implementing new policies at the ground level, we propose a movement away from a top-down approach to managing the forest through formation of the ‘Barandabhar Forest Management Council’. Under the council, the forest management group will include the Leasehold, Community and Religious Forest User Groups (Fig. 4).



**Figure 4.** Proposed management regimes [Abbreviation- (LHFUG- (Leasehold Forest User Group); CFUG (Community Forest User Group). RFUG (Religion Forest User Group)]

Such a management structure will facilitate conditions for favorable resource access for all, regardless of the caste and cultural background. Although current forest policy is participatory, it does not necessarily set conditions for achieving downward accountability, transparency and fairness. Therefore, greater attention will be given to these issues to better serve the poor and marginalized populations within northern BFC user groups. In this way, sustainable cultivation, traditional agriculture and the harvesting of medicinal and aromatic plants will be promoted. Viable enterprises based on local resources also need to be promoted, such as non-timber forest

product (NTFPs) collection and handicraft preparation using traditional skills. The results of interviews with local people demonstrated that they are highly motivated to conserve rhino, tiger and other wildlife, and to ultimately attract tourists to their area for wildlife viewing. This could have positive impacts on their economic condition through the promotion of “wildlife tourism”.

We recommend that management zones are defined and delineated into core areas, for protection and conservation of endangered and endemic species including rhino and tiger, and access areas, from where local communities can collect forest products based on prescribed management plans. The core zone should include a central protected forest area (75%), with access area (25%) surrounding the protected core forest area. We further suggest that an area extending between 500m to 1000m around the core zone is allocated to the local community as a community forest (area <199ha for each CF). We also propose that management plans are prepared and implemented which incorporate all essential management and conservation parameters, including population monitoring protocols for rare and endangered species such as rhino, tiger and deer. Long-term wildlife research programs should be initiated by government and research institutions, to monitor populations of key species, define habitat needs, and provide information necessary for better population and habitat management. In addition, detailed surveys are also required for fauna that were not recorded in this study including rodents, bats and migratory birds. The maintenance and enhancement of the floral diversity of the area, including NTFPs, by effectively limiting their overexploitation is also a management requirement.

For rhino and tiger specifically, detailed surveys should be undertaken in the hotspots identified in the present study. Comprehensive guidelines for the overall biodiversity management in the northern BFC should be prepared, and implemented in coordination with the relevant local communities. Each community forest on the edges of northern BFC should delineate areas to

promote natural vegetation and restore open areas with plantation of indigenous grass and other plant species that can provide suitable habitat for wildlife.

The collection of timber, fuel wood, fodder and NTFPs from degraded areas should be strictly controlled. However, local communities should be encouraged toward sustainable use of forest resources through guidelines imbedded in their community forest plans. In doing so, private households in the fringe areas of northern BFC should be supported by government in the production and distribution of trees, NTFPs and seedlings/cuttings. In the forest area, re-plantation should be undertaken where plantation targets have not been achieved, and suitable silvicultural treatments should also be introduced to manage plantations. Practical and viable systems should be established to regulate grazing by introducing the concept of rotational grazing in degraded and vulnerable areas.

The forest should be subject to ecological survey periodically every five years to update information on existing grassland, forest and wetland areas associated with the northern BFC. A standard survey method should be developed as per the government guidelines of 2004 (Department of Forest, Government of Nepal 2004). The introduction of exotic species should be regulated in coordination with the governmental and non-governmental agencies operating in the northern BFC.

A ban on livestock grazing in the core zones of the northern BFC should be implemented and strictly enforced. The habitat and nesting sites of important resident and migratory birds should be mapped out. Patches of degraded forest should be protected for rehabilitation according to the Operational Plan and encourage CFUG to integrate sustainable ways of traditional forest management and control systems. Required technical support should be provided to northern BFC management committee to implement management activities effectively.

The East-West Mahendra Highway that bisects the BFC presents a risk to wildlife movement across two sides of BFC. Wildlife monitoring has indicated that at least 5-6 animals/year have been killed due to road accidents on this stretch of the highway (Tiwari et al. 2007). Additionally, light and noise associated with heavy traffic causes considerable disturbance in the movement of wildlife between the two sides of the BFC. It is therefore essential to establish alternative paths for wildlife to cross the highway safely, in the form of bridges or tunnels. In addition, a camera-enforced speed limit could be introduced along with a campaign raising awareness for drivers to reduce wildlife accidents.

### **Implications for conservation**

The current study has highlighted the likely importance of the northern BFC as a wildlife corridor between the CNP and the higher altitudes of the Mahabharat range. It forms an example of the approach required for biodiversity conservation, moving away from the isolated protected area system to an integrated, sustainable model, which incorporates local communities that are dependent on the resources these natural habitats provide. This approach is necessary to meet conservation goals of sustaining wildlife habitats and populations by providing incentives for local communities to engage in such conservation efforts. In the context of Nepal's Terai and inner-Terai, participatory forest management still requires research to optimize its effectiveness at addressing these twin goals simultaneously, and the BFC could represent an example in this direction. Although a detailed survey was not possible during the current study, it forms a basis with which to begin to further study the importance of the BFC for biodiversity. Retention and restoration of this corridor, as proposed here, is anticipated to be an important step in ensuring the preservation of landscape connectivity in Nepal for the movement of wildlife, especially rhino and tiger. Only by including local communities in habitat management will conservation of areas outside national parks be feasible in the long-term.

## **Acknowledgments**

This study was funded by District Forest Office, Chitwan/Department of Forest, Ministry of Forest and Soil Conservation Nepal, Keidanren Nature Conservation Fund Japan, and Massey University Research Fund, New Zealand. We are thankful to the staff of District Forest Office/ (Government of Nepal), Chitwan, Nepal for their logistic and organizational support to conduct this study. We thank to Mr. Birodh Pandey for his editing, comments and suggestions on early version of the manuscript. We specially thank to Mr. Baburam Upreti and Phadindra Pokharel (Forest officers, Government of Nepal) who supported the project in the field throughout the study period.

## **References**

- Joshi, A. R. 2002. Establishing biological monitoring system for Terai Arc Landscape. A report submitted to World Wildlife Fund (WWF) Nepal Program. Kathmandu, Nepal.
- Bennet, A. F. 2004. Integrating biodiversity conservation and sustainable use: lessons learned from ecological networks.pp.36-37, IUCN. The World Conservation Union, Cambridge University Press Cambridge.
- Shrestha R.N. 2001. The political economy of land, landlessness and migration in Nepal. Delhi: Nirala.
- Ojha, D. P. 1983. History of land settlement in Nepal Terai. *Contributions to Nepalese Studies*. 11 (1): 22-44.
- Panta, M., Kim K., and Joshi, C. 2008. Temporal mapping of deforestation and forest degradation in Nepal: applications to forest conservation. *Forest Ecology and Management*. 256: 1587-1595.

- Satyal, P.P. 2006. Forest policies in Terai and a history of forest politics in the Terai, Nepal: a case of equity or ecology? Paper submitted to the ECPR Summer School on Environmental Policies, Keele University.
- MOPE. 2002. Nepal: national action programme on land degradation and desertification in the context of the UN Convention to Combat Desertification. Ministry of Population and Environment, Kathmandu, Nepal.
- Dhakal, R.R., Kafle, G., and Yadav, J.N. 2011. Comparative assessment of floristic diversity in a buffer zone community forest and a community forest of Barandabhar corridor, Chitwan, Nepal. *Journal of Horticulture and Forestry* 3(8): 244–250.
- Bhattarai, B.P., and Basnet K. 2004. Assessment of crop damage by wild ungulates in the eastern side of Barandabhar Corridor Forest, Chitwan. *Proceedings of IV National Conference on Science and Technology* March 23-26.
- Bhattarai, B.P. 2003. Conservation threats to wild ungulates in Barandabhar Corridor Forest, Chitwan, Nepal. MSc Thesis. Central Department of Zoology-Ecology Program, Tribhuvan University, Nepal.
- Tiwari, S., Regmi, R., and Green, M. 2007. Tiger-rhino conservation project: landscape-scale conservation of the endangered tiger and rhino population in and around Chitwan National Park. Report of the final evaluation mission. United Nations Development Programme.
- Graner, E. 1999. Forest policies and access to forests in Nepal: winners and losers. In: *anthropology and sociology of Nepal*. Chhetri, B. R., and Gurung, P. O. (Eds.), pp.212-224. Modern Printing Press, Kathmandu.
- Mehta, J. N., and Heinen, J. T. 2001. Does community-based conservation shape favorable attitudes among locals? An empirical study from Nepal. *Environmental Management* 28(2):165-77.

- Forest Act 1999. Forest Act 2049. Government of Nepal, Ministry of Forests and Soil Conservation, Nepal (In Nepali).
- Shrestha, S., and Narayan, K. 2010. Global forest resources assessment 2010 country report: Nepal. Food and Agriculture Organization of the United Nations.
- Heinen, J.T. 1993. Park–people relations in Kosi Tappu Wildlife Reserve, Nepal: a socio-economic analysis. *Environmental Conservation* 20: 25-34.
- Department of Forest, Government of Nepal 2004. Community forest inventory guidelines. Ministry of Forests and Soil Conservation, Department of Forest, Nepal.
- Ramsar Convention Secretariat 2010. Wise use of wetlands: concepts and approaches for the wise use of wetlands. In: *Ramsar handbooks for the wise use of wetlands, 4<sup>th</sup> edition, vol. 1*. Pritchard, D (Ed.). Ramsar Convention Secretariat, Gland, Switzerland.
- Bacon, P.R. 1997. Wetlands and biodiversity. In: *wetlands, biodiversity and the Ramsar Convention: the role of the Convention on Wetlands in the conservation and wise use of biodiversity*. Halls, A.J. (ed.). Ramsar Convention Bureau, Gland, Switzerland.
- IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 05 January 2012.
- Pandit, R. and Bevilacqua, E. 2011. Social heterogeneity and community forestry processes: reflections from forest users of Dhading District, Nepal. *Small-scale Forestry*, 10(1): 97-113.
- Bray, D. B., Merino-Perez, L., Negreros-Castillo, P., Segura-Warnholtz, G., Torres-Rojo, J. and Vester H.F.M. 2003. Mexico's community-managed forests as a global model for sustainable landscapes. *Conservation Biology*. 17(3):672-677.
- Poffenberger, M., and McGean, B., 2006. Village voices, forest choices: joint forest management in India. Oxford University Press.

Ostrom, E. 1990. *Governing the commons: the evaluation of Institutions for collective action*.  
Cambridge University Press, Cambridge.

## Chapter Two

### Ecology and conservation of brown bears

#### Summary

This chapter is the first document of its kind to investigate the conservation status of brown bears in Nepal. Brown bear has received little attention in the Himalayas and conventional wisdom asserted that brown bears were extirpated from Nepal. I contested this view and conducted a systematic survey across the Nepalese Himalaya region. This study confirms the existence of a small population of brown bear, analyzes human-bear conflict, and develops a network with local people to improve the bear conservation efforts in the region. I worked comprehensively with local communities and conducted two different workshops to complete a brown bear conservation action plan with the support of IUCN/SSC/Bear Specialist Group/South Asian Brown Bear expert team (Dr. S. Sathyakumar). In recognition of my research and its contribution towards brown bear research and conservation, IUCN/SSC/Bear Specialist Group has appointed me as an active member of the group since 2010, and recently (from 2 January 2013) I have been appointed Co-Chair of IUCN/SSC/Bear Specialist Group/South Asian Brown Bear Expert Team (SABBET). I initially documented the presence of brown bears in the Manasalu Conservation Area, and then extended investigations and conservation activities to the Annapurna Conservation Area. Both the studies that are published in *Ursus* (Vol. 22 and Vol. 23; Papers *I & II* below) have focused on the distribution, ecology, and diet of the brown bear. After understanding the general distribution and ecology of brown bears in Nepal, further work has been carried out to prepare a brown bear conservation action plan for Nepal. This led to the preparation of a draft conservation action plan. The summary of the brown bear conservation action plan and distribution is published in *Diversity* (Vol. 4; Paper *III* below).

*This chapter contains three papers as follows:*

- I. Aryal, A., S. Sathyakumar, & C.C. Schwartz. 2010. Current status of the brown bear in Manasalu Conservation Area Nepal. *Ursus* 21(1):109-114. doi: 10.2192/09GR029.1
- II. Aryal, A., J. Hopkins, W. Ji, D. Raubenheimer and D. Brunton. 2012. Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (2): 231-236.
- III. Aryal A., D. Raubenheimer, S. Sathyakumar, B.S. Poudel, W. Ji, K.J. Kunwar, J. Kok, S. Kohshima and D. Brunton. 2012. Conservation strategy for brown bear and its habitat in Nepal. *Diversity* 4(3): 301-317.

# **Paper I: Current status of brown bears in the Manasalu Conservation Area, Nepal**

## **Abstract**

Although brown bears (*Ursus arctos*) are rare in the Himalayan region, populations have been documented in alpine habitats of Pakistan and India. Brown bears were once known to exist in both Nepal and Bhutan, but current information on their numbers and distributions was lacking. We document the presence of brown bears (*Ursus arctos*) in the Manasalu Conservation Area (MCA) in Nepal using field surveys and interviews with local people. We were able to confirm the existence of a remnant population based on finding bear scat and locations where bears excavated for Himalayan marmots (*Marmota himalayana*). Based on interviews with local people, it appeared that the presence of brown bears in the area is relatively recent and likely as a result of immigration of bears from the Tibetan Autonomous Region. Interviews with local herders also indicated that livestock losses from brown bear predation amounted to approximately 318,000 Nepali Rupees (NRs) (US \$4,240) from February 2006 through July 2008.

**Key words:** brown bear, distribution, livestock depredation, Nepal, *Ursus arctos*.

## **Introduction**

The brown bear (*Ursus arctos*) is the most widely distributed ursid in the world (Servheen et al. 1999, Schwartz et al. 2003). Historically, the species ranged across a large portion of North America, including northern Mexico, throughout Europe, Asia, the Middle East, and even across North Africa. Status of the brown bear varies throughout the world from endangered to common; they are listed as vulnerable under criteria C2a(i) version 3.1

(<http://www.iucnredist.org.details/41688/0>) in the IUCN Red List. They are also listed in Appendix II of the Convention on International Trade in Endangered Species (CITES). The species is endangered in many regions in Asia, where small, isolated populations exist mostly in remote mountainous areas (Servheen 1990, Servheen et al. 1999).

Remnant populations of brown bears are scattered across many portions of Asia, however very little is known about numbers or connectivity. In Pakistan, there are an estimated 150–200 bears in seven separate populations in the Himalaya, Karakoram and Hindu Kush Ranges, but only one has >20 individuals (Nawaz 2007). In India, brown bears exist in 23 protected areas and 35 other localities in the northern states of Jammu, Kashmir, Himachal Pradesh, and Uttarakhandl, but they are regarded as common in only two protected areas. Country-wide, it has been estimated that there are 500 to 750 individuals (Sathyakumar 2001, 2006). In China, brown bears exist in poorly defined populations in the west and northeast, with estimates of 6,000 and 1,000 in each of these regions, respectively (Gong and Harris 2006).

The Himalayan brown bear (*U. a. isabellinus*), a subspecies that represents an ancient lineage of the brown bear (Galbreath et al. 2007, Gong and Harris 2006), was distributed over the Greater Himalaya region. Conservation efforts have been hindered by the lack of information about its current status (Servheen et al. 1999). This subspecies is thought to occur at very low densities in the alpine regions of the Greater and Trans Himalayan regions of India (Sathyakumar 2006). Nothing is known about the distribution and abundance of brown bears in Nepal, and the species has not been recorded in Bhutan to the east since the 1950s (S. Sathyakumar, unpublished data). The bear populations in Nepal and Tibetan Autonomous Region of the People's Republic of China (TAR) belong to a separate subspecies (*U. a. pruinosus*) not connected to the bear population in India (*U. a. isabellinus*) because of a gap in the distribution between western Nepal and India (Galbreath et al. (2007).

In Nepal, brown bears are thought to be distributed in the Annapurna and Manasalu Conservation Areas, Shey-Phoksundo National Park (unconfirmed) and corridors connecting these areas. Locally, the brown bear is known as “Tingting” in the Gorkha area of Manasalu Conservation Area and “Mithe” in the Upper Mustang area of Annapurna Conservation Area, bears are sometimes referred to as “Yeti”. The government of Nepal has laws protecting endangered flora and fauna (Government of Nepal 1982), including brown and Asiatic black bears (*Ursus thibetanus*). Nepal has established national park, reserve and conservation areas for the conservation of endangered flora and fauna, but many species are severely depleted due to over exploitation, pollution, habitat destruction, poaching, and human and livestock pressures in the natural habitats (NBS/Nepal 2002). Both bear species are believed to be depleted due to poaching, and habitat destruction (NBS/Nepal 2002), but information is inadequate to make such a determination. We initiated this study to investigate the potential presence and distribution of brown bears in Manasalu Conservation Area using field surveys and interviews with local people. We also gathered data on human-bear conflicts.

## **Method and Materials**

### Study site

Our study site was the Manasalu Conservation Area, Nepal (Fig. 1). The Manasalu Conservation Area in Nepal covers an area of 1,663 km<sup>2</sup> and consists of a mosaic of habitats for 33 mammals, 110 bird, 11 butterfly, and 3 reptile species (Shrestha1997, NBS/Nepal 2002). There are approximately 2,000 species of plants, 11 types of forests, and over 50 different medicinal plants. The bio-climatic zones vary from sub-tropical to nival (>5,000 m). The altitude ranges from 600 m to the summit of Manasalu (8,163 m). The Manasalu region has six climatic zones. Our study area was located in 3 zones: sub-alpine, alpine, and arctic all above

3,000 m. In the sub-alpine zone, winters are cold and summer mean temperature reaches 6 to 10°C. The alpine zone is mostly open meadows. The arctic climatic zone is > 4,500m with snow line at 5,000 m. Monsoons (Jun-Sep) providing three-fourths of the total precipitation. Post-monsoon (October to February) is usually dry. Average precipitation is around 1,900 mm/year. The southern part of the region remains cloudier and wetter than the upper subalpine and alpine areas (NBS/Nepal 2002).



Fig.1a

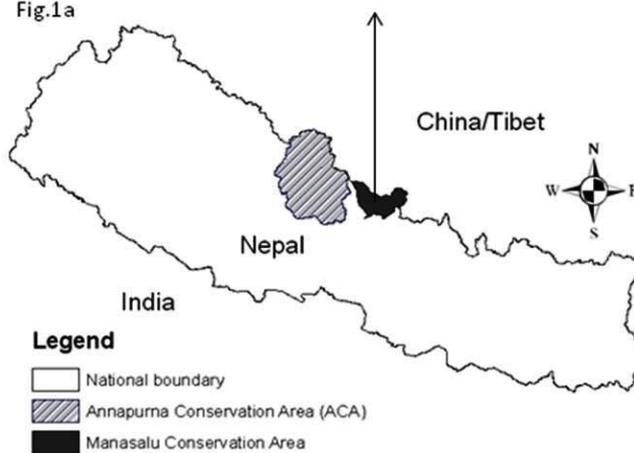


Fig.1b

**Figure 1.** Manaslu Conservation Area, Nepal (top) showing the survey area and brown bear death site and protected areas of Nepal (bottom)

## **Methods**

### ***Presence/absence survey***

During April-July 2008, we conducted a presence and absence survey in Manasalu. First we interviewed local people to identify potential locations where brown bears resided. Based on this, we decided to focus our field survey efforts in the Sama Village Development Committee (VDC) area. We carried out field surveys by walking along livestock and human trails in the most likely habitat (i.e., convenience sampling). We verified the presence of brown bears with clearly identifiable sign including tracks, scats, and excavations made to capture Himalayan marmots (*Marmota himalayana*). We assumed all bear scats found were from brown bears because the area we searched was well above treeline and outside the known range of the Asiatic black bear (Shrestha 1997). We also documented body parts of bears that were shown us by local people and that could be related to time and place of collection, and considered them recent evidence of bear presence. We photographed and measured all specimens. Finally we considered interactions between bears and people, including depredation of crops and livestock, as evidence of bear presence when we had reasonable assurance that bear were indeed involved. We focused on brown bears, but we also collected information on Asiatic black bears (not presented here) to provide base line information for further research and management. We showed photographs of the 2 bear species to local people during interviews to help ensure they knew the difference between species.

### ***Livestock depredation data***

We interviewed local villagers and herders from the 3 villages of Sama, Lho, and Prok VDC to document bear depredation of livestock. We only considered livestock depredations that occurred from February 2005 through July 2008. Because brown bears are the only possible predator occurring within potential brown bear range in the Manasalu Conservation Area, we assumed that all livestock predation within this area was directly associated with brown bears.

To our knowledge there are no snow leopards (*Unica uncia*) or other large predators in the Samdo area of Manasalu Conservation Area. We attempted to verify the response of individual herders by independently interviewing other family members or others from the area, because of some pastoralists' have a propensity to exaggerate numbers of livestock killed by predators, perhaps in the hope of compensatory remittance from the concerned authorities. We estimated prevailing market value for each type of livestock by interviewing herders and on the basis of local selling and buying rates. The income of local people is estimated to be between \$20 and \$100 US/month. We plotted field data and local information to develop a distribution map of brown bears in the Manasalu Conservation Area using ArcMap (version 9.1, ESRI Inc.) software.

## **Results**

### *Presence and absence survey*

We walked >200 km of trails within the Manasalu Conservation Area. We did not see any brown bears, but documented 29 scats and 67 marmot digs. Brown bear scats (0.3 bear scats/km<sup>2</sup>) and digging (0.8 digs/km<sup>2</sup>) were found in 7 areas (Chhewang, Gyala, Lajun, Mayoal, Rongcha, Mendethang, and Wachhang) above Samdo village.

We interviewed 287 individuals (including 19 visitors from TAR) were interviewed from the Samdo, Sama, Lho, Prok and Bhimtang areas. Samdo, Sama, Lho, and Prok are in close proximity (<10 km apart) to each other, whereas Bhimtang is about 27 km distant from them. However, in these areas people frequently visit each village for business purposes; they also use the Samdo area for grazing of livestock. One hundred and seventy nine people we interviewed reported observing brown bears in Sama (specifically, in the Gyala, Mayol, Yaguthang, Chhetang, and Lajung areas). Based upon the plotted locations of reported sightings, we

concluded that a single brown bear was first observed in 2005 (Gyala area), with 2, 4, and 9 different individuals sighted in 2006, 2007, and 2008, respectively. Local people interviewed felt that the brown bears they observed in Nepal moved into the Manasalu Conservation Area from the TAR. The general belief was that presence of brown bears in the Manasalu Conservation Area was quite recent; the number of observations seemed to have increased each year. Based on our interviews, we ascertained that there were likely 9 brown bears (5 adult with 4 cubs) in the Samdo area. These bears were observed between February and June, 2008 when people were engaged collecting *Cordyceps sinensis* (locally called Yarshagumba, see <http://www.brtf.org.np/information/publication/41/>). Additional sightings occurred during October-December, the time period when livestock were moved to lower elevations outside the Manasalu Conservation Area, and human activities were low.

The consensus of the 19 TAR people we interviewed (who also use areas within Manasalu) was they believed there to be 20-30 brown bears present in the Qurung district of TAR adjacent to Sama. All felt the area within Nepal was more secure for brown bears because of higher levels of poaching in TAR. These Chinese citizens reported that Tibetans set traps/snares to kill or capture cubs of brown bears and snow leopards for sale. One respondent reported selling a brown bear cub for 1500 Chinese yuan (¥) (US\$220 at the prevailing exchange rate). Local Tibetan people indicated that brown bear predation on livestock was a problem and as a consequence, livestock herders used poison to kill brown bears. They reported that at least 2 brown bears were known to have been killed in December 2007, one in the TAR and the other in Gayal area in Nepal (Figures 1). Both were poisoned and the Nepalese citizens we interviewed blamed local herders from TAR. The skull of one specimen suggested it was a young bear (Figure 2).



**Figure 2.** Skull of Brown bear found in Sama Area. Note that the eruption of the upper canine teeth is incomplete (length about equal to 3rd incisor) suggesting this bear was a juvenile.

#### *Brown bears and human conflict*

The herders we interviewed reported losing 29 livestock between February, 2005 through July, 2008 (Table 1). Most were yak calves (<1 year); the remainder were horses or mules. Based on our interviews with local people, they suggested depredation of their livestock had increased during this period. They reported that brown bears were the major predator of their livestock, and reported that there were no other predators (i.e. snow leopard, Tibetan wolf [*Canis lupus chanco*], Eurasian lynx [*Lynx lynx*]) in the Samdo region.

Our sense was local people had generally negative attitudes toward bears because of their perceptions about livestock predation. Interviews suggested little awareness about brown bear conservation issues. Based on our analysis of livestock depredation, we estimated a financial

loss of approximately 318,000 NR (US \$4,240) from February, 2005 through July, 2008 (Table 1).

**Table 1. Livestock depredation by brown bears in Manasulu Conservation Area, Nepal, February 2005–July 2008, as reported by respondents to a questionnaire survey ( $n = 287$ ). Costs are in Nepali rupees (1 US\$ = 75 Nepali rupees [NR] in 2008).**

Livestock type ( <i>n</i> )	Location	Cost/animal, NR	Total cost, NR <sup>a</sup>	Year	Livestock age (years)
Horse (1)	Larke Pass	25,000	25,000	2008	4
Horse (3)	Mayal	24,000	72,000	2008	3
Yak (2)	Rengchu	8,000	16,000	2007	0.67
Yak (3)	Chhetang	8,000	24,000	2007	0.67
Yak (9)	Samdo	6,000	54,000	2008	<1
Yak (4)	Lajung	9,000	36,000	2007	1
Mule (2)	Yaguthang	13,000	26,000	2008	7
Mule (1)	Samdo Danda	13,000	13,000	2006	5
Mule (4)	Gyala	13,000	52,000	2006	3
	Mayol			2008	
	Yaguthang				
	Chhetang				
<b>Total (29)</b>			<b>318,000</b>		

<sup>a</sup>Based on consultation with local people during interviews.

## Discussion

Our survey indicates that brown bears occupy part of Manasalu in Nepal, but that numbers are quite low. Local herders indicated that the brown bears observed in this area were recent immigrants from TAR. Because of local religious beliefs, local people do not kill marmots; this likely contributes to their abundance. Preliminary scat analyses suggested that marmots constituted a major source of food for brown bears in this area.

Our interviews with local herders suggested they were more concerned with the health and safety of their livestock than conserving this remnant population of bears. This observation was consistent with observations made by Stubblefield and Shrestha (2007) in Nepal where locals viewed Asiatic black bear primarily as agricultural pests. Although legislation protects brown bears in Nepal, conflicts between bears and herders will likely require an approach that considers both brown bear conservation and maintaining the livelihoods of local peoples. Such an approach might be patterned after the successful management program in Deosai National Park, Pakistan, where increased protection of a remnant brown bear population has resulted in an annual growth rate of about 5% since the program's inception (Nawaz et al. 2008). Long term

success of any brown bear conservation program requires minimizing human–caused mortality, especially to adult females. To reduce killing and improve acceptance of brown bears by local people, we suggest exploring a payment program that compensates local herders for lost livestock. Our results indicate that (with strict controls to minimize abuse), improved forage production near villages, or the use of guard dogs to protect livestock. For example, the annual costs of a compensation program would be reasonable (about \$1,500 U.S. annually based on reported losses ) and might be covered by a nongovernment organization program similar to one in North America where the Defenders of Wildlife compensates for livestock losses due to grizzly bears and gray wolves (*Canis lupus*).

## **Acknowledgements**

We thank respondents and informants from the study area for providing us valuable information. We are indebted to Narendra Lama, (Officer-Incharge of ACAP, Lomanagthang) for his support and coordination with local people. We acknowledge Mr. Madhu Chhetri for providing permission to conduct this study in Manasalu Conservation Area Project. We thank the International Association for Bear Research and Management (IBA), USA, Rufford Small Grant Foundation, UK, and Keidanren Nature Conservation Fund (KNCF), Japan for providing financial support, and F. Dean and D. Garshelis for their encouragement and support. We thank Idea Wild for providing research equipment. We also thank Mr. Prabhat Pal, Til Bahadur Chhetri for supporting as field assistant and Tej Kumar Shrestha for suggested edits. We thank P. Gogan, E. Olexa, and K Kendall for providing reviews as part of the Fundamental Sciences Practices requirements for the USGS. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

## Literature Cited

- Galbreath, G. J., C. P. Groves, and L. P. Waits. 2007. Genetic resolution of composition and phylogenetic placement of the Isabeline bear. *Ursus* 18: 129–131.
- Gong, J., and R. Harris. 2006. The status of bears in China. *Understanding Asian bears to secure their future*. pp: 96–101. Japan Bear Network, Ibaraki, Japan.
- Government of Nepal. 1982. National Park and Wildlife Conservation Act 2039. Government of Nepal (in Nepali).
- Nawaz, M. A. 2007. Status of the brown bear in Pakistan. *Ursus*. 18:89–100.
- Nawaz, M.A., J. E. Swenson, and V. Zakaria . 2008. Pragmatic management increases a flagship species, the Himalayan brown bear, in Pakistan's Deosai National Park. *Biological Conservation* 141:2230–2241.
- NBS/Nepal. 2002. Nepal Biodiversity Strategy (NBS), His Majesty's Government of Nepal.
- Sathyakumar, S. 2001. Status and management of Asiatic black bear and Himalayan brown bear in India. *Ursus* 12:21–30
- Sathyakumar, S. 2006. The status of brown bears in India. *Understanding Asian bears to secure their future*. pp: 7-11. Japan Bear Network, Ibaraki, Japan.
- Schwartz, C.C., S. D. Miller, and M. A. Haroldson. 2003. Grizzly/brown bear. Pages 556–586 *in* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. *Wild mammals of North America: biology, management, and conservation*. Johns Hopkins University Press, Baltimore, Maryland, USA.
- Servheen C. 1990. The status and conservation of the bears of the world. *International Conference for Bear Research and Management.*, Monograph Series No.2
- Servheen C., S. Herrero, and B. Peyton. 1999. Bears. Status survey and conservation action plan. *Bears*. IUCN/SSC Bear and Polar Bear Specialist Groups. IUCN, Gland, Switzerland and Cambridge, U.K.

Shrestha, T.K. 1997. Mammals of Nepal. Kathmandu Nepal.

Stubblefield, C. H., and M. Shrestha. 2007. Status of Asiatic black bears in protected areas of Nepal and the effects of political turmoil. *Ursus* 18:101–108.

## **Paper II: Distribution and diet of brown bears in the upper Mustang region, Nepal**

### **Abstract**

We investigated the distribution and diet of brown bears (*Ursus arctos*) in the upper Mustang region (UMR) of the Annapurna Conservation Area (ACA) in Nepal by interviewing local residents ( $n = 166$ ) and collecting bear sign ( $n = 109$ ). Local residents reported that brown bears predominantly used the Dhalung and Chungjung pastures and the Damodar Kunda Valley of the UMR from May to November, as well as the unprotected area between this region and Shey-Phoksundo National Park. We conducted dietary analyses on 56 bear scats; bears were predominately carnivorous in the UMR. Plant matter comprised 8% of fecal volume in scats. Small mammal hair was the most commonly identified item (75%), with marmots (46%) being the largest contributor. In addition, hair from ungulates (14%) and livestock (10%) were identified in scats. Few bear depredations occurred between 2003–2010 in the UMR.

**Key words:** Annapurna Conservation Area, bear incident, brown bear, diet, distribution, Nepal, upper Mustang, *Ursus arctos*

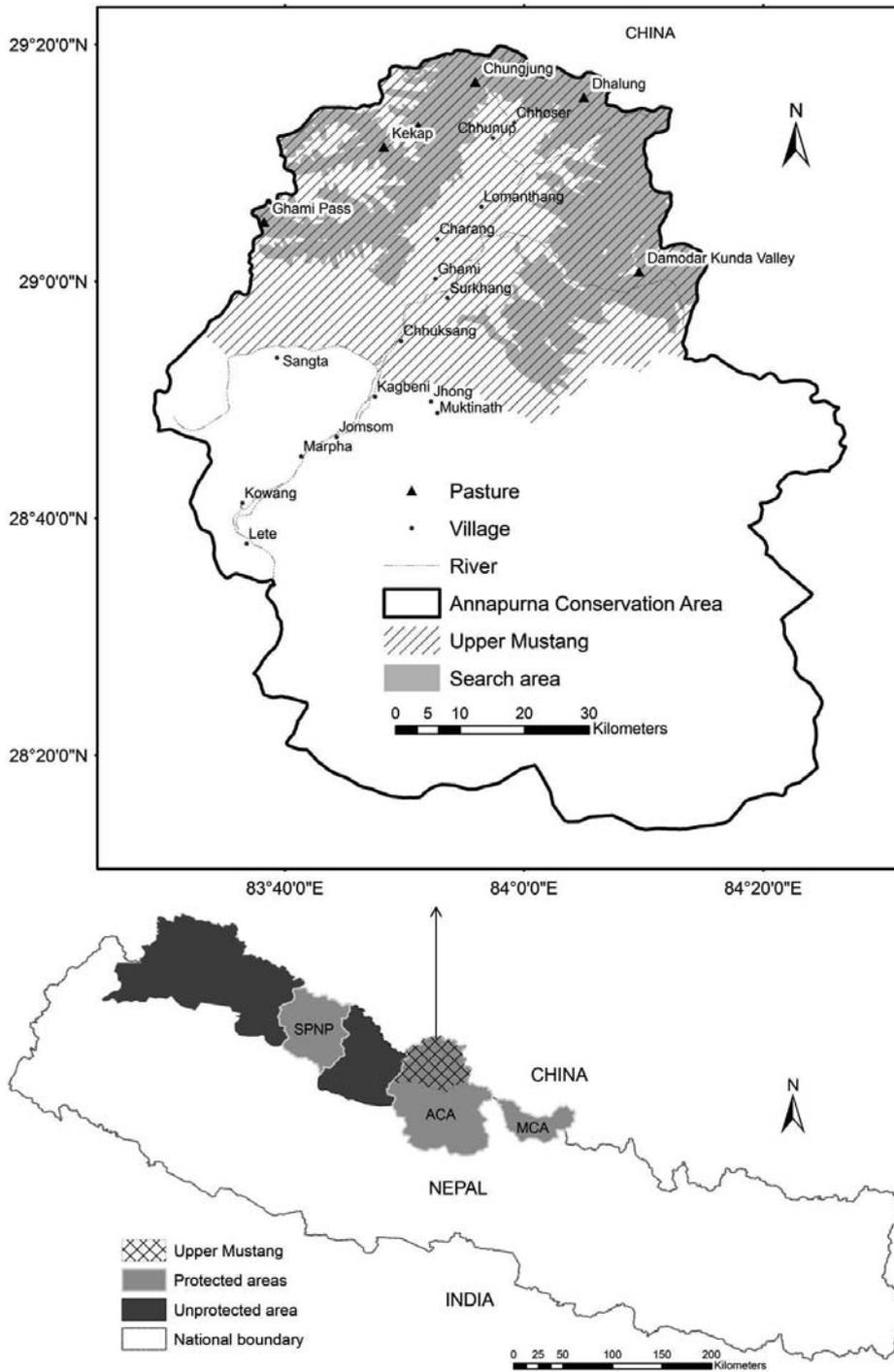
### **Introduction**

Brown bears (*Ursus arctos*) occur in small isolated populations in remote mountain regions of Eurasia and North America (Servheen 1990, Servheen et al. 1999). The Himalayan brown bear (*U. a. isabellinus*) and Tibetan brown bear (*U. a. pruinosus*) are thought to occur in very low

densities in disconnected alpine regions (Galbreath et al. 2007) of the Greater and Trans Himalayan regions of India (Sathyakumar 2006) and the Tibetan Autonomous Region of China (Jackson 1990, Schaller 1998, Harris 2008), respectively. Although Schaller (1998) reported that the Himalayan brown bear is distributed in northwestern Nepal, the subspecies that occurs in this region is currently unconfirmed.

Little is known about the ecology of brown bears in Nepal (Gurung 2004, Aryal et al. 2010). Brown bears have been sighted and their sign collected in the upper (Chetri and Gurung 2004, Gurung 2004) and lower (Schaller 1998) Mustang regions of the Annapurna Conservation Area (ACA) and the Manasalu Conservation Area (Aryal et al. 2010). Brown bears are also thought to occur in northwestern Nepal and the western Dolpa region (Gurung 2004), which includes Shey-Phoksundo National Park and the unprotected region connecting the Park to the ACA (Aryal et al. 2010, Fig. 1).

We investigated the distribution and diet of brown bears in the upper Mustang region (UMR) of the ACA by interviewing local residents and collecting brown bear sign from the region. Results from this study will be used to develop a comprehensive brown bear conservation plan for Nepal.



**Figure 1.** The Upper Mustang Region of the Annapurna conservation Area, Nepal and searching for sign in the search area(gray: from 3,800-6,000m).

## Method and Materials

### Study area

The UMR (approximately 2,500 km<sup>2</sup>) of the ACA (Fig. 1) is home to approximately 5,700 non-winter human residents in seven Village Development Committees (hereinafter villages; Fig. 2). The UMR is located in the Dhaulagiri–Annapurna mountain rain-shadow zone, and is characterized as cold desert, desiccated by strong winds and high solar radiation. Most of the area remains under snow from November to March, and total annual precipitation is <200 mm, half of which is winter snow (Chetri and Gurung 2004, ACAP 2010).

Agricultural production in the area is limited due to low rainfall and scarcity of ground water, lack of mechanised irrigation, and long periods of low temperatures. The majority of the land is uncultivated and barren, with only 1.7% of the area being cultivatable (approximately 0.35 ha/person). Local production of food meets only 55% of subsistence needs and only 8% of the local population are self-sufficient on their own agricultural products (Chetri and Gurung 2004, ACAP 2010).

Animal husbandry is the main source of income for local residents, with regular trade of goats and sheep with China (Chetri 2008). In 2002, an average of 36,503 livestock were raised by local residents, including cattle (*Bos* spp.), yaks (*Bos grunniens*), dzos (cattle/yak hybrid), sheep (*Ovis* spp.), goats (*Capra hircus*), horses (*Equus caballus*), donkeys (*Equus asinus*), and mules (Chetri 2008).

The rangelands of the UMR (Fig. 1) provided grazing opportunity for livestock and also support a biodiversity of native flora and fauna (Chetri 2008). These high-altitude Tibetan grassland communities comprised a diversity of plants including *Caragana* spp., *Lonicera* spp., *Stipa* spp., *Carex* spp., *Kobresia* spp., and *Lagotis* spp. (Stainton 1972, Chetri and Gurung 2004) as well as predators including snow leopard (*Panthera uncia*), lynx (*Lynx lynx isabellinus*), brown bear,

and grey wolf (*Canis lupus*) (Chetri and Gurung 2004, Chetri 2008). The prey species for these predators include argali (*Ovis ammon*), Tibetan gazelle (*Procapra picticaudata*), wild ass (*Equus kiang*), blue sheep (*Pseudois nayaur*), Himalayan marmot (*Marmota himalayana*), Royle's spika (*Ochotona roylei*), and Himalayan woolly hare (*Lepus oiostolus*).

## Methods

### *Brown bear sign*

We searched the UMR for brown bear sign during October–November 2009, March–April and July–October 2010, and June 2011 (Table 1). We conducted our search from 3,800 m to 6,000 m (Fig. 1). We identified areas to search in 2009 by interviewing local residents ( $n = 166$ ) in each of the seven villages (Fig. 1). We searched areas where: 1) bears had been sighted by local residents; 2) bear depredations had occurred; or 3) bear sign had been observed. We also searched for sign around each village and during our travel to each site. In 2009, six field staff searched each area by walking 10–100 m apart along known trails and riverbeds. In 2010 and 2011, we conducted more extensive searches of each area. In particular, we searched Ghami and Charang in March–April 2010, Damodar Kunda in July–October 2010, and Dhalung and Chhoser in June 2011. At each area, we collected bear scats and bear hair and documented bear tracks and excavated marmot burrows, i.e., digs (Fig. 2).

### *Diet analysis*

We visually identified bear scats (Xu et al. 2006), as no other species in the study area produce feces similar to bears. We washed scats in hot water and separated hair, bones, and plants. We calculated the percent volume of plants and unidentified matter in our sample. We then identified prey species from each scat using microscopic methods similar to those described by Mukherjee et al. (1994). We soaked hair in xylol for 24 hours. We then mixed hairs, and with

eyes closed, pinched a group of hairs from each sample. We mounted these hairs on slides. We matched the medulla and cuticle structure for the first 17 hairs from each sample to reference material collected from dead animals in the region, and from references provided by Bahuguna et al. (2010). We observed slides under a light microscope and photographed each sample. We identified each hair to species and grouped species by dietary category: 1) small mammals, 2) ungulates, 3) livestock, or 4) birds. We calculated the percent frequency of occurrence (total hairs of a species or dietary category/total hairs) for each species in our sample and for each of the four dietary categories.

### *Bear depredations*

We recorded brown bear depredations of livestock during interviews with local residents, and validated reports by interviewing their family members or other local residents from the area. These cross-checks were necessary to avoid exaggeration of numbers of livestock killed. We also estimated monetary losses due to livestock depredations by interviewing local herders and determining the market value for livestock.

## **Results**

### *Brown bear sign*

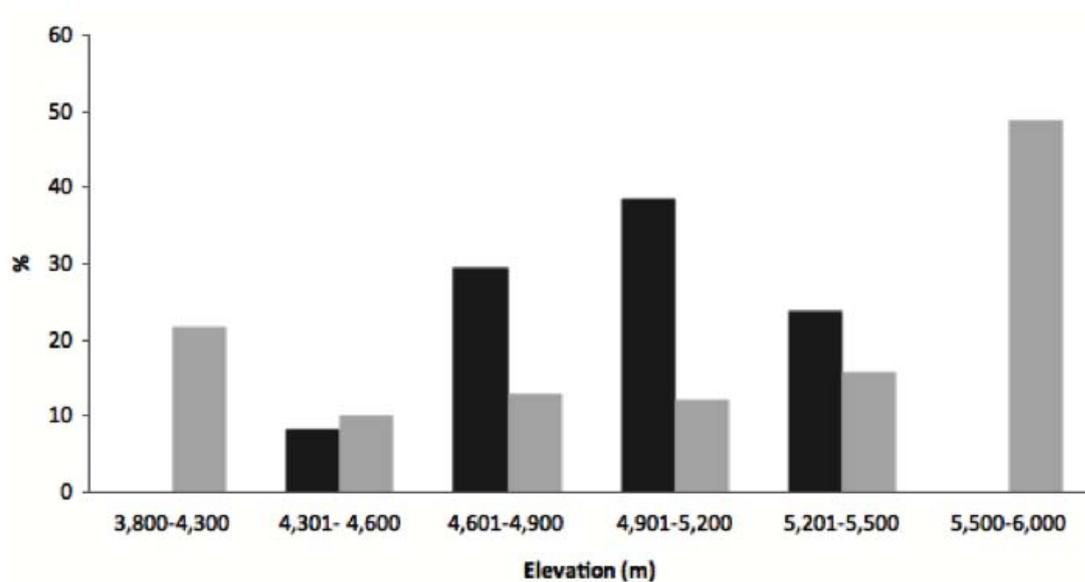
One-hundred and nine of 166 local residents reported an increase in brown bear presence in the UMR from 2009–2011. Local residents ( $n = 8$ ) reported bear sightings ( $n = 2$ ) in Dhalung pasture and Damodar Kunda Valley. Based on reports from 48 local residents (all from Ghami, Surkhang, and Sangta), we infer brown bear presence in the unprotected area between the UMR and Shey-Phoksundo National Park; most of these local residents reported that bears were resident in this unprotected area throughout the year (Fig. 1). On 3 October 2009, we observed a

bear ( $83^{\circ} 46' 59.29''$  E,  $29^{\circ} 12' 1.86''$  N) between 1.5–2 km away, excavating a marmot burrow (Fig. 2) in the high pastures around Kekap. On 16 October 2009, we observed what we believed to be a different bear ( $83^{\circ} 39' 12.57''$  E,  $29^{\circ} 4' 51.7''$  N) bedded-down in grassland between Ghami village and Ghami Pass.

We collected bear sign from all areas where local residents reported that they had observed sign. In addition to our two bear sightings, we collected sign ( $n = 107$ ; Table 1) at sites around Chhoser, Chhunup, Lomangthang, Ghami, and Surkhang (Fig. 1); however, no bear sign was observed <4 km from any village in the study area. We collected two hair samples at excavated marmot burrows in the Damodar Kunda Valley and one sample from a burrow in Dhalung (Fig. 2). We collected all sign from 4,300 m to 5,500 m (Fig. 3).



**Figure 2.** Excavated marmot burrows from the Dhalung area, upper Mustang region, Nepal, 2009. Photo on the left and upper right are images of the same excavated burrow.



**Figure 3.** Elevation of study area (gray bar) and sign (black bars) collected in the upper Mustang region, Annapurna Conservation Area, Nepal, 2009–2011.

**Table 1.** Brown bear sign and sightings collected in the upper Mustang region, Nepal, 2009–2011.

Bear Sign	Oct–Nov 2009 (57 days)	Mar–Apr 2010 (20 days)	July–Oct 2010 (49 days)	June 2011 (26 days)	Total (152 days)
Scats	23	4	19	10	56
Digs	14	7	12	6	39
Tracks	4			5	9

Hairs			3		3
Bear sightings	2				2
Total	43	11	34	21	109

### *Dietary analysis*

We collected scats ( $n = 56$ ) from four regions of the UMR: Chhoser/Chhunup ( $n=14$ ); Lomanthang ( $n = 3$ ), Ghami ( $n = 16$ ); and Surkhang ( $n = 23$ ) (Fig. 1). We did not separate scats by season or by site, because of low sample size. Instead, the diet data (Table 2) are a summary of the entire collection of scats. Plant matter and unidentified material (including unknown insect chitin ( $n = 3$ ), but not including bones), comprised 8% and <1% of fecal volume, respectively. Small mammal hair was the most frequently identified prey category, followed by ungulates, livestock, and birds (Table 2). Marmots were the most commonly identified prey species, followed by pika, woolly hare, blue sheep, yak, sheep, wild ass, argali, and goat (Table 2). Although local residents never observed bears preying on ungulates in the area, one resident did report a bear scavenging on an argali in the Damodar Kunda Valley.

**Table 2.** Relative occurrence (%) of hairs in brown bear scats ( $n = 56$ ) sampled in the upper Mustang region, Nepal, 2009–2011. We grouped feathers and identified hair from prey species using microscopic analysis.

Food items	Number of hair/feather samples	Frequency of occurrence (%)
------------	--------------------------------	-----------------------------

---

Small mammals		
Himalayan marmot	441	46.3
Royle's pika	180	18.9
Himalayan woolly hare	90	9.4
Category total	711	74.6
Ungulates		
Blue sheep	79	8.3
Wild ass	36	3.8
A argali	22	2.3
Category total	137	14.4
Livestock		
Yak	44	4.6
Sheep	40	4.2
Goat	9	1.0
Category total	93	9.8
Birds	12	1.2
Total	953	

---

### *Brown bear depredations*

From interviews, we documented only 6 livestock depredations occurring during May–November, 2003–2010: 1 yak in Panga (2003; also reported in Chetri 2008), 1 yak in Ghami (2009), 1 yak (2008) and 1 goat (2009) in Dhalung, and 1 yak and 1 sheep in Damodar Kunda (2010). These depredations resulted in an estimated financial loss of approximately 86,000 Nepalese Rupees (USD = \$1,229): four yaks (80,000), one goat (3,000), and one sheep (3,000).

## Discussion

Reports from local residents and a lack of bear sign near villages indicate that bears do not frequent villages and rarely feed on livestock in the UMR. Instead, local residents reported that most of their losses were attributed to snow leopard predation in the mountains. However, we found that approximately 10% of hairs identified in scats were from livestock, suggesting that brown bears might feed on livestock more often than local residents reported. Similar to the Manasalu Conservation Area (Aryal et al. 2010), a continued increase in brown bear activity in the UMR could lead to increases in livestock depredations and other bear incidents (as defined in Hopkins et al. 2010).

Our dietary analyses suggest that brown bears are mainly carnivorous in the UMR because plants comprised only about 8% of the fecal material. Similar to Qinghai Province, China (Xu et al. 2006), brown bears primarily preyed on small mammals and likely scavenged on wild ungulates. Our results suggest that bears preferentially feed on marmots in Nepal (see also Aryal et al. 2010), whereas the preferred prey in China has been reported to be plateau pikas (*Ochotona curzoniae*; Smith and Foggin 1999, Xu et al. 2006, Worthy and Foggin 2008).

China has recently attempted to reduce grazing pressure by eradicating plateau pika from some areas (Miehe 1988, 1996). These programs may have had a negative effect on the reproduction and survival of brown bears in China (Smith and Foggin 1999, Xu et al. 2006). In addition to pika reductions, hunting and lethal control of marmots has increased in order to prevent the spread of bubonic plague on the Tibetan Plateau (Worthy and Foggin 2008).

We advocate future research efforts to confirm brown bear presence along the border of Nepal and China. We also recommend initiating regional brown bear research efforts that focus on estimating their occupancy and movements using both genetic hair-snare sampling and GPS data. In particular, it is important to conduct such research in Shey-Phoksundo National Park and

the unprotected land between this park and the ACA to determine if this land serves as a corridor to these protected areas.

## **Acknowledgments**

We thank the Department of National Parks, Wildlife Conservation and Ministry of Forest and Soil Conservation, and the National Trust for Nature Conservation for supporting our research. Thanks to K. Dutta Awasti, L. Gurung, S. Jnawali, S. Kohshima, R. Koirala, N. Lama, R. Lamsal, S. Sathyakumar, C. Schwartz, and H. Tripathi for support and encouragement. We are also grateful to The Institute of Forestry (Tribhuvan University, Pokhara, Nepal) for providing lab facilities and to our lab staff: B. Adhikari, F. Gurung, S. Gurung, and S. Paudel. Finally, a special thanks to the Rufford Small Grant Foundation (UK), Alteris (Netherlands), Keidanren Nature Conservation Fund (Japan), and Massey University Research Fund (New Zealand) for providing financial support.

## **Literature cited**

- ACAP. 2010. Annual Report upper Mustang Unit Conservation Office. Annapurna Conservation area, UCO, Lomanthang, Mustang, Nepal.
- Aryal, A., and B. Kreigenhofer. 2009. Summer diet composition of the Common Leopard *Panthera pardus* (Carnivora: Felidae) in Nepal. *Journal of Threatened Taxa* 1:562–566.
- Aryal A., S. Sathyakumar, and C. C. Schwartz. 2010. Current status of the brown bear in Manasalu Conservation Area Nepal. *Ursus* 21:109–114.
- Bahuguna, A., V. Sahajpal, S.P Goyal, S.K. Mukherjee, and V. Thakur. 2010. Species Identification from Guard Hair of Selected Indian Mammals; A Reference Guide. Wildlife Institute of India, Dehradun, India.
- Chetri, M. 2008. Brown bear (*Ursus arctos*) from upper Mustang. *Prakriti Newsletter/NTNC*. Jan-June 2008 Issue:19–22.

- Chetri, M., and C.R. Gurung. 2004. Vegetation Composition, species performance and its relationship among the livestock and wildlife in the grassland of upper Mustang, Nepal. Yak Production in Central Asian Highlands. In: Proceedings of the Fourth International Congress on Yak. 235–244.
- Galbreath, G. J., C. P. Groves, and L. P. Waits. 2007. Genetic resolution of composition and phylogenetic placement of the Isabeline bear. *Ursus* 18:129–131.
- Gurung, M. 2004. Brown bear observation in the Damodar Kunda Valley, Mustang District, Nepal. *International Bear News* 13:12–14.
- Harris, R. B. 2008. Wildlife conservation in China: Preserving the habitat of China's wild west. M.E. Sharpe, Armonk, New York, New York, USA.
- Hopkins III, J. B., S. Herrero, R. T. Shideler, K. A. Gunther, C. C. Schwartz, and S. T. Kalinowski. 2010. A proposed lexicon of terms and concepts for human-bear management in North America. *Ursus* 21:154–168.
- Jackson R. 1990. Threatened Wildlife, Crop and Livestock Depredation and Grazing in the Makalu-Barun Conservation area. Working Paper Series. Report No. 12. 105 pp.
- Miehe, G. 1988. Geocological reconnaissance in the alpine belt of southern Tibet. *GeoJournal* 17:635–648.
- Miehe, G. 1996. On the connexion of vegetation dynamics with climatic changes in High Asia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 120:5-24
- Mukherjee, S., S. P. Goyal, and R. Chellam. 1994. Standardization of scat analysis techniques for leopards (*Panthera pardus*) in Gir National Park, Western India. *Mammalia* 58:139–143.
- Sathyakumar, S. 2006. The status of brown bears in India. Understanding Asian bears to secure their future. Japan Bear Network, Ibaraki, Japan: 7–11.
- Schaller, G. B. 1998. Wildlife of the Tibetan Steppe. Chicago: University of

Chicago Press.

- Servheen, C. 1990. The status and conservation of the bears of the world. International Conference for Bear Research and Management, Monograph Series No.2.
- Sevheen, C., S. Herrero, and B. Peyton. 1999. Bears. Status survey and conservation action plan. Bears. IUCN/SSC Bear and Polar Bear Specialist Groups. IUCN, Gland, Switzerland and Cambridge, U.K.
- Smith, A. T., and J. M. Foggin. 1999. The Plateau Pika (*Ochotona curzoniae*) is a keystone species for biodiversity on the Tibetan plateau. *Animal Conservation* 2:235–240.
- Swenson, J. E., A. Jansson, R. Riig, and F. Sandegren. 1999. Bears and ants: Myrmecophagy by brown bears in central Scandinavia. *Canadian Journal of Zoology* 77:551-561.
- Worthy, F. R., and J. M. Foggin. 2008. Conflicts between local villagers and Tibetan brown bears threaten conservation of bears in a remote region of the Tibetan plateau. *Human-Wildlife Conflicts* 2:200–205.
- Xu, A., Z. G. Jiang, Li, C.W., Guo, J.X., Wu, G.S., and Cai, P. 2006. Summer food habits of brown bears in Kekexili Nature Reserve, Qinghai–Tibetan plateau, China. *Ursus* 17:132–137.

## **Paper III: Conservation strategy for brown bear and its habitat in Nepal**

### **Abstract**

The Himalaya region of Nepal encompasses significant habitats for several endangered species, among them the brown bear (*Ursus arctos pruinosus*). However, owing to the remoteness of the region and a dearth of research, knowledge on the conservation status, habitat and population size of this species is lacking. Our aim in this paper is to report a habitat survey designed to assess the distribution and habitat characteristics of the brown bear in the Nepalese Himalaya, and to summarise a conservation action plan for the species devised at a pair of recent workshops held in Nepal. Results of our survey showed that brown bear were potentially distributed between 3800m and 5500m in the high mountainous region of Nepal, across an area of 4037 km<sup>2</sup> between the eastern border of Shey Phoksundo National Park (SPNP) and the Manasalu Conservation Area (MCA). Of that area, 2066 km<sup>2</sup> lies inside the protected area (350 km<sup>2</sup> in the MCA; 1716 km<sup>2</sup> in the Annapurna Conservation Area) and 48% (1917 km<sup>2</sup>) lies outside the protected area in Dolpa district. Furthermore, 37% of brown bear habitat also forms potential habitat for blue sheep (or bharal, *Pseudois nayaur*), and 17% of these habitats are used by livestock, suggesting significant potential for resource competition. Several plant species continue to be uprooted by local people for fuel wood. Based on the results of our field survey combined with consultation with local communities and scientists, we propose that government and non-government organizations should implement a three-stage program of conservation activities for brown bear. This program should: (a) detail research activities in and outside the protected area of Nepal; (b) support livelihood and conservation

awareness at local and national levels; and (c) strengthen local capacity and reduce human-wildlife conflict in the region.

**Keywords:** brown bear; Nepal; Annapurna; habitat overlap; livestock; blue sheep

## **Introduction**

The extreme variation in elevation in Nepal provides habitat for three species of bear. Sloth bears (*Melursus ursinus*) inhabit the southern lowlands (Terai; <1500 m); Asiatic black bears (*Ursus thibetanus*) live in the Middle Hills region up to the tree line (1500–3500 m); and Tibetan brown bears (*Ursus arctos pruinosus*) (Aryal et al. 2010a, Aryal 2011, Aryal et al. 2012,), which represent the most widely distributed *Ursid* in the world (Servheen 1999), occur in the Northern Mountain region of Nepal (Servheen 1999, Chetri and Gurung 2004, Chetri 2008, Aryal et al. 2010a, Aryal 2011, Aryal et al. 2012).

The brown bear population reported in the higher Himalayan protected area of Nepal, that is, in the Annapurna Conservation Area (ACA) and Manasalu Conservation Area (MCA), share habitat with other types of prey and predators of the region (Chetri and Gurung 2004, Chetri 2008, Aryal et al. 2010a, Aryal 2011, Aryal et al. 2012). These include blue sheep, or Bharal (*Pseudois nayaur*), which is the major wild prey species, and consequently also their predators such as snow leopard (*Panthera uncia*). Additionally, livestock farming is the predominant human activity in the region, and most of the available pasture land is used for livestock grazing (Chetri 2008, Aryal et al. 2010a & b, Aryal et al. 2011, Aryal et al. 2012). The coexistence between wildlife and agricultural practices has the potential for conflict. Brown bears are known to predate livestock in the region; it has been estimated that in the ACA 10% of the brown bears' diet comes from livestock (Aryal et al 2010a). Local people do not frequently encounter brown bears, and consequently associate livestock losses with other predators such as the snow leopard.

Nonetheless, livestock depredation may lead to retaliatory killings and consequently a negative impact on conservation of the predatory species in the area (Aryal et al. 2010a).

The first aim in this study is to assess the extent of brown bear habitat in Nepal. The composition of the vegetation is a major factor defining the suitability of habitat for wild herbivore and livestock populations (Chetri 2008, Aryal et al. 2010b), and yet there is limited information on the vegetation composition of the habitat that the brown bear shares with blue sheep and livestock in the upper Mustang region. An understanding of the resource base shared by these species is important for the preparation of a management plan to ensure the long-term sustainability of the native fauna and minimize conflicts between wildlife and agricultural practices on which the local communities are dependent. The second aim of the present study is to examine habitat use by brown bear and its overlap with the blue sheep and livestock in relation to vegetation composition in the upper Mustang region.

The government of Nepal has given legal protection to brown bear under the National Park and Wildlife Act (NPWA) 1973. Brown bear research and conservation activities were initiated in Nepal in 2004 (Chetri and Gurung 2004, Chetri 2008, Aryal et al. 2010a & b, Aryal 2011, Aryal et al. 2012). This included a survey for the presence of the brown bear in ACA, and in 2010 Aryal et al. (2010a) confirmed the presence of brown bears in the MCA. Since that time, continued research and conservation has been conducted in the ACA. In January 2010, the first brown bear conservation action plan preparation workshop was organized with the involvement of local people, relevant government agencies, non-government organizations (NGOs), international non-governmental organizations (INGOs), and local and international bear scientists (Aryal et al. 2010c). Following those activities, a draft brown bear conservation action plan was prepared and discussed at a second national level workshop in March 2011.

The third aim of this paper is to explore the workshop findings and outline the core components of a plan for bear research and conservation in Nepal. The plan highlights the major activities

proposed by local people, scientists and the field-based investigation for brown bear conservation in Nepal. It is anticipated that a conservation strategy that focuses on a top predator, the brown bear, will not only help to ensure stable coexistence between this species and its competitors, including livestock, but also produce an umbrella effect for the conservation of other wild species and livestock in the region.

## **Method and Materials**

### Study area

Nepal (147,181 km<sup>2</sup>) is located in south-Asia on the southern slopes of the central-Himalayan Range (Fig. 1 and 2). The average length of Nepal is 885 km, and the width varies from 145–241 km. Mountains cover ~86% of the total land area, while the remaining 14% is comprised of the Terai flatlands (60–300 m above sea level). Nepal contains eight of the ten highest mountains in the world, the tallest being Sagarmatha (Mount Everest; 8,848 m) (NBS/Nepal, 2002).

In addition to Nepal's legendary Himalayan Range, the country is a hotspot for biodiversity. Species richness in Nepal is a product of its geographic position as well as its diverse altitudinal and climatic gradients. Nepal contains ~4.3 million ha (29%) of forest, 1.6 million ha (10.6%) of scrubland and degraded forest, 1.7 million ha (12%) of grassland, 3.0 million ha (21%) of farmland, and about 1.0 million ha (7%) of uncultivated lands outside Nepal's protected areas (NBS/Nepal 2002). Within Nepal there are 10 national parks, three wildlife reserves, one hunting reserve, six conservation areas, and 11 buffer zones covering 34,187 km<sup>2</sup> (23.23%) (DNPWC 2011).

Our field study was conducted in the upper Mustang region of ACA in Nepal (Fig. 1). The northern part of this area borders the Tibetan region of China and has very low annual rainfall (<200 mm). Animal husbandry is the main income source of the local people of the region (Chetri 2004). The upper Mustang region consists of seven village development committees

(VDCs), with a human population of <15000 (NBS/Nepal 2002). We performed a habitat survey during September-October 2010, in the pasture land of the upper Mustang VDCs (Lomangthang, Chhoser, Chhunup, Surkhang) and its border regions in ACA and Dolpa district (Figure 2). We used brown bear distribution data from the MCA from our earlier study (Aryal et al. 2010a) and these data were also used for modelling the brown bear distribution in the area.



**Figure 1.** Location of the study area within Nepal.

## Methods

### *Potential Brown Bear Habitat in Nepal*

We prepared potential brown bear distribution habitat map using past records of brown bear presence (Sevheen 1999, Chetri 2008, Aryal et al. 2010a, Aryal 2011, Aryal et al. 2012) and information about the habitat based on the present study in ACA and the border regions of ACA and the Dolpa district. To determine the distribution of potential habitat for brown bears within the ACA, the MCA (Aryal et al. 2010a), and the corridors between the ACA and Shey Phoksundo National Park (SPNP), habitat features were quantified in locations where brown bear presence was directly confirmed. Arc GIS 9.3 (version 9.3, ESRI Inc., Redlands, California, USA) software was used to prepare maps and modelling. The features we included in the model were elevation, slope, aspect, and vegetation types. We used habitat layers (elevation, land use-ecology and settlement) that were freely available from <http://geoportal.icimod.org>. A 20 meter contour interval layer was used to make a digital elevation model (DEM) of the bear distribution area, and 3D analysis was used to further reclassify the DEM at 500 meter elevation intervals. Aspect and slope were also computed from 3D analysis. This was then converted to a shape file for area calculation and analysis.

Additionally, we used information derived from two national level workshops on a conservation action plan for brown bear that were conducted in Nepal. At the workshops, the participants (scientists, conservation officials, field personnel and representatives of local communities) pooled information to generate an understanding of the features of brown bear habitat. On this basis, together with information on direct signs of brown bear (sightings, scats etc.), maps of brown bear distributions were prepared during the workshop sessions. These were subsequently

loaded and geo-referenced in the GIS vectors layers to refine our distribution model of brown bear in the region.

### *Brown Bear Habitat Survey*

A vegetation survey was conducted in the confirmed brown bear habitat of the upper Mustang region in 2010-2011. Vegetation was sampled using ‘animal use plots’ where bear signs were encountered (digging sites, footprints, hair, scats). Plot sizes were 4 m x 4 m for estimating species composition and coverage of woody shrubs (woody plants <3 m height), and 1 m×1 m for estimating species composition and coverage of herbs (plants ≤1m height). Additionally, parameters such as aspect, slope, elevation, vegetation, anthropogenic activities, and the presence of blue sheep and livestock, as well as the presence/absence of uprooted plants for fuel wood were recorded during the survey.

Based on the frequency and abundance of herbs and shrubs, an Importance Value Index (IVI) (*equation 1*) of vegetation for brown bear habitat was calculated (Aryal et al. 201b). The IVI is ranging from 0 to 300, the highest value of vegetation represents more important than the lowest value.

$$IVI = RF+RD+RC \quad (1)$$

Where: *frequency (F)* = number of plots with the individual species × 100/total number of plots; *relative frequency (RF)* = frequency of any one species ×100/total frequency of all species; *density (D)* = total number of species in all plots/total number of plots× area of plots; *relative density (RD)* = density of a species ×100/total density of all species; and *relative coverage (RC)* = coverage of a species × 100/total coverage.

### *Habitat Overlap among Brown Bear, Livestock, and Blue Sheep*

The overlap of habitat among brown bears, livestock and blue sheep was determined using methods developed by Real (1999) and Real and Vargas (1996). Once signs of brown bears

(scat, tracks, or dig sites) were encountered, the site was sampled (plots = 90; size 50 m x 50 m) and an additional sample plot (50 m x 50 m) located 200 meters in a random direction was used as a matched pair plot. Both the primary and matched pair plots (n=90) were searched for signs of blue sheep, livestock and brown bear. Habitat overlap between brown bear (A) and blue sheep or livestock (B) was calculated separately using Jaccard's similarity index ( $J$ ) (equation 2) from presence/absence data recorded from these plots (Peter and Darling 1985, Real and Vergajs 1996, Aryal et al. 2010b). The associated probability for  $J$  was calculated to determine if the value for the index (ranging from 0 to 1) differed from what would be expected at random (Real 1999, DNPWC 2011) as

$$J = C / (A + B - C) \quad (2)$$

where  $C$  is the number of plots used by both brown bear and blue sheep or livestock. In this case, the probabilities associated with Jaccard's index depend on the total number of attributes present in either of the two habitats compared ( $N$ ) (equation 3).  $N$  was calculated as:

$$N = (A + B) / (1 + J) \quad (3)$$

Finally, the percentage of area overlap by blue sheep and livestock with brown bear occurrence was calculated as:

$$\text{Habitat overlap with blue sheep} = \Sigma nb / TA \quad (4)$$

$$\text{Habitat overlap with livestock} = \Sigma nl / TA \quad (5)$$

Here:  $nb$  is the plot area in which blue sheep signs were recorded;  $TA$  is total sample plot area (i.e. including presence and absence); and  $nl$  is the plot area with livestock signs.

*Brown Bear Conservation Workshops*

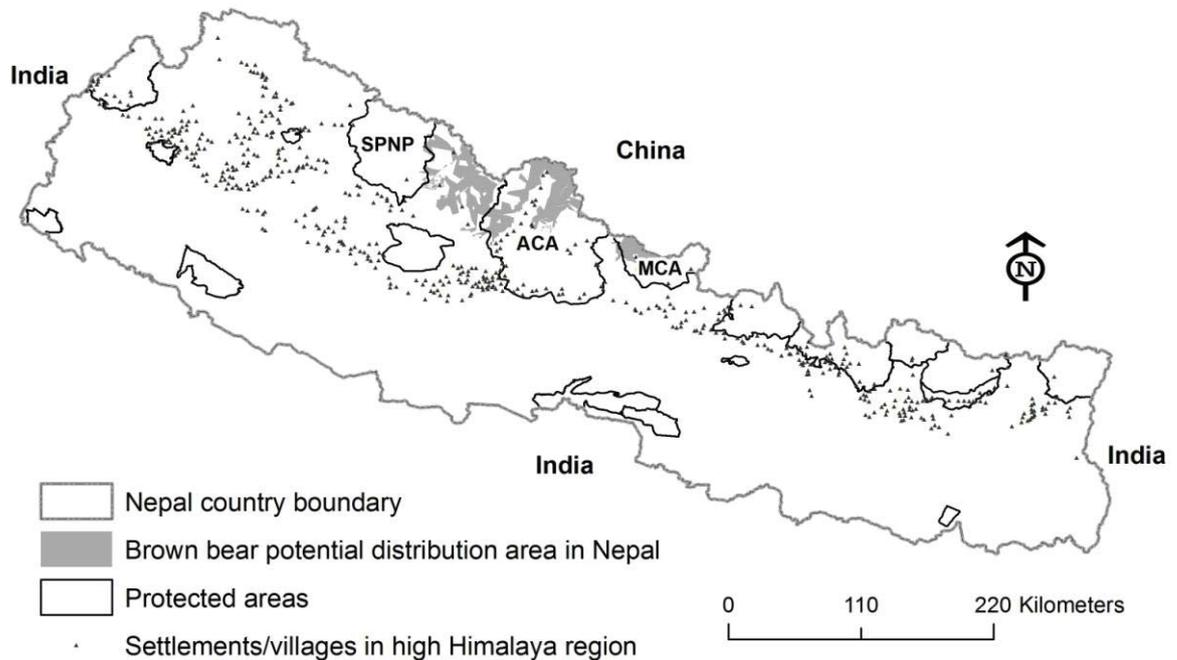
Nepal's first systematic brown bear study was conducted in 2008 (Aryal et al. 2010a), and the first national brown bear conservation participatory action plan workshop was conducted in January 2010 (Aryal et al. 2010c). The second workshop took place on 9 March 2011 at the Annapurna Conservation Area Project (ACAP) offices, Pokhara, in collaboration with the ACAP, the Department of National Park and Wildlife Conservation (NPWC), Department of Forest and the Ministry of Forest and Soil Conservation/Government of Nepal. The main aim of this workshop was to review feedback, comments and suggestions for finalizing the draft brown bear conservation action plan. The workshop was conducted in a participatory way with the active involvement of 63 participants from government, NGOs, local leaders, and the Institute of Forestry, Tribhuvan University, Pokhara. In the workshop the proposed brown bear conservation activities in Nepal were presented and each plan was discussed with the participants and their suggestions for improvements were noted. Additionally, priorities for research into brown bear conservation in Nepal were discussed. We report in the present paper the main outputs and major findings from the discussion and feedback sessions that were included in the emerging brown bear conservation plan.

## **Results**

### ***Brown Bear Distribution in Nepal***

A total of 286 GPS locations with brown bear sign were used to prepare a brown bear distribution map encompassing the MCA, ACA and the corridor between SPNP and the ACA. Brown bears were confirmed in a 4037 km<sup>2</sup> area between the SPNP and the MCA in Nepal; of this, 2066 km<sup>2</sup> lies inside the protected area (350 km<sup>2</sup> in MCA; 1716 km<sup>2</sup> in ACA) and the remaining 48% (1917 km<sup>2</sup>) lies outside the protected area (in the Dolpa district) (Figure 2). The sightings spanned an altitude range of 3800m to 5500m. The corridor between the eastern border

of SPNP and the Annapurna Conservation Area was the most important region for brown bear distribution outside of the protected area of Nepal.



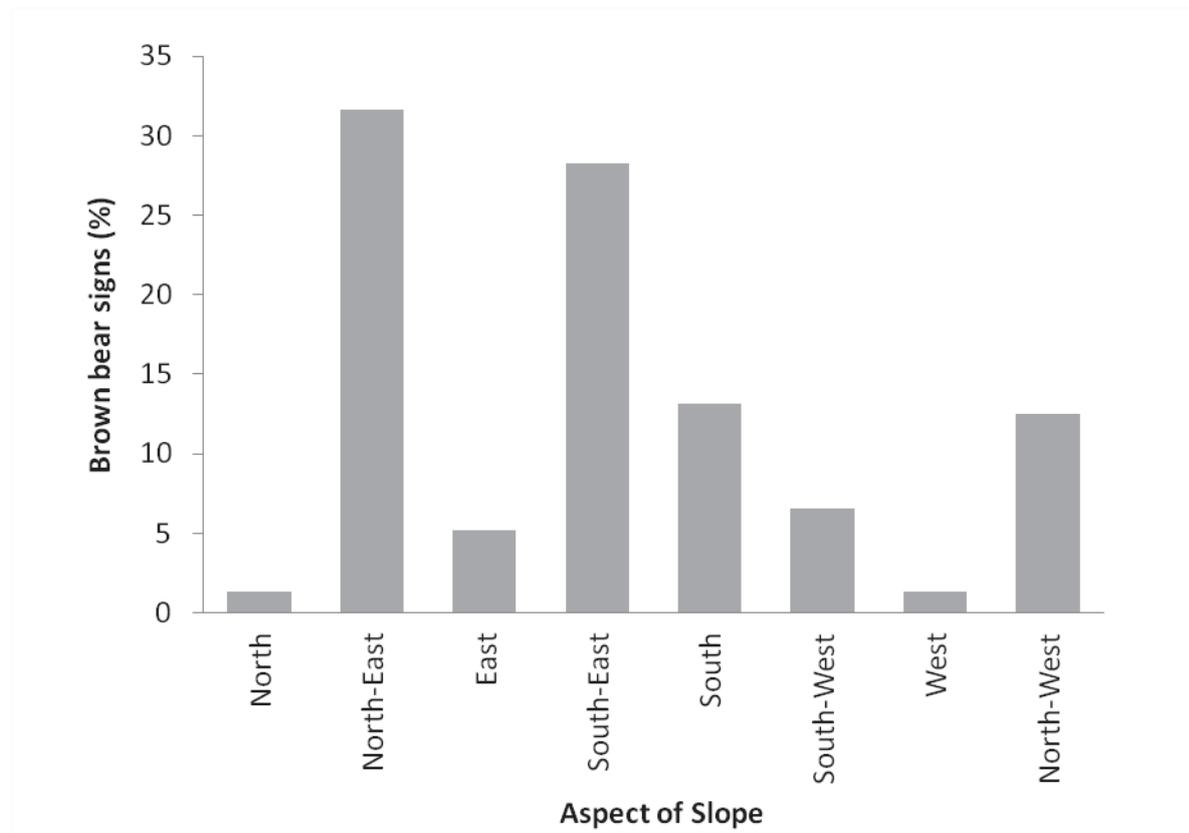
**Figure 2.** Potential brown bear distribution between the eastern border of Shey Phoksundo National Park (SPNP) and the Manasalu Conservation Area (MCA) predicted by our model.

#### *Habitat Use by Brown Bears in Upper Mustang*

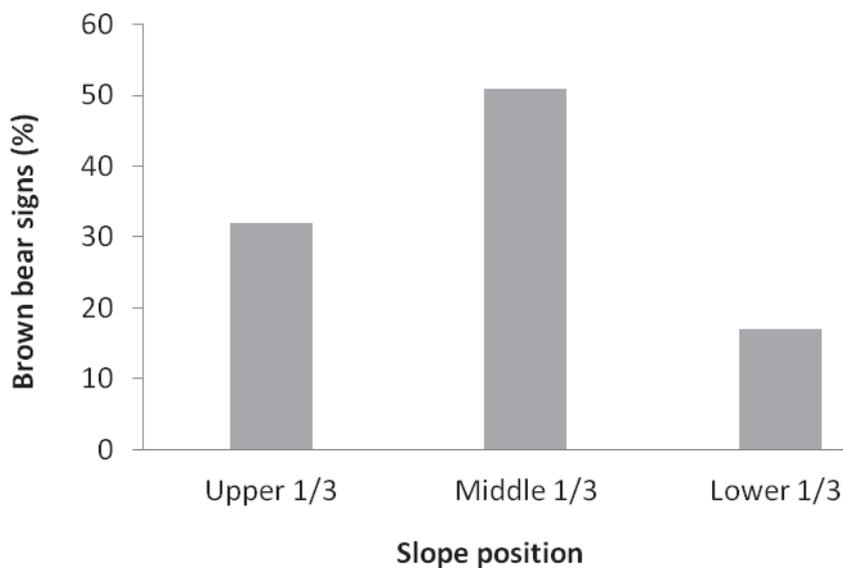
In the ACA, brown bears were distributed in Chhoser, Chhunup, Surkhang, Ghami, and Lomangthang VDC of upper Mustang. A total of 180 plots were laid out in brown bear habitat. Brown bears mostly used North-East (36.8%) and South-East (28.9%) aspects and were found less often on Northern and Western aspects ( $\chi^2 = 1.71, P = 0.055$ , Fig.3A).

Slope positions were divided into three categories, namely the lower 1/3, middle 1/3 and upper 1/3 of the elevation between rivers and ridges. Brown bears primarily used the middle 1/3 slope (51%), followed by the upper 1/3 and lower 1/3 slopes ( $\chi^2 = 2.9, P = 0.014$ ) (Fig. 3B). In terms

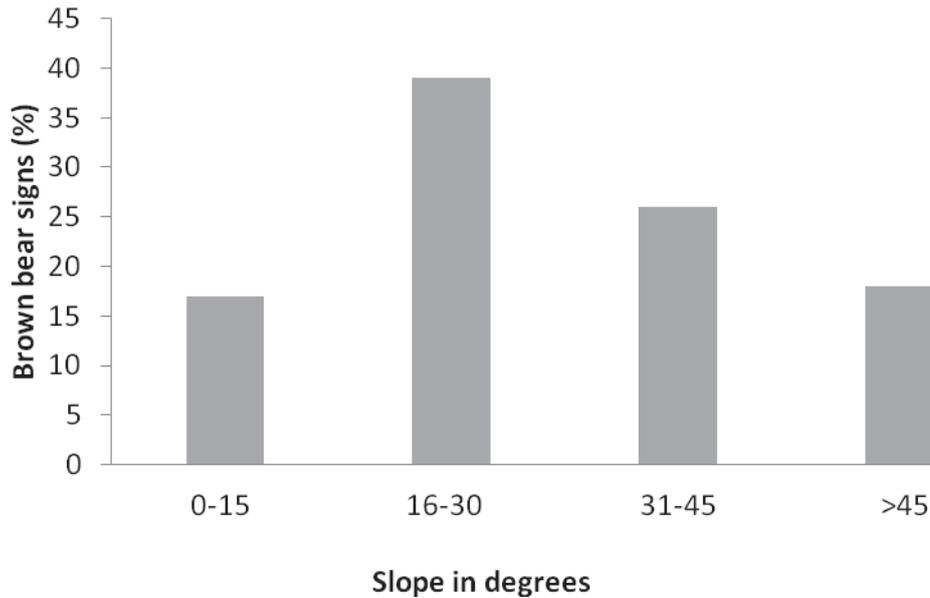
of gradient, slopes of 16-30 degree were preferred (39%), followed by 31-45 degrees and >45 degree, with slopes of 0-15 degrees being used the least ( $\chi^2 = 1.1, P = 0.008$ ) (Fig. 3C).



(A)



(B)



(C)

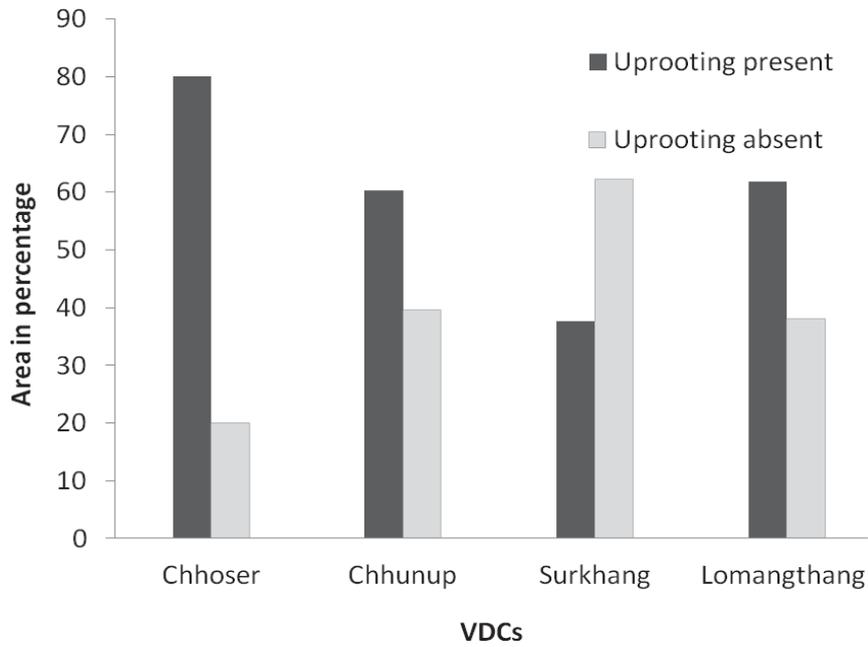
**Figure 3.** Habitat use by brown bears A) Aspect B) Position on slope relative to river and ridge. C). Gradient of slope.

#### *Vegetation in Brown Bear Habitat in Upper Mustang*

The upper Mustang rangeland provides prime habitat for endangered wildlife, and the rangeland resources support healthy populations of brown bears, blue sheep, livestock as well as other wildlife. The plant species with the highest Importance Value Index scores in the brown bear habitat are *Kobresia pygmaea* ( $IVI = 59.3$ ) followed by *Caragana* spp ( $IVI = 26.2$ ), *Carex* spp ( $IVI=25.32$ ), and *Saxifraga* spp ( $IVI = 25.2$ ). Brown bears mostly used habitat containing *Kobresia pygmaea*, *Carex* spp, *Saxifraga* spp, and *Potentilla* spp (Table 2). Uprooting by humans of shrubs and hardwood-root plant species was found in most of the brown bear habitat. Plant uprooting practices were observed in all VDCs of the upper Mustang region, with a maximum occurring in Chhoser VDC (in 80% of the area) followed by Lomangthang VDC (79%), Chhunup (59%) and Surkhang VDC (37%) (Fig. 4).

**Table 2.** Vegetation use in brown bear habitat. Relative Frequency (RF), Relative Density (RD), Relative Cover (RC), and Importance Value Index (IVI) of vegetation.

<b>Species</b>	<b>RF</b>	<b>RD</b>	<b>RC</b>	<b>IVI</b>
<i>Anaphalis</i> spp.	4.2	8.3	7.4	20
<i>Anaphalis triplinervis</i>	3.2	1.3	0.4	4.9
<i>Androsace</i> spp.	7.0	1.7	1.87	10.5
<i>Artemisia</i> spp.	5.1	4.7	4.1	13.9
<i>Bistorta</i> spp.	3.3	2.0	0.98	6.3
<i>Carex</i> spp.	7.3	6.6	11.4	25.3
<i>Cortia depressa</i>	2.1	3.1	0.4	5.7
<i>Chesneya nubigena</i>	5.6	6.0	2.1	13.7
<i>Euphorbia estachyei</i>	5.8	3.3	2.4	11.5
<i>Caragana</i> spp.	8.1	6.8	11.3	26.2
<i>Corydalis govaniiana</i>	1.5	3.1	1.0	5.6
<i>Clematis</i> sp.	0.9	1.6	1.0	3.5
<i>Kobresia pygmaea</i>	13.6	16.1	29.6	59.3
<i>Lancea tibetica</i>	4.2	6.1	3.6	13.9
<i>Lonicera</i> spp.	3.1	4.1	5.3	12.5
<i>Oxytropis</i> spp	3.6	5.1	1.7	10.4
<i>Pedicularis</i> spp.	1.4	3.0	1.9	6.4
<i>Poa</i> spp.	3.1	5.2	1.3	9.6
<i>Potentilla</i> spp.	5.2	2.0	2.0	9.2
<i>Saussurea nepalensis</i>	2.4	3.1	1.0	6.5
<i>Saxifraga</i> spp.	9.2	6.8	9.2	25.2



**Figure 4.** Percentage of area in which uprooting of plants by local people was observed in the brown bear habitat of the upper Mustang region

#### *Habitat Overlap with Blue Sheep and Domestic Livestock*

Brown bear sign was found in 62 of the 180 plots sampled, livestock sign in 29, and blue sheep sign in 43. Both brown bear and blue sheep sign was found in 28 plots, and brown bear and livestock in 18. Statistical analysis of these data showed that there was significant habitat overlap between brown bear and blue sheep (37% overlap,  $J = 0.19$ ,  $P = 0.01$ ), as well as between brown bear and livestock (17% overlap,  $J = 0.17$   $P = 0.01$ ).

#### *Brown Bear Conservation Strategy and Action Plan*

The main achievement of the second round of the brown bear conservation workshop (9 March 2011, Figure 5) was to combine shared information with results of our field surveys to finalize a draft brown bear conservation action plan (see below). However, the Nepalese government has

deferred its implementation until it is expanded to also include the other two bear species in Nepal (sloth bears and black bears). In what follows, we summarize the main components of the proposed brown bear action conservation plan.

#### *Brown Bear Research and Studies throughout Nepal*

There is little knowledge about the population trends, habitat, threats and problems associated with the brown bear, and there is inadequate research and monitoring of the food, population and habitat of this species. Moreover, the human, technical and financial resources are inadequate for the long-term conservation and management of the brown bear in Nepal. This issue should be addressed by further research and studies throughout the bear's habitat in the country.

#### *Habitat Monitoring and the Need for Habitat Restoration*

It is believed that brown bears are vulnerable to anthropogenic threats, which limit the viability of the population and preclude its expansion. Furthermore, its habitat range is not fully known and the extent and quality of the brown bear population is unknown. Due to increasing populations of humans and livestock, habitat is believed to be disturbed, fragmented and shrinking. Some pastures have been degraded by heavy livestock grazing. Apart from over-grazing, there is over-exploitation of natural vegetation for fuel and for medicinal and aromatic plants (MAPs). In general, there is a lack of a habitat evaluation programs and a lack monitoring and management strategies, for example delineating different utilization zones. Additionally, there is very little information on the existing and potential biological corridors for brown bear in the area. Potential corridors are increasingly vulnerable to habitat degradation and poaching, and there is an urgent need for the monitoring, protection and where necessary restoration of these corridors.

### *A need for Anti-Poaching Operations*

Poaching poses a significant threat to all wildlife in Nepal including the brown bear. Although reported cases of poaching of brown bears are fewer than for other species, their killing for the harvesting of bile has been reported from several parts of the country. Due to Nepal's porous border and limited law enforcement, many threatened species are poached and illegally traded. Further, due to a low level of security people are often hesitant to cooperate with law enforcement agencies in controlling poaching and illegal trade. Local communities are not equipped with adequate field equipment and facilities, and the poor economic condition of the local people is also associated with poaching and illegal trade. Anti-poaching operations are urgently needed.

### *Reduction in Human-Brown Bear Conflict*

Human-brown bear conflict is identified as one of the major problems in ensuring the long-term conservation of brown bear in Tibet/China, and some level of conflict has been noted in the MCA and ACA region. Although not frequent, livestock loss has been associated with brown bears providing the potential for conflict. On the other hand, local people have reported that the Himalayan marmot (*Marmota himalayana*), which is a prey species for brown bear, is causing crop damage in farmlands, and therefore brown bear conservation might reduce human-wildlife conflict in the region. Wildlife damage relief guidelines have been approved by the Nepalese government, but as yet they have not been implemented in the field in these regions.

Conservation awareness activities are lacking in the remote parts of the brown bear's distribution range, and there is a need to encourage traditional Buddhist beliefs in conservation in the area. Further, the people are not aware on the methods and techniques that can be used for the reduction of loss/damage. The damage caused by the brown bear and associated species to

human livelihoods has meant that in general the local people have a negative attitude towards wildlife conservation.

In summary, human-wildlife conflict in the area could be mitigated by the establishment of a livestock insurance program, developing awareness among local people of the need for conserving wildlife such as the brown bear, the introduction of incentive programs and involving local people in alternative income generation activities that do not present the potential for human-wildlife conflict.

### *Strengthening of Local Capacity*

The capacity of the local Conservation Area Management Committee (CAMC) and responsible agencies and local authorities outside the protected areas should be build up to formulate and implement the brown bear conservation activities. The CAMC is a local legal institutional body formed by the ACAP and MCAP under the Protected Area Management Act and is responsible for implementing conservation, social, educational and economic development activities at the local level. The CAMC needs to regularly monitor the brown bear habitat using patrols and by conducting different programs and activities for brown bear conservation in their area. The CAMC should coordinate with different stakeholders for the conservation of the brown bear with the help of the DNPWC (Department of National Park and Wildlife Conservation), the ACAP (Annapurna Conservation Area Project), the MCAP (Manasalu Conservation Area Project) and the government of Nepal. Activities which help to strengthen the capacity of local people will reduce the pressure on the brown bear habitat. For example, formal or informal training in activities such as nature guiding, cooking and baking and handicraft should be provided for the local people. Most important, training in institutional capacity building (e.g. administration and financial management) should be provided for committee members. Similarly current existing local conservation committees and youth clubs should be empowered and their capacity for conservation of brown bear outside the protected area strengthened.

### *Support for Local People to improve their Livelihoods*

Without an improvement in the livelihoods of the local people, it is hard to conserve Nepal's natural resources such as the brown bear, the snow leopard and other wildlife. For this reason, species conservation needs a livelihood improvement program. Sources of incomes for local people in the area are livestock (sheep/goat/yak) farming, agriculture, collecting medicinal plants for sale, and tourism. Local people are directly dependent on resources such as fuel wood for their livelihood. Hunger and poor economic status have encouraged people to become involved in illegal activities, such as brown bear poaching.

In some parts of this landscape, there is a large open area near the villages. The CAMC could plant indigenous plants such as apples in that area and the *Populus* tree (for timber and fuel) in the upper Mustang and Samdo regions. Apple plantations are one of the main income sources of the local people. Creating employment opportunities for those people who have a poor economic situation will be helpful in promoting sustainable livelihoods.

Non-Timber Forest Products (NTFPs)/medicinal plant cultivation on farmland or forest land or community land is one the most lucrative potential income-generation activities because the area has a unique ecological character and favours high value medicinal plants.

Important priorities of local people are the raising of sheep/yak. Sheep/yak keeping was found to be very popular in the area because the animals are easy to raise using traditional practice, and they are the main source of meat and milk in the area. Nevertheless, livelihood conditions remain quite precarious in the upper Himalaya region. Food deficiency is the norm rather than the exception in many households. This is aggravated by the paucity of agricultural land and its skewed distribution, the lack of sustainable management of rangeland resources, and the low productivity of traditional agriculture due to inadequate inputs. Traditional knowledge and expertise related to medicinal and aromatic plants remains for the most part unutilised in enhancing resource productivity. Such knowledge and expertise can easily be forgotten by the

community if it is not brought into economic use. Changes in local eating habits, the demand created by tourism and the likely rise in demand due to road construction in the future indicates that there are considerable prospects for the production of green vegetables and fruits in the area. Concerted efforts are required to realise these potential developments.

Off-farm employment and income opportunities in the Himalaya region are scarce. Local resources and traditional skills based on enterprise potentials have not been adequately identified and assessed. Potential exists in handicraft production, in livestock based production and in the area of traditional skills that need to be explored and promoted. Seasonal migration has evolved as a survival strategy for the upper Mustang population.



(A)



(B)

**Figure 5.** Conservation Action Plan Workshop (Pokhara, Nepal) participants. (A) 9 March 2011 workshop (B) 21-24 January 2010.

### **Discussion**

Brown bear research in Nepal started after 2004 and confirmed the presence of the brown bear in the ACA, the MCA and in the corridor between SPNP and the ACA (Chetri and Gurung 2004, Aryal 2011, Aryal et al. 2012). The present study extends this research, providing an estimate of the potential brown bear habitat and distribution within the area. Our research found that an area of  $\sim 4000 \text{ km}^2$  is predicted to be suitable habitat for brown bear, of which approximately 48% falls outside of the protected area. This has meant that it is excluded from research and conservation activities for not only the brown bear, but also for other mammal species in that region. It is important that presence/absence surveys be conducted in these regions, and effective conservation activities should be implemented.

Top priority should be given to brown bear research and conservation in the corridor between the SPNP and the ACA, and these activities should be extended in the western and eastern parts of country. Furthermore, specific conservation and research activities should also be included in each protected area. Habitat modeling in the present study has shown that there is a potential

connecting corridor between ACA and SPNP (Fig. 1), but the current threats of climate change, habitat fragmentation, and human disturbance and settlement have created obstacles to the movement of animals through these landscapes. Changing climate appears to result in animal ranges shifting to different elevations and the disappearance of habitat for some species (Peter and Darling 1985). Perhaps significantly, local people living in the mid hill regions of Samma village of Gorkha district have reported the appearance of Asiatic black bears at elevations higher than they usually occur. Ecological connectivity is a good strategy for reducing the negative effects of climate change on biological diversity (Heller and Zavaleta 2009, Krosby et al. 2010) and will help the flow of animals and ecological processes across the landscape (Taylor 1993). Maintaining connectivity between protected areas should help brown bear populations to cope with changing climate patterns and help to maintain a viable population of brown bears in Nepal.

The uprooting of shrubs and the collection of dung are very common practices within the study area due to the absence of trees necessary to meet demands for fuel wood. *Caragana* spp, *Androsace sarmentosa*, *Lonicera* spp, and *Rosa* spp continue to be over-harvested for this purpose. In most cases the entire shrub is harvested, and the woody roots are stored on the roofs of houses to dry for winter use (Fig. 6). Such practices also exist in the Himalayan region of India (Uniyal 2009). There is no alternative fuel wood available, with the exception of a few private plantations the upper Mustang region. The uncontrolled collection of wild plants for fuel should gradually be banned, and alternative fuel wood sources should be provided for local people. Private fuel wood tree plantations could be promoted, as can the use of solar energy.



**Figure 6.** Transportation [(A) and (B)] and storage [(C) and (D)] of uprooted plants for winter fuel.

The Trans-Himalayan rangeland maintains a very low plant biomass, and there is substantial overlap in habitat and resource use by wild ungulates and livestock (Chundawat et al 1994, Mishra 2001, Bhatnagar et al. 2000, Bagchi et al. 2004, Mishra et al. 2004, Namgail et al 2007, Shrestha and Wegge 2008). The results of the present study give new insight into the extent of this habitat overlap between livestock, blue sheep and the omnivorous brown bear. Given the limited plant resources in this region (Chundawat et al 1994, Mishra 2001, Bhatnagar et al. 2000, Bagchi et al. 2004, Mishra et al. 2004, Namgail et al 2007, Shrestha and Wegge 2008), it is likely that there is substantial competition for available foods between the overlapping species. For this reason, in addition to the threat that brown bears pose to livestock and blue sheep pose to crops (Aryal et al. 2010a), this overlap should be taken into consideration in the preparation of species management and land use plans in the Trans-Himalaya region. Further detailed studies should be

conducted to understand the ecological interactions between the co-occurring wildlife species within the shared habitats.

In addition to resource availability, brown bear habitat selection is influenced by a suite of dynamic factors, including risk of predation and human disturbance (Darling 1987, McLellan 2001, McLoughlin et al. 2002, Sathyakumar and Qureshi 2003). In the present study we did not find any signs of brown bears closer than 5 km from villages and human settlements, most likely because of the combined effects of over-exploitation of resources and perceived threat from humans. Blue sheep and livestock generally use the middle slope positions for grazing, as do Himalayan marmots. Himalayan marmots also prefer areas with good food availability and high sun exposure (Sathyakumar and Qureshi 2003); these locations were also selected by the brown bear. Blue sheep used higher elevations than smaller livestock, but overlap extensively with yaks. Although the brown bears overlapped more with blue sheep than with domestic livestock, there was still a sharing of habitat, and this is likely to increase the conflict between brown bears and local people (by retaliatory killing) if this overlap causes bears to depredate livestock more frequently.

Brown bears are of high conservation value in Nepal, and in the present paper we have reported on an initial draft of an evidence-based recommendation for a conservation action plan for this species. However, more information is needed, particularly regarding the status and distribution of brown bears in far western regions of the country. We propose the implementation of a three-stage program of conservation activities for brown bear conservation in Nepal. This program should include: (a) detailed research activities in and outside the protected areas of Nepal; (b) support for local livelihood and conservation awareness; and (c) the strengthening of local capacity and a reduction in human-wildlife conflict, including poaching, in the region. However, it needs to be noted that within the brown bear distribution of the Himalayan region there is a

diversity of cultures, religions and economic status. For this reason, site-specific brown bear conservation research action plans should be prepared and implemented.

### **Acknowledgments**

We thank Annapurna Conservation Area Project and Ministry of Forest and Soil Conservation, Department of National Park and Wildlife Conservation for providing permission and support to conduct both the research and the workshop discussed in this paper. Thanks also to all the participants who were involved in the two workshops for their valuable comments and suggestions. For financial support, we are grateful to the Rufford Small Grant Foundation, UK; Alteris, Netherland; Keidanren Nature Conservation Fund (KNCF), Japan and British Ecological Society (BES, UK), and the Massey University Research Fund (New Zealand).

### **References**

- Aryal, A. 2011. Cultural and Religious Beliefs Pose Challenges for Bear Conservation in Nepal. *International Bear News* 20(1): 12-14.
- Aryal, A.; Hipkins, J.; Ji, W.; Raubenhimer, D.; Brunton, D. 2012. Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (2): 231-236
- Aryal, A.; Raubenheimer, D.; Subedi, S.; Kattel, B. 2010b. Spatial Habitat Overlap and Habitat Preference of Himalayan Musk deer *Moschus chrysogaster* in Sagarmatha (Mt. Everest) National Park, Nepal. *Current Research Journal of Biological Sciences* 2: 217-225.
- Aryal, A.; Sathyakumar, S.; Lama, N.; Chhetri, T.B. 2010. Community-based Conservation Action Planning for Brown Bear in Nepal. *International Bear News* 19(2):16-18.

- Aryal, A.; Sathyakumar, S.; Schwartz, CC. 2010a. Current status of the brown bear in Manasalu Conservation Area Nepal. *Ursus* 21: 109-114. doi: 10.2192/09GR029.1
- Bagchi, S.; Mishra, C.; Bhatnagar, Y.V. 2004. Conflicts between traditional pastoralism and conservation of Himalayan ibex (*Capra sibirica*) in the Trans-Himalayan Mountains. *Animal Conservation* 7: 121–128.
- Bhatnagar, Y.V.; Rawat, G.S.; Johnsingh, A.J.T.; Stuwe, M. 2000. Ecological separation between ibex and resident livestock in a Trans-Himalayan protected area. In: Grassland Ecology and Management in Protected Areas of Nepal. Ed. C. Richard, pp. 70–84. Kathmandu, Nepal: International Centre for Integrated Mountain Development.
- Chetri, M. 2008. Brown bear (*Ursus arctos*) from Upper Mustang. *Prakriti Newsletter/NTNC-Jan-June* Issue, 19-22.
- Chetri, M.; Gurung, C.R. 2004. Vegetation Composition, species performance and its relationship among livestock and wildlife in the grassland of Upper Mustang, Nepal. In: Jincheng, Z., Z.Xiangdong, H. Jianlin, & C. Zhihua, (Eds.), Yak Production in Central Asian Highlands, Proceeding of the Fourth International Congress on Yak. Sichuan Publishing Group, Sichuan Publication House of Science and Technology, pp. 235-244.
- Chundawat, R.S.; Rawat, G.S. 1994. Indian cold deserts: a status report on biodiversity. Wildlife Institute of India, Dehradun, Uttaranchal, India.
- Darling, L.M. 1987. Habitat use by grizzly bear family groups in interior Alaska. *International Conference on Bear Research and Management* 7:169-178.

- DNPWC.2011.Protected Area of Nepal. Department of National Park and Wildlife Conservation/Ministry of Forest and Soil Conservation, Kathmandu Nepal. Pp 52+ (Nepali version). <http://www.dnpwc.gov.np/publications/pustika>
- Gurung, M. 2004. Brown Bear Observation in the Damodar Kunda Valley, Mustang District, Nepal. *International Bear News* 13:12-14
- Heller, N.E.; Zavaleta, E. S. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation* 142: 14–32.
- Krosby, M.; Tewksbury, J.; Haddad, N.M.; Hoekstra, J. 2010. Ecological Connectivity for a Changing Climate. *Conservation Biology* 24 ( 6): 1686–1689.
- McLellan, B.N.; Hovey, F.W. 2001. Habitats selected by grizzly bears in a multiple use landscape. *Journal of Wildlife Management* 65: 92-99.
- McLoughlin, P.D.; Case, R.L.; Gau, R.J.; Cluff, H.D.; Mulders, R.; Messier, F. 2002. Hierarchical habitat selection by barren ground grizzly bears in the central Canadian Arctic. *Oecologia* 132: 102-108.
- Mishra, C. 2001. High altitude survival: conflicts between pastoralism and wildlife in the Trans-Himalaya. Ph.D. thesis, Wageningen University, the Netherlands.
- Mishra, C.; Wierenvan, S.E.; Ketner, P.; Heitkonig, M.A.; Prins, H.H.T. 2004. Competition between domestic livestock and wild bharal *Pseudois nayaur* in the Indian Trans-Himalaya. *Journal of Applied Ecology* 41: 344–354.
- Namgail, T.; Fox, J.L.; Bhatnagar, Y.V. 2007. Habitat shift and time budget of the Tibetan argali: the influence of livestock grazing. *Ecological Research* 22: 25–31.

- NBS/Nepal. 2002. Nepal Biodiversity Strategy (NBS), His Majesty's Government of Nepal, Supported by GEF and UNDP.
- Peters, R.L.; and Darling, J. D. S.1985. The greenhouse effect and nature reserves. *BioScience* 35: 707–717.
- Real, R. 1999. Tables of significant values of Jaccard's index of similarity. *Misc. Zoologica* 22(1): 29-40
- Real, R.; Vergajs, M. 1996. The probabilistic basis of Jaccard's index of similarity. *Systematic Biology* 45:380-385
- Sathyakumar S.; Qureshi, Q. 2003. Modelling Distribution pattern for brown bear in Zankar and Suru Valleys, Ladakh. Wildlife Institute of India, Dehradun, India.
- Servheen, C.; Herrero, S.; Peyton, B. 1999. Bears. Status survey and conservation action plan. Bears. IUCN/SSC Bear and Polar Bear Specialist Groups. IUCN, Gland, Switzerland and Cambridge, U.K.
- Shrestha, R.; Wegge, P. 2008. Wild sheep and livestock in Nepal Trans-Himalaya: coexistence or competition? *Environmental Conservation* 35: 125–136.
- Taylor, P.D.; Fahrig, L.; Henein, K.; Merriam, G. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68:571–572
- Uniyal, S.K.; Awasthi, A.; Rawat, G.S. 2009. Biomass availability and forage quality of *Eurotia ceratoides* Mey in the rangends of Changthang eastern Ladakh. *Current Sciences* 89: 201-205



## Chapter Three

### Conservation and ecology of snow leopards and their main prey species (blue sheep)

#### Summary

The Himalayan region of Nepal provides a habitat for the endangered snow leopard (*Panthera uncia*) and its principal prey species, the blue sheep (*Pseudois nayaur*). This chapter has three objectives:

- 1) to describe the ecology of blue sheep in terms of their habitat, distribution, and population structure, and to estimate their contribution to the carrying capacity of snow leopards in the upper Mustang region of Nepal.
- 2) to estimate the abundance, habitat preferences, and diet profile of the snow leopard in the Annapurna Conservation Area (ACA), Nepal.
- 3) to assess the habitat in order to translocate blue sheep to the Mt. Everest region of Nepal where snow leopards have recently returned.

Three papers comprise this chapter. The first paper reports that the upper Mustang region has the lowest population density of blue sheep recorded within their distribution range in Nepal (0.86 blue sheep/km<sup>2</sup>). It is estimated that the existing blue sheep population biomass of approximately 38,925 kg in the upper Mustang region could support approximately 19 snow leopards; equivalent to 1.6 snow leopards per 100 km<sup>2</sup> (Paper I below). The second paper included in this chapter presents non-invasive genetic analysis of snow leopard scats. The analysis confirmed five different individuals with the estimated home ranges spanning 89.4 km<sup>2</sup> for males and 59.3 km<sup>2</sup> for females. A total of 21-30 snow leopards (1.3-1.9 individuals/100

km<sup>2</sup>) are estimated in the upper Mustang region of ACA. Microhistological analysis of scats (n=248) revealed that blue sheep (*Pseudois nayaur*) is the primary wild prey of snow leopards, constituting 63% of its diet. Livestock also makes up 18% of the snow leopard's diet (Paper II below).

The final component of this chapter discusses the possibility of a blue sheep translocation in the Mt. Everest region to maintain a viable population of snow leopards and to reduce the human-snow leopard conflict in the region. The paper documents potential blue sheep distribution areas throughout its distribution range, and confirms that overall Sagarmatha (Mt. Everest) National Park is similar to Kanchanjunga Conservation Area (Bray Curtis Similarity Coefficient 'S' > 72%) in terms of vegetation, elevation, precipitation, soil, aspect, and slope. Therefore, a translocation of blue sheep from Kanchanjunga Conservation Area to Sagarmatha (Mt. Everest) National Park is recommended to meet the conservation aim of supporting the population of snow leopards and other predators in the park (Paper III below).

*This chapter contains three papers as follows:*

- I. Aryal A., D. Brunton T. McCarthy, D. Karmacharya, W. Ji., R. Bencini and D. Raubenheimer. (Revision submitted). Food habits, movements and habitat preference of the snow leopard in an area of Central Himalaya.
- II. Aryal, A., D. Brunton, W. Ji and D. Raubenheimer. 2012. Blue sheep in the Annapurna Conservation Area, Nepal: habitat use, population biomass and their contribution to the carrying capacity of snow leopards. *Integrative Zoology*. **In press** (DOI: 10.1111/1749-4877.12004).
- III. Aryal, A., D. Brunton and D. Raubenheimer. 2013. Habitat assessment to translocating blue sheep to maintain a viable snow leopard population in the Mt

Everest Region, Nepal. *Zoology and Ecology* (formally *Acta Zoologica Lituanica*) 32(1): 66-82. DOI:10.1080/21658005.2013.765634

# **Paper I: Food habits, movements and habitat preference of the snow leopard in an area of Central Himalaya**

## **Abstract**

The snow leopard (*Panthera uncia*) is an endangered carnivore of Southern and Central Asia. Approximate 10% of the global population occurs in the Himalayan region of Nepal and it is thought to be in decline because of human-wildlife conflict, poaching, habitat loss/fragmentation, decreasing prey populations, lack of awareness and conservation legislation enforcement. In this study, we use participatory map occupancy and surveys based on genetic analyses of putative snow leopard scats, along with Snow Leopard Information Management System survey protocols, to estimate the abundance, habitat preferences, and diet profile of the snow leopard in the Annapurna Conservation Area (ACA), Nepal. Cliffs, grassland and shrubland at high elevation (3000-5000 m) were the preferred habitats by snow leopards. Of 34 scat samples collected, 83% were verified to be from snow leopards using mtDNA cytochrome b species-specific Polymerase Chain Reaction assay. Of these, 62% were successfully genotyped using six microsatellite markers, and identified as having originated from five different individuals. The dispersion of multiple scats from the same specific individuals suggested minimum movement ranges of 89.4 km<sup>2</sup> for males and 59.3 km<sup>2</sup> for females. The estimated snow leopards' population density was 1.9 individuals/100 km<sup>2</sup> and 22 snow leopards were estimated to inhabit the upper Mustang region. Microhistological analysis of scats (n=248) revealed that blue sheep, *Pseudois nayaur*, was the primary wild prey (63%), and livestock also contributed significantly (18%) to the snow leopard diet. The findings from this study will be helpful in managing snow leopard populations not only in the Himalayas but also across its entire distribution range.

**Key words:** *non-invasive genetic analysis, occupancy, diet, distribution, prey, livestock.*

## **Introduction**

The snow leopard (*Panthera uncia*) is an endangered carnivore of Southern and Central Asia, with an estimated population of 3,500 – 7,000 and a distribution range of over 3,024,728 km<sup>2</sup> (Hunter 1997; McCarthy et al. 2003; Jackson et al. 2008; IUCN 2011). Fox (1989) estimated an area of 1,230,000 km<sup>2</sup> were suitable area for snow leopard entire its distribution range The Himalayas region Nepal contains an area of approximately 27,432 km<sup>2</sup> potential habitat for snow leopards (Jackson and Hunter 1996; Jackson 2002) with about 65% of this occurring outside protected areas (Jackson and Ahlborn 1984; Jackson et al. 2008). Approximate 10% (300-500 individuals) of global snow leopard populations are thought to occur in both protected and unprotected areas in Nepal (Fig. 1) (Jackson and Ahlborn 1984; Oli 1997; Aryal 2008; Khatiwada and Ghimery 2009; Wolf and Ale 2009; DNPWC 2011; IUCN 2011; Aryal et al. 2013b).

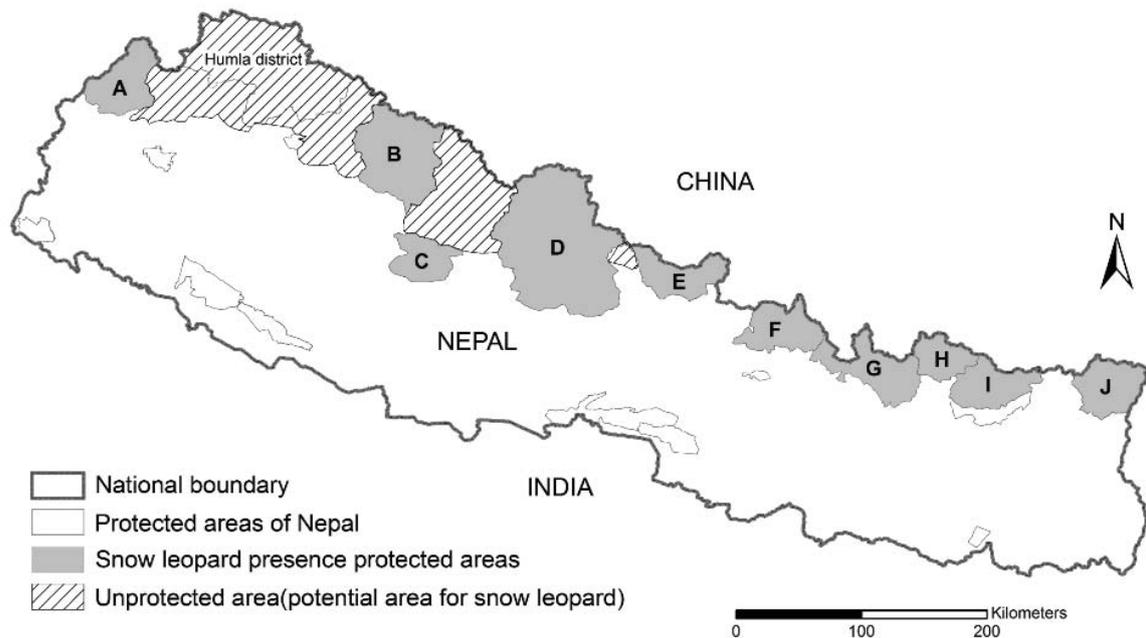
The snow leopard is one of the top predators in the Himalayas' ecosystem (Fox 1994; Oli 1997; Jackson et al. 2008; Lovari et al. 2009; Ale 2009). Its population in Nepal is in decline, primarily due to human-wildlife conflict including retaliatory killing for livestock depredation, poaching, loss of habitat due to high densities of livestock, habitat fragmentation, decreasing prey populations, as well as a lack of conservation awareness and a lack of conservation legislation enforcement (McCarthy et al. 2003; Oli 1997; Lovari et al. 2009; Ale 2007; Shetha and Wegge 2008; Namgail et al. 2010; Aryal et al. 2010a & b; Fox 1994; Ale and Brown 2009; McCarthy et al. 2005; Janecka et al. 2008; Shehzad et al. 2012; Jacson et al. 2006). However, our knowledge of the distribution and ecology of snow leopard in Nepal is lacking, and the snow leopard's secretive habits and distribution in inaccessible habitats make it challenging to gather critical

information on this species (Fox 1994; Oli 1997; Jacson et al. 2006; Jackson et al. 2008; Ale and Brown 2009; Lovari et al. 2009; Shehzad et al. 2012; Aryal et al. 2013b).

Published studies on the snow leopard in Nepal (Oli 1997; Ale 2007; Lovari et al. 2009; Karmacharya et al. 2011) mainly focus on presence/absence, diet, home range and habitat in the Dolpa, Manang and Sagarmatha regions. Lacking, however, is information for the upper Mustang region. The Mustang region has a cold desert climate, low human density, low prey and predator densities, and lacks forest (Aryal et al. 2012a, b & c). These environmental variables are known to influence snow leopard density, abundance, home range and feeding ecology (Aryal et al. 2012a). Furthermore, the *Snow Leopard Information Management System* (SLIMS) methodology has been widely used in previous studies for estimating snow leopard status in the entire distribution range countries (Jackson and Hunter 1996; Ale 2007). The methodology has reported bias (Janecka et al. 2008; McCarthy et al. 2008), however, it is cost effective, easy to implement, useful to understand preliminary status of snow leopard and their monitoring (Jackson and Hunter 1996; Ale 2007; McCarthy et al. 2008; Lovari et al. 2009). Recently, genetic analysis of DNA from faecal samples and camera trapping have been recognised as more reliable methods to identify individuals and to estimate population sizes (Janecka et al. 2008; McCarthy et al. 2008; Karmacharya et al. 2011; Shehzad et al. 2012).

Here we report the results of a population survey based on genetic analysis of putative snow leopard scats in the upper Mustang region of Nepal for species and individual recognition. This technique has recently been used for snow leopard studies throughout its range, and is more reliable in identifying field-collected scats for use in diet analysis, landscape connectivity, gene flow, distribution, and population density (DeYong and Honeycutt 2005; McCarthy et al. 2008; Lovari et al. 2009; Karmacharya et al. 2011; Shehzad et al. 2012). The aim of our study was to estimate snow leopard abundance in the upper Mustang region, to compare the feeding ecology

between snow leopards in the Manang and Mustang districts, and to estimate potential habitats for snow leopards in the Annapurna Conservation Area.



**Figure 1.** Snow leopard distribution protected areas and possible snow leopard distribution unprotected area in Nepal [ A). Appinappa Conservation Area, B). Shey Phoksundo National Park, C). Dhorpatan Hunting Reserve, D). Annapurna Conservation Area, E). Manasalu Conservation Area, F). Langtang National Park, G). Gaurishankar Conservation Area, H). Sagarmatha National Park, I). Makalu Barun National Park, J). Kanchanjunga Conservation Area]

## Methods

### *Study area*

The study was conducted in the upper regions of the districts of Mustang (N 28° 47' 39" to 29° 19' 54" and E 83° 28' 55" to 84° 15' 16") and Manang (28° 27' – 28° 54' N to 83° 40' – 84° 34' E) in the Annapurna Conservation Area in Nepal. Habitat surveys were conducted in the upper Mustang region, where putative snow leopard scats were collected. However, only known snow

leopard scats were collected from the Manang district. The Manang district covers an area of 2246 km<sup>2</sup> and its elevation ranges from 1600 (Tal) to 8156 metres (Mt. Manaslu) (Aryal et al. 2012a, b & c). Further details about the study area are described in Aryal et al. (2012a, b & c). The climate of the districts is sub-alpine, with temperatures ranging from 25°C to -3°C (Aryal et al. 2013a). Agricultural production is very limited and animal husbandry and tourism are the major sources of income (Aryal et al. 2012a, b & c; Aryal et al. 2013a). The vegetation of the area is primarily high-altitude grassland and includes species such as *Caragana* spp., *Carex* spp. and *Kobresia* spp. (Chetri 2004; Aryal et al. 2012a, b & c; Aryal et al. 2013a). The Mustang and Manang districts both provide good pastureland for livestock and also support a large number of rare and endangered fauna, including blue sheep (*Pseudois nayaur*), grey wolf (*Canis lupus*), brown bear (*Ursus arctos*), and lynx (*Lynx lynx*) and snow leopard (Chetri 2004; Aryal et al. 2012a, b & c)

## ***Survey methods***

### *Snow leopard occupancy, habitat use and availability in upper Mustang*

In May 2010, we visited the six Village Development Committees (VDC) in upper Mustang and met with local people and herders (N=241). We conducted a workshop to explain the threats faced by the snow leopard and to prepare a participatory map for quantifying the distribution of the snow leopard. We divided upper Mustang into grids with a cell size of 4.5 km x 4.5 km, based on an average snow leopard home range size of approximately 20 km<sup>2</sup> (11 - 37 km<sup>2</sup>- Jackson (1996), and 13.9 - 22.3 km<sup>2</sup>- Oli 1997). These participatory maps were approximately geo-referenced using a topographic map of the region. A single occupancy method for the snow leopard survey in the grids of upper Mustang was used to estimate their population density and distribution. If we found a sign or direct observation of the target species in a grid, we recorded that grid as an area of habitat use / snow leopard presence stopping the survey in that grid and

starting in another grid (Hall et al. 1997; Mackenzie et al. 2006). The main purpose of this survey was to understand the habitat use and availability for snow leopards in the region. Based on the survey, we first visited the most probable snow leopard habitat, including riverbeds, ridges and gullies, on horseback to search for snow leopard signs. If we found no signs of snow leopards, we noted the area as an absence or as available habitat area, and then moved to another grid. For remote and inaccessible areas, we used information from local people to determine snow leopard presence or absence. We entered all presence and absence data into ArcGIS 9.3 (ESRI, Redlands, California) to draw the presence/absence grid, and then overlapped this with the study area using Hawth's Tools for ArcGIS 9.x ([www.spatial-ecology.com](http://www.spatial-ecology.com)). We characterised presence areas as habitat areas currently in use and absence areas as potential habitat. Habitat features such as elevation, slope, aspect and land use characterising each of the presence/absence grids were taken into consideration for analysis. Vector layers (contours of 20m interval, land use layer and ecological layers) were obtained from the Department of Survey, Government of Nepal and ICIMOD (<http://geoportal.icimod.org/>). We took 20-metre interval contour layers and created 500-metre interval elevation model (DEM – Digital Elevation Model) using 3D analysis, and prepared slope and aspect layers for further analysis. Overlapping the presence/absence grid with the layers allowed further analysis of habitat use and availability for snow leopards in the upper Mustang region. We also overlapped the presence/absence grid with ecological, slope and aspect layers to further understand habitat use and availability related to those parameters. For each of the presence/absence grids we classified separately the elevation, slope, aspect and ecological layers as well as the distance to water sources and villages. Slope was reclassified into seven categories using 10° intervals ( $1 \leq 10^\circ$  to  $7 \geq 60^\circ$ ). Aspect was reclassified into eight classes (north, northeast, east, southeast, south, southwest, west, and northwest). We used Ivlev's Electivity Index (IEI) to understand habitat preference of snow leopards [ $IEI = (U\% - A\% / U\% + A\%)$ ] (Ivlev 1961, Krebs 1989, Hall et al 1997, Aryal et al.

2010, Ale and Brown 2009) where “A” represents “availability area” (absence area) and “U” represents “use area” (presence area) (Ivelv 1961; Krebs 1989). A one-way ANOVA was performed to evaluate significantly preferred habitats, with the null hypothesis being that all habitats were used in proportion to their availability. “Use area” as a dependent variable and “available area” as an independent variable were used for the analysis. Spearman’s correlation was used to test for significance between various “use” and “available” areas of snow leopard habitats.

### *Snow Leopard Information Monitoring System (SLIMS) habitat surveys and scat collection*

SLIMS surveys of snow leopard signs were conducted from January to June 2010 in the upper Mustang region (Jackson and Hunter 1996). Putative snow leopard scat samples were identified based on size, pugmarks, scrapes and scent spray (Aryal and Kreighhofer 2009). Scat samples were collected from ridges, riverbeds and cliffs, with SLIMS minimising misidentification and collecting scats from other predators. We only collected the scats for diet analysis if we found signs of snow leopard scraping or scent spray (Jackson and Hunter 1996; Ale 2007); however, non-invasive genetic work on scats from India, China and Mongolia suggested that up to 54% of scats collected as snow leopard scats were misidentified and were actually from other species, such as the red fox (*Vulpes vulpes*) (Janecka et al. 2008). Snow leopard scats were collected from both study areas for three seasons (winter: November 2009, January-February 2010; spring: March-April 2010; summer: June-July 2010). Further scats were collected in April-July 2011 and March-April 2012 for non-invasive genetics analysis. This detailed survey methodology was adopted in the upper Mustang region to collect putative scats. However, from the Manang district, we only collected scats of snow leopards from January 2010 to April 2010, and did not conduct habitat surveys.

### *Non-invasive genetics analyses*

### *DNA Extraction*

Putative scats of snow leopards (n=34) were collected from upper Mustang using SLIMS recommended protocols in April- July 2011 and March-April 2012 for genetic analysis. Scats were preserved in silica gel and transported to the genetic laboratory of the Center for Molecular Dynamics Nepal (CMDN) for analysis. DNA was extracted using the Qiagen QIAamp DNA Stool kit following the recommended protocol (Qiagen, Germany).

### *Species identification*

A Cytochrome b segment of mtDNA specific for snow leopard was amplified using a PCR primer set (CYTB-SCT-PUN F and CYTB-SCT-PUN R) for species identification (Janecka et al. 2008). A 7 $\mu$ l PCR reaction was prepared containing 3.5 $\mu$ l of 5X Qiagen Master Mix, 0.7 $\mu$ l of 5X Qiagen Solution, 0.07 $\mu$ l of each primer, 1.16 $\mu$ l of distilled water and 1.5 $\mu$ l of extracted undiluted DNA. The PCR reaction was carried out at the following thermo-cycling conditions: 95°C for 15 minutes followed by 50 cycles of 94°C for 30 seconds, 60°C for 15 seconds and 72°C for 1 minute. One known snow Leopard positive sample was incorporated as positive control. The amplified PCR products were visualized in 1.8% agarose gel.

### *Sex identification*

Sex identification was done using PCR on snow leopard species PCR positive samples with felid sex specific PCR primers (AMELY F and AMELY R) (Murphy et al. 1999). A 7 $\mu$ l PCR reaction was prepared containing 3.5 $\mu$ l of 2X Qiagen Master Mix, 0.7 $\mu$ l of 5X Qiagen Solution, 0.07  $\mu$ l of each primer, 1.16  $\mu$ l of distilled water and 1.5  $\mu$ l of extracted undiluted DNA. PCR thermo-cycling conditions were: 95°C for 15 minutes followed by 50 cycles of each 94°C for 15 seconds, 55°C for 30 seconds and 72°C for 1 minute. The PCR products, with incorporated male and female snow leopard positive controls, were visualized in 2% agarose gel.

### *Individual identification by PCR assay*

Six microsatellite loci located at six different chromosomes of the snow leopard genome were targeted using sets of six primers with tagged fluorescent dyes (see detail for six microsatellite primer sequences in Jananecka et al. 2008 and Karmacharya et al 2011). Six polymorphic microsatellite loci chosen were sufficient to give the value of  $P_{ID}$  (Probability of Identity) that was adequate to characterize individuals in a population sharing the same genotype (Janecka et al. 2008).

Genotyping for individual identification was optimized for multiplex PCR. Six microsatellite primers were divided into two combinations each containing three of the primer pairs. One combination of primer pairs included tagged forward and untagged reverse primers for loci PUN124, PUN229 and PUN1157 (Janecka et al. 2008). The second combination consisted of primer pairs, tagged forward and untagged reverse primer, for loci PUN132, PUN894 and PUN935 (Janecka et al. 2008). For each sample, multiplex PCR was performed for both combinations in a 7 $\mu$ l reaction volume. For the first multiplex PCR combination, a total of 7 $\mu$ l reaction volume contained 3.5 $\mu$ l of Qiagen master mix (2x) (Qiagen, Germany), 0.7 $\mu$ l of Q-solution (5x) (Qiagen, Germany), primers for PUN124 at 0.5 $\mu$ M, primers for PUN229 at 0.4 $\mu$ M, primers for PUN1157 at 0.2 $\mu$ M and 1.5 $\mu$ l of DNA. Similarly for the second multiplex PCR combination, a total of 7 $\mu$ l reaction volume contained 3.5 $\mu$ l of Qiagen mastermix (2x) (Qiagen, Germany), 0.7 $\mu$ l of Q-solution (5x) (Qiagen, Germany), primers for PUN132 at 0.5 $\mu$ M, primers for PUN894 at 0.4 $\mu$ M, primers for PUN935 at 0.2 $\mu$ M and 1.5 $\mu$ l of DNA.

The PCR reaction was carried out at the following thermo-cycling conditions: 95°C for 15 minutes followed by 40 cycles at 94°C for 30 seconds, 55°C for 90 seconds and 72°C for 90 seconds and a final extension of 72°C for 10 minutes. The PCR product was diluted to 1:60 by adding 118 $\mu$ l of

distilled water to 2µl of the PCR product. 1µl of the diluted PCR product was then mixed with 9µl of Hi-Di formamide (Applied Biosystems, USA) and 0.25µl of GeneScan 500-Liz DNA size standard (Applied Biosystems, UK). The mixture was denatured at 94<sup>0</sup>C for 5 mins and immediately cooled. The samples were then injected into a capillary tube (36cm, POP4 polymer) by applying an injection voltage of 1kV for 5sec in an ABI310 Genetic Analyzer (Applied Biosystems, USA). The capillary electrophoresis was performed at a voltage of 15kV at 60<sup>0</sup>C. We determined the size of alleles using the software Genemapper 4.0. Individuals were identified using unique composite genotypes.

#### *Movement pattern analysis*

The locations of scats from genetically identified snow leopard individuals were plotted in the “land use” layer of the region. Minimum convex polygons were created to calculate the home ranges and understand the movement pattern and area covered by the animal. We used Hawth’s Tools for ArcGIS 9.x ([www.spatial ecology.com](http://www.spatial ecology.com)) for the calculation of area coverage by all individuals and by each individual. For each individual the distribution and movement area were plotted and calculated thus yielding an estimate of home range. The movement area of all identified male and female snow leopards was delineated with the Hawth’s Tools for ArcGIS 9.x to create minimum convex polygons and calculate the movement and area coverage of each snow leopard. Once the home range area was calculated it was used to estimate the number of snow leopards living in the region by dividing the area of suitable habitats of the upper Mustang region by the average home range sizes of snow leopards.

#### *Diet analysis*

Standard micro-histological methodology was used to identify prey species from hair samples found in scats by comparing to reference hair samples from all potential prey species (Oli et al. 1993; Oli 1993; Mukherjee et al. 1994; Aryal et al. 2012b; Aryal and Kreigenhofer 2009).

Snow leopard scats were collected via SLIMS; therefore, we collected scats only if we found snow leopard signs around the scats, such as scent spray, scrapes and/or pugmarks. There were no other cat species in the area; however, we made careful observations in order to distinguish snow leopard scats from those of other carnivores, like fox, jackal (*Canis aureus*), wolf, and dog (*Canis familiaris*) (Aryal and Kreigenhofer 2009; Aryal et al. 2012c). The microscopic structure of the medulla and cuticular structure of hair were observed to identify prey items in the scats (Oli 1993; Oli et al. 1994; Bahuguna et al. 2010; Aryal et al. 2012c).

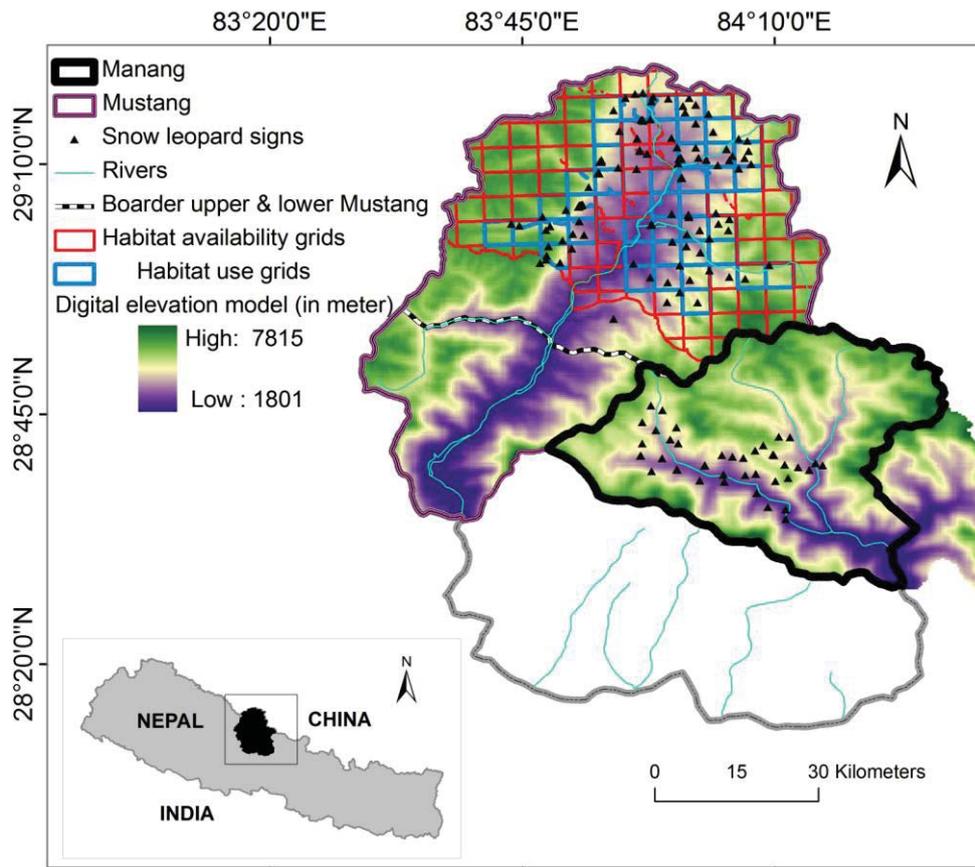
Hair samples from the scat were first washed in hot water. Items other than hair such as mud, bones and vegetation were recorded and then removed; only hair samples were processed further. Hairs were thoroughly air-dried and then cleaned in ether for one hour to remove wax and any traces of moisture. Finally, the hairs were passed through Xylol for 24 hours. A gelatin solution was used to prepare slides to show the cuticular structure of hairs and examine the medulla structure of the hair; cuticular scales were observed by the impression technique. Slides were observed under a light microscope (100x and 400x). At least 20 hair samples were analysed from each scat sample and we calculated the frequency of occurrence of each prey item in the snow leopard scats (Oli 1993; Oli et al. 1994; Mukharjee et al. 1994; Aryal and Kreigenhofer 2009; Bahuguna et al. 2010; Aryal et al. 2012c). A chi-square test was used to determine significant differences between prey frequencies within each season and between seasons.

## **Results**

### *Status of snow leopards*

Snow leopard surveys were conducted in six VDCs (Lomangthnag, Chhunup, Chhoser, Charang, Ghami and Surkhang) of the upper Mustang region (Fig. 2). An occupancy survey showed that

the presence of snow leopards was recorded in 41 grids covering an area of 846.02 km<sup>2</sup>, while snow leopards were absent in 77 grids covering 1211 km<sup>2</sup> (Fig. 2).



**Figure 2.** Digital Elevation Model of snow leopard distribution areas (Manang and Mustang districts of Annapurna Conservation Area) and habitat characters.

One hundred and thirty-eight transect lines were surveyed in potential snow leopard habitats, including ridgelines, riverbanks and gullies in the upper Mustang region. Transect line lengths varied from 100-1000 m and covered 59.9 km. Altogether, 283 signs of snow leopards were recorded along the transects. Scrapes were the most common type of sign (62%) observed, followed by scats (35%), pugmarks (1%) and urine spray (1%) (Table 1). Chhoser and Surkhang VDCs contained most of the snow leopard signs – 34% and 33% respectively –

followed by the Ghami, Lomangthang, Charang and Chhunup VDCs (Table 1). However, there was no significant difference in the distribution or density of signs throughout the study area ( $\chi^2=2.25$ ,  $df=5$ ,  $p>0.05$ ; Table 1).

**Table 1: Density of signs of snow leopards in the upper Mustang region (using the SLIMS) during November 2009 to April 2010.**

Survey VDCs	Transect (km)	Scrape	Feces	Pugmark	Spray/hair	Total	Mean sign (all)/km	scrape/km
Lomangthang	10.5	24	11	3	2	40	3.81	2.29
Chhoser	11.4	53	36	1	0	90	7.89	4.65
Chhunup	2.9	11	5	0	0	16	5.52	3.79
Surkhang	16.8	36	28	1	1	66	3.93	2.14
Ghami	12.2	41	16	0	0	57	4.67	3.36
Charang	6.1	6	8	0	0	14	2.30	0.98
Total	59.9	171	104	5	3	283	4.72	2.85

### *Habitat types*

Snow leopards preferred cliffs (IEI=0.80), grassland (IEI=0.29), shrubland (IEI=0.67), and areas near water bodies (IEI=0.41), while they avoided agriculture areas and glaciers (IEI=<0) (Table 2A). Snow leopards primarily used barren land (55%), followed by grassland (39.5%), but did not frequent sand (2%) or glaciers (<1%). Snow leopards also used less than one percent of land near human settlement, a habitat type that comprised approximately 2% of available land in the upper Mustang region.

### *Elevation*

Snow leopards preferred elevations ranging between 3500 and 5000 metres (IEI=>04 - <0.44), especially elevation ranges of 4000-4500 metres (IEI=0.59) and 4500-5000 metres (IEI=0.44).

Snow leopards avoided elevations greater than 6000 metres and less than 3000 metres (IEI=<-0.01) (Table 2B). Elevations utilised were significantly correlated with utilised habitat types ( $r_s=0.720$ ,  $df=9$ ,  $p=0.29$ ), but their use by snow leopards was not correlated with aspect ( $r_s=-0.234$ ,  $df=9$ ,  $p=0.54$ ) or slope ( $r_s=0.661$ ,  $df=9$ ,  $p=0.53$ ).

### *Aspect and slope*

Although the IEI was positive for southern (IEI=>0.05), south-western (IEI=0.01), western (IEI=0.08) and north-western aspects (IEI=0.04), and negative for the other aspects (IEI=<-0.02; Table 2), there was no significant difference in the use of different aspects by the snow leopards ( $\chi^2=0.78$ ,  $df=7$ ,  $p=0.99$ ; Table 2C). Snow leopards had positive IEI for slopes of 41°-51° (IEI=0.03) and 51°-64° (IEI=0.19), but there was no significant difference in the use of different slopes by snow leopards ( $\chi^2=0.0001$ ,  $df=8$ ,  $p=1$ ; Table 2D).

Table 2: Habitat preference of snow leopards, comparison of habitat use and availability of different habitat features A) Habitat type B) Elevation C) Aspect D) Slope in upper Mustang region of Nepal based on habitat information for grids of 4.5km x 4.5km presence and absence plots.

Habitat features	Absence area (km <sup>2</sup> )	Presence area (km <sup>2</sup> )	Use %	Available %	IEI
A) Habitat types preference					
Cliff	0.2	1.5	0.2	0	0.81
Agriculture and settlement	27.6	3.8	0.4	2.3	-0.68
Grassland	257	335.6	39	21.5	0.29
Shrub land	4.2	15.4	1.8	0.4	0.67
sandy area	38.7	22.4	2.6	3.2	-0.11
Barren land	840.8	476.1	55.4	70.4	-0.12
water body	0.2	0.3	0	0	0.41
Glacier	24.6	4.2	0.5	2.1	-0.62
Pond/lake	1.8	0.1	0	0.1	-0.88
B) Elevation (in meters) preference					

2900-3000	0	0.1	0	0	-1
3000-3500	40	30	3.6	3.3	0.04
3500-4000	171.8	137.9	16.3	14.2	0.07
4000-4500	96.3	261.4	30.9	8	0.59
4500-5000	120.8	216.5	25.6	10	0.44
5000-5500	251.9	142.7	16.9	20.8	-0.1
5500-6000	460.9	54.7	6.5	38.1	-0.71
6000-6500	67.9	1.6	0.2	5.6	-0.94
6500-7000	0.2	0	0	0	-1
C) Aspect preferences					
Flat (-1)	169.6	114.8	13.6	14	-0.02
North (0-22.5)	71.9	46.2	5.5	5.9	-0.04
Northeast (22.5-67.5)	137.2	91.6	10.8	11.3	-0.02
East (67.5-112.5)	143.7	88	10.4	11.9	-0.07
Southeast (112.5-157.5)	131.8	84.9	10	10.9	-0.04
South (157.5-202.5)	126	98.3	11.6	10.4	0.05
Southwest (202.5-247.5)	133.9	96.3	11.4	11.1	0.01
West (247.5-292.5)	118.3	97.8	11.6	9.8	0.08
Northwest (292.5-337.5)	115.5	87.8	10.4	9.5	0.04
North (337.5-360)	62.7	40.3	4.8	5.2	-0.04
D) Slope (in degree) preferences					
0 - 5.18	1.2	118.4	14	0.1	0.98
5.18 - 13.48	191.3	94.1	11.1	19	-0.26
13.48 - 21.09	208	165.4	19.6	20.7	-0.03
21.09 - 28.01	201.5	151.3	17.9	20	-0.06
28.01 - 34.58	180.6	133.6	15.8	17.9	-0.06
34.58 - 41.85	132.4	98	11.6	13.2	-0.06
41.85- 51.19	63.4	56.2	6.6	6.3	0.03

51.19 - 64.67	19.9	24.7	2.9	2	0.19
>64.67	8.4	4.3	0.5	0.8	-0.24

### *Genetic analysis of snow leopard scats*

#### *Species identification*

Out of 34 putative scat samples, 85% (29) were identified as originating from snow leopard. Of these, 27.6% were identified as originate from male and 72.4% from female . Out of the 29 snow leopard-positive PCR samples, 62% were successfully genotyped using 6 microsatellite markers. Five unique individuals (three males and two females) were identified (Fig. 3, Table 3).

**Table 3:** Snow leopard movement pattern based on individual identification from 17 scats of snow leopards from the upper Mustang region. Scats were collected from two time series in April- August (2011) and again in February-April (2012). Each individual leopard travelled throughout the year and areas were calculated by minimum convex polygon tools from the Arc GIS 9.3 with the extension tool of Hawth's.

Individual	Area	Remarks
Male 1	89.43 km <sup>2</sup>	Seven points
Female 3	59.31 km <sup>2</sup>	Six points
Female 2		One point
Female 1		One point

---

Male 2		Two points
All 3 Female and 2 male coverage area	264.74 km <sup>2</sup>	Female 1 and Male 1 were not sharing habitat with other snow leopards (Fig 3)

---

### *Movement pattern and population density*

The five snow leopards (three females and two males) ranged over an area of 264.74-km<sup>2</sup> during the study periods in which we collected scats (Fig. 3). Using the Minimum Convex Polygon method, we calculated that the coverage area of Female 3 was 59.31 km<sup>2</sup> and the coverage area of Male 1 was 89.43 km<sup>2</sup> for the year; an average per snow leopard covered 52.9 km<sup>2</sup> (Fig. 3). Male 1 and Females 2 and 3 had overlapping movement areas. However, the single data points for Male 2 and Female 1 fell outside of the movement areas of all other individuals (Fig. 3). The snow leopards' population density was 1.9 individuals/100 km<sup>2</sup>, estimating an average 22 snow leopards [snow leopard suitable area (1162.5km<sup>2</sup>) divided by average movement area (52.9km<sup>2</sup>)] in the upper Mustang region.

### *Diet composition of snow leopard*

A total of 248 snow leopard scats were collected from the study area (157 from upper Mustang 2009-2012 and 97 from Manang 2009-2010) and were subjected to micro-histological diet analysis to identify the prey of snow leopards.

Blue sheep represented most of the snow leopards' diet (63%) in the Annapurna Conservation Area ( $\chi^2=1.3$ ,  $df=15$ ,  $p=0.01$ ; Fig. 4 and Table 4), with the second most consumed prey item being livestock (18.4%), followed by the Himalayan marmot (*Marmota himalayana*) contributed the third highest proportion to the diet (7%).

**Table 4:** Frequency of occurrence (in percentage) of wild and domestic livestock hair found in snow leopard scats at Manang and Mustang district (Upper Mustang region) of Annapurna Conservation Area, Nepal.

Prey species /Seasons	Upper Mustang Region				Non-invasive genetically identify snow leopard scats (n=34)	Manang District				Overall in Manang and Mustang districts N=248
	2009-2010-2011					2009-2010				
	Winter (Nov-Jan) (scats n= 36)	Spring (March-April) (scats n= 68)	Summer (June-July) (scats n= 53)		All season (n=15 7)	winter (Nov-dec) (scats n= 34)	Spring/summer (March-May) (scats n= 57)	All season (n=91)		
Wild prey										
Blue sheep ( <i>Pseudois nayaur</i> )	65.8	61.4	54.8	69.4	65.0	61.7	58.0	59.9	63.3	
Himalayan marmot ( <i>Marmota himalayana</i> )	4.4	11.8	21.3	10.0	11.3	0.0	0.0	0.0	7.5	
Royle's pika ( <i>Ochotona roylei</i> )	1.8	3.4	1.4	0.0	1.1	0.0	3.2	1.6	1.3	
Himalayan woolly hare ( <i>Lepus oiostolus</i> )	2.9	5.3	3.5	3.2	3.6	0.0	0.0	0.0	2.4	
Wild ass ( <i>Equus kiang</i> )	0.0	0.0	2.4	0.0	0.4	0.0	0.0	0.0	0.3	
Tibetan argali ( <i>Ovis ammon hodgsonii</i> )	0.0	0.8	3.1	0.0	0.7	0.0	0.0	0.0	0.4	
Red fox ( <i>Vulpes vulpes</i> )	1.3	0.9	0.0	0.0	0.4	2.8	4.3	3.6	1.4	
Musk deer ( <i>Moschus</i> spp)	0.0	0.0	0.0	0	0.0	6.3	9.7	8.0	2.7	
Weasel ( <i>Mustela nivalis</i> )	0.0	0.0	0.0	0.0	0.0	2.5	0.0	1.3	0.4	

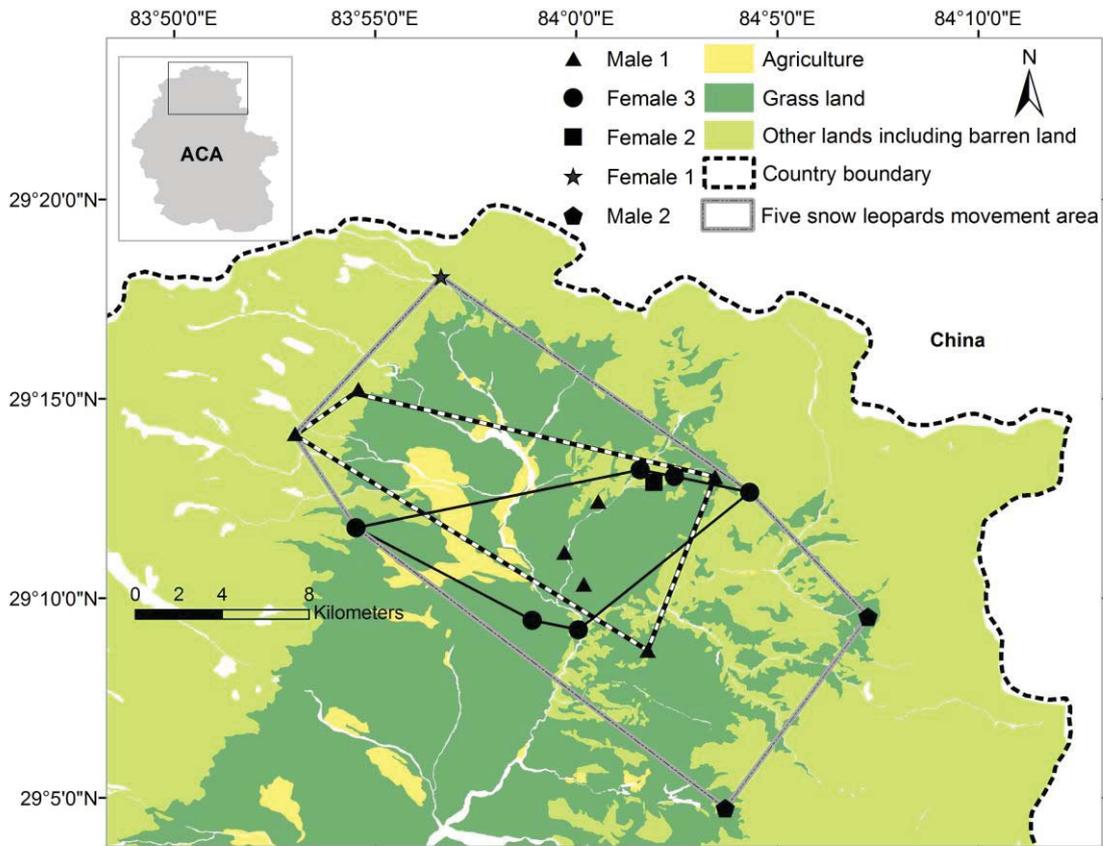
Marten ( <i>Martes foina</i> )	0.0	0.0	0.0	0.0	0.0	0.4	3.2	1.8	0.6
Birds	1.0	0.8	0.5	0	0.4	0.2	0.7	0.5	0.4
Domestic livestock									
Yak ( <i>Bos grunniens</i> )	4.6	3.1	2.5	1.4	2.4	2.8	1.9	2.4	2.4
Sheep ( <i>Ovis</i> spp)	3.8	2.5	1.2	4.0	3.3	5.7	4.6	5.2	3.9
Goat ( <i>Capra</i> spp)	9.8	6.2	6.1	11.0	9.2	14.3	11.4	12.9	10.4
Horse ( <i>Equus caballus</i> )	3.6	3.5	3.2	0.9	2.2	2.6	2.1	2.4	2.2
Bovine ( <i>Bos</i> spp)	1.0	0.3	0.0	0.1	0.3	0.7	0.9	0.8	0.4

#### *Upper Mustang region*

Overall, blue sheep contributed a significant majority (65%) of the diet content for snow leopards in the upper Mustang region ( $\chi^2=14.3$ ,  $df=12$ ,  $p=0.0001$ ). This was uniform across all seasons, with blue sheep comprising the highest percentage of prey species in snow leopard scats in winter (65%;  $\chi^2=9.9$ ,  $df=10$ ,  $p=0.01$ ), spring (61%;  $\chi^2=12.24$ ,  $df=11$ ,  $p=0.0001$ ) and summer (54%;  $\chi^2=9.12$ ,  $df=10$ ,  $p=0.0001$ ; Table 4). Livestock contributed an average of 17.4% to the snow leopard diet throughout all seasons in the upper Mustang region, with slightly more livestock contributing in winter (21%), followed by spring (15%) and summer (13%; Table 4).

#### *Manang region*

In the Manang region blue sheep also represented a significant majority of the diet of snow leopard (59%,  $\chi^2=2.39$ ,  $df=15$ ,  $p=0.0001$ ). This predominance of blue sheep as the main prey of the snow leopard occurred throughout all seasons, with 58% in spring/summer ( $\chi^2=16$ ,  $df=15$ ,  $p=0.008$ ) and 61.7% in winter ( $\chi^2=1.4$ ,  $df=15$ ,  $p=0.23$ ; Table 4). Livestock comprised an average of 23.5% of the overall diet of snow leopards in the Manang region, but again slightly more livestock was found in winter 25.6% than in spring 20.7% (Table 5).



**Figure 3.** Snow leopard movement area base on genetically identified snow leopard individual (Female and Male). The map showed that the distribution and movement pattern or of snow leopards (3 Female and 2 Male) in upper Mustang region of Nepal.

## Discussion

### *Occupancy and SLIMS*

In our occupancy survey, we used a 4.5 km x 4.5 km grid, this representing the assumed average home range size for snow leopards in Nepal (Jackson 1996; Oli 1997). The home range of snow leopards depends on prey availability and the landscape pattern (McCarthy 2000), with home ranges expected to be smaller in regions of high density of prey, as is the case in the study area (MacArthur 1972; Oli 1994; McCarthy 2000). Our small sample sizes did not enable us to estimate actual home ranges, but rather minimum home ranges of the snow leopards for which

we collected multiple scats. Our estimates of minimum home range size were nonetheless larger than previous estimates of 37 km<sup>2</sup> obtained by radio tracking (Jackson 1996).

Site occupancy modelling is commonly used to estimate population density, occupied habitats and species richness (Mackenzie et al. 2002, Mackenzie et al. 2006). We used one season occupancy survey and didn't find the snow leopard signs in 77 grids plots, which however it does not mean that snow leopards have not been present in these grids; therefore, two or more season occupancy survey should be recommended to imply further to understand season habitat use and occurrence of the species. We had relied on the SLIMS methods which use sign density to estimate cat numbers, we would have concluded that 8 to 25 snow leopards existed in the upper Mustang region. The SLIMS methodology has several weaknesses, including observer bias, misidentification of signs, environmental conditions and site selection bias. It is, nonetheless, a useful method for obtaining preliminary presence and absence data on snow leopards in a region (McCarthy et al. 2008). McCarthy et al. (2008) suggested a more reliable and lower-cost method to determine snow leopard populations and distribution estimates via faecal DNA analysis. However, multi-season presence/absence site occupancy surveys may be the best option when DNA analysis is prohibitively expensive (Mackenzie et al. 2002; Mackenzie et al. 2006). Our result showed that non-invasive genetic best method to estimate snow leopard density than other two methods (SLIMS and Occupancy); however estimated density ranges were approximate similar. These methods can be implemented in other prey and predators at the region level to explore their status such as brown bears, red fox, wolf, blue sheep, and marmots etc. These species were co-existing sharing similar habitat with snow leopards at the regional level (Oli 1994; Aryal et al. 2012 a , b, & c; Aryal et al. 2013b).

#### *Habitat use and availability*

Our results showed that snow leopards avoided areas associated with agriculture and human settlement in the upper Mustang region, where the cats used only about 0.4% of this area, a

result similar to previous studies (Jackson and Hunter 1996; Schaller 1997). However, a lack of wild prey species causes snow leopards to approach human settlement in search of livestock. Most of the upper Mustang pastureland was utilised seasonally by livestock. Similarly, snow leopard habitats in Sagarmatha National Park were significantly used by tourists, porters, guides and livestock, which disturb and harass snow leopards in the region (Wolf and Ale 2009). In upper Mustang, habitat preference by the snow leopard depended on prey availability. Cliffs, grasslands, shrublands, ridges and gullies were preferred by snow leopards where more livestock and wild prey were observed grazing regularly. Barren land and glaciers were avoided by snow leopards, although they might be used by leopards opportunistically while hunting, mating and marking territory borders (Wolf and Ale 2009; Lovari et al. 2009). Similar habitat features used by brown bears (Aryal et al. 2012b), blue sheep (Aryal et al. 2012a) in the region.

Our study showed that in upper Mustang and Manang, snow leopards preferred the 3000-5000 m elevation range, but not higher than 5000 m. Other studies suggested that the snow leopards preferred higher elevations (Schaller et al. 1988; Schaller 1998; Fox et al. 1991), while Wolf and Ale (2009) recorded a preference for lower elevations. Snow leopards showed a preference for steep slopes of 41-65° degrees, while Wolf and Ale (2009) found that snow leopards avoided such steep slopes.

#### *Genetic based estimates of movement areas and density*

Our study confirmed that snow leopard movement area/ home ranges vary from 59 to 89 km<sup>2</sup>, which was greater than reported in previous studies in this region (Jackson and Ahlborn 1984; Jackson 1996; Oli 1997) but much smaller than the home range of >300km<sup>2</sup> reported for snow leopards in Mongolia (McCarthy 2005). The home range of carnivores depends heavily on prey availability and carrying capacity in the region (Aryal et al. 2012c), with a high density of prey leading to small home ranges, and conversely, a low availability of prey leading to large home ranges. A low availability in natural prey can also result in livestock predation and increase the

risk of retaliatory killing of snow leopards. Given the small number of samples from each snow leopard, these figures almost certainly underestimated home range size, but nonetheless indicate a minimum home range size for the study animals. We estimated 22 snow leopards in the upper Mustang region, the estimate was similar to carrying capacity estimated by Aryal et al. (2012c) for the region. The home range we estimated for the snow leopard was similar to other large predators such as tiger (*Panthera tigris*) (Sunquist 1981; Seidensticker 1976; Smith 1993; Majumder et al. 2012).

#### *Diet and non-invasive analysis*

In recent studies (Karmacharya et al. 2011) only 27% of putative snow leopard scats were found to be actually from the target species. Similarly, Lovari et al. (2009) reported that only 44% of field-collected scats belonged to snow leopards. Sheldaz et al. (2012) reported that only 43.3% of scats belonged to snow leopards out of all collected samples (n=203). However, in our study about 85% of scat samples were of snow leopards most, likely because we only collected the scat where they were associated with snow leopard scrapes, presumably leading to this resulting in very low misidentification.

Our analyses suggested that the snow leopard's primary wild prey species was the blue sheep followed by the Himalayan marmot in upper Mustang, and musk deer in the Manang region, where Himalayan marmots were absent. Significantly, livestock was the second most consumed item, which may be of concern to both the local farmers and the snow leopards. Predation of livestock was particularly severe in winter, when marmots are unavailable. We analysed indigestible hair samples from snow leopard scats collected in upper Mustang and Manang. It is important to recognise that by only studying hair samples from scat, we cannot determine whether the prey was killed or scavenged, and it is impossible to predict how many individuals of the identified prey species were consumed, especially with small mammals like pika (*Ochotona roylei*) and marmot commonly found in the scats (Floyd et al. 1978; Oli et al. 1993;

Aryal and Kreigenhofer 2009). Earlier studies in Nepal also documented conflicts between people and snow leopards, due to snow leopard depredation of livestock; these data were collected through interviews with local people and diet analysis (Schaller 1987; Fox et al. 1991; Oli 1993; Oli et al. 1993; Aryal and Kreigenhofer 2009).

Blue sheep was the main prey species of snow leopards in Manang and upper Mustang, while Himalayan tahr (*Hemitragus jemlahicus*) was the primary prey species in Sagarmatha National Park (Lovari et al. 2009). Micro-histological based diet analysis gives lower estimate for small mammals and the method relies on proportional of hairs or animals remains in the scats (Ackerman et al. 1984), therefore, our result estimated minimum proportional of small mammals such as pika and marmot. Our diet analyses indicated that there was no marmot in the snow leopard diet from the Manang district; however, Oli et al. (1993) reported that about 20% of the overall diet consisted of marmot in the same area two decades ago. Field surveys for marmot and interviews with local people (n=279) over the past three years have indicated that the marmot is only found in the Mustang region and is not found in the Manang region. Therefore, marmot found in snow leopard scats in Manang district (Oli et al. 1993) might be due to snow leopards travelling from upper Mustang to Manang, even though there was a 7 km area comprising a high mountain and barren land with no grasses and an absence of prey species representing a barrier between Manang and upper Mustang and no connectivity of the habitat (Fig. 2). Further genetic-based studies should be conducted to examine the connectivity of snow leopard populations between the Manang and upper Mustang regions. There were other predators in the region such as brown bears, red fox, wolf which were depend upon the similar habitat and preys (Aryal et al. 2012a), therefore, both snow leopard and brown bear have feeding and habitat overlap in the region and created the competition between them. This research would be model research which can be replicated to other prey and predator at the region level species study to understand their interaction with similar habitats utilization, co-existing and population

estimate. Finally, we feel the findings may be useful in the preparation of a conservation strategy for snow leopard and its associate prey-predators at a regional level.

### **Acknowledgement**

We thank the Department of National Parks Wildlife Conservation/Ministry of Forest and Soil Conservation, and the National Trust for Nature Conservation for supporting our research by providing permission and logistic support. A special thanks to the Keidanren Nature Conservation Fund, Japan and Massey University Research Fund (New Zealand) for providing financial support; and IDEA WILD, USA for equipment support. We thank all staff in the Center for Molecular Dynamic, Kathmandu, Nepal for their support on genetic lab work and analysis.

### **References**

- Ale SB (2007) Ecology of the snow leopard and the Himalayan thar in Sagarmatha (Mt. Everest) National Park, Nepal. Ph.D. Thesis, University of Illinois at Chicago, USA.
- Ale SB, Brown JS (2009) Prey behavior leads to predator: a case study of the Himalayan tahr and the snow leopard in Sagarmatha (Mt. Everest) National Park, Nepal. *Israel J Ecol Evol* 55: 315–327.
- Ackerman BB, Lindzey FG, Hemker TP. 1984. Cougarfood habits in southern Utah. *J Wild Manag* 48 (1): 147–55.
- Aryal A (2008) *Population Ecology and Predators of Blue Sheep (Pseudois nayaur) in Dhorpatan Hunting Reserve –Nepal*. MSc Thesis, University of Freiburg, Germany.
- Aryal A, Brunton D, Raubenheimer D (2103a) Impacts of climate change on human-wildlife-ecosystem interactions in the Trans-Himalayan region of Nepal. *Theor Appl Climatol* DOI: 10.1007/s00704-013-0902-4. Online first

- Aryal A, Gastaur S, Menzel S, Chhetri TB, Hopkins J (2010a) Estimation of blue sheep population parameters in the Dhorpatan Hunting Reserve, Nepal. *Int J Biod Conser* 2: 051-056
- Aryal A, Hipkins J, Ji W, Raubenheimer D, Brunton D (2012a) Distribution and Diet of Brown Bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (2): 231–236
- Aryal A, Kreigenhofer B (2009) Summer diet composition of the Common Leopard *Panthera pardus* (Carnivora: Felidae) in Nepal. *J Threat Taxa* 1: 562-566
- Aryal A, Raubenheimer D, Sathyakumar S, Poudel BS, Ji W, Kunwar K J, Kok J, Kohshima S, Brunton D (2012b) Conservation Strategy for Brown bear and its habitat in Nepal. *Diversity* 4: 301-317.
- Aryal A, Raubenheimer D, Brunton D (2013b) Habitat assessment for the translocation of blue sheep maintains a viable snow leopard population in the Mt Everest Region, Nepal. *Zool and Ecol* 23(1): 66-82 DOI:10.1080/21658005.2013.765634.
- Aryal A, Raubenheimer D, Subedi S, Kattel B (2010) Spatial Habitat Overlap & Habitat Preference of Himalayan Musk deer '*Moschus chrysogaster*' in Sagarmatha (Mt. Everest) National Park, Nepal. *Curr Res J Biol Scien* 2: 217-225.
- Aryal A, Raubenheimer D, Weihong J, Brunton D (2012c) Blue sheep and snow leopard: Prey population density, distribution and habitat use of a principal prey species determines the carrying capacity for the predator. *Integr. Zool. In Press* DOI: 10.1111/1749-4877.12004
- Aryal A, Sathyakumar S, Schwartz C C (2010b) Current status of the brown bear in Manasalu Conservation Area Nepal. *Ursus* 21: 109-114. Doi: 10.2192/09GR029.1
- Bahuguna A, Sahajpal V, Goyal SP, Mukherjee SK, Thakur V (2010) Species Identification from Guard Hair of Selected Indian Mammals; A Reference Guide. Wildlife Institute of India, Dehradun, India.

- Chetri M, Gurung CR (2004) Vegetation Composition, species performance and its relationship among livestock and wildlife in the grassland of Upper Mustang, Nepal. *Yak Production in Central Asian Highlands, Proceeding of the Fourth International Congress on Yak*. Sichuan Publishing Group, Sichuan Publication House of Science and Technology, pp. 235-244.
- DeYoung RW, Honeycutt RL (2005) The molecular toolbox: genetic techniques in wildlife ecology and management. *J Wildl Manag* 69: 1362-1384.
- DNPWC (2011) *Protected Area of Nepal 2068*. Department of National Park and Wildlife Conservation, Government of Nepal, Babarmahal, Kathamandu, Nepal pp+ 59 (Nepali); access <http://www.dnpwc.gov.np/publications/pustika>
- Floyd TJ, Mech LD, Jordan PA (1978) Relating wolf scat content to prey consumed. *J Wildl Manag* 42: 528-532.
- Fox JL (1994) Snow leopard conservation in the wild - a comprehensive perspective on a low density and highly fragmented population. In: *Proceedings of the Seventh International Snow Leopard Symposium*, eds. J.L. Fox and D. Jizeng, pp. 3-15. International Snow Leopard Trust, Seattle, USA.
- Fox JL (1989) A review of the status and ecology of the snow leopard (*Panthera uncia*). International Snow Leopard Trust, Seattle
- Fox JL, Sinah SP, Chundawat RS, Das PK (1991) Status of the snow leopard *Panthera uncia* in northern India. *Biol Conser* 55: 283-298.
- Hall L S, Krausman PR, Morrison ML (1997) The habitat concept and a plea for standard terminology. *Wild Soci Bull* 25:173-182.
- Hunter DO, Jackson R (1997) *A range-wide model of potential snow leopard habitat*. In: R. Jackson and A. Ahmad (eds). *Proceedings of the 8th International Snow Leopard*

- Symposium, Islamabad, November 1995. International Snow Leopard Trust, Seattle and WWF-Pakistan, Lahore.
- IUCN (2011) *IUCN Red List of Threatened Species*. Version 2011.2. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 14 January 2012.
- Ivelv VS (1961) *Experimental Ecology of the feeding of Fishes*. Yales University Press, New Haven.
- Jackson R (2002) Snow leopard status, distribution and protected areas coverage. Contributed paper to Snow Leopard Survival Strategy Summit, the International Snow Leopard Trust, pp 79-102.
- Jackson RM, Roe JD, Wangchuk R, Hunter DO (2006) Estimating snow leopard population abundance using photography and capture-recapture techniques. *Wild Soci Bull* 32: 772-781.
- Jackson R, Ahlborn G (1984) A preliminary habitat suitability model for the snow leopard, *Panthera uncia*, in West Nepal. *Int. Ped. Book of Snow leopards* 4. 43-52.
- Jackson R, Hunter DO (1996) *Snow Leopard Survey and Conservation Handbook*. International Snow Leopard Trust, Seattle, USA.
- Jackson R, Mallon D, McCarthy T, Chundaway RA, Habib B (2008) *Panthera uncia*. In: IUCN 2011. *IUCN Red List of Threatened Species*. Version 2011.2. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 14 January 2012.
- Jackson RM (1996). Home range, movements and habitat use of snow leopard (*Uncia uncia*) in Nepal. PhD Thesis, University of London, London, UK.
- Janecka JE, Jackson R, Yuquang Z, Diqiang L, Munkhtsog B, Buckley-Beason V, Murphy WJ (2008) Population monitoring of snow leopards using noninvasive collection of scat samples: a pilot study. *Anim Conser* 11: 401–411.

- Karmacharya D, Thapa K, Shrestha R, Dhakal M, Janecka JE (2011) Non-invasive genetic population survey of snow leopards (*Panthera uncia*) in Kangchenjunga Conservation Area, Shey Phoksundo National Park and surrounding buffer zones of Nepal. BMC Res Notes. **4**:516.
- Khatiwada JR, Ghimery Y (2009) Status of Snow leopard (*Uncia uncia*) in Humla district, Western Nepal. Scientific World **7**: 49-52
- Krebs CJ (1989) *Ecological Methodology*. Harper and Row, New York, USA.
- Lovari S, Boesi R, Minder I, Mucci N, Randi E, Dematteis A, Ale SB (2009) Restoring a keystone predator may endanger a prey species in a human altered ecosystem: the return of the snow leopard to Sagarmatha National Park. Anim Conser **12**: 559-570. doi: 10.1111/j.1469-1795.2009.00285.x.
- MacArthur R H (1972) *Geographical Ecology: Patterns in the Distribution of Species*. Harper and Row. New York, USA.
- MacKenzie D I, Nichols JD, Gideon BL, Droege S, Royle JA, Langtimm CA (2002) Estimating site occupancy rates when detection probabilities are less than one. Ecology **83**: 2248–2255.
- MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey LL, Hines JE (2006) *Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence*. Academic Press, San Diego, California, USA
- McCarthy KP, Fuller TK, Ming M, McCarthy TM, Waits L, Jumabaev K (2008) Assessing estimators of snow leopard Abundance. J Wildl Manag **72**: 1826-1833.
- McCarthy T (2000) Ecology and conservation of snow leopards, Gobi brown bears, and wild Bactrian camels in Mongolia. Ph.D. Thesis. University of Massachusetts, Amherst.
- McCarthy TM, Allen PM, Fox J, Chapron G, Jackson RM, Mishra C, Theile S (2003) *Snow leopard survival strategy*. ISLT, Seattle.

- McCarthy TM, Fuller TK, Munkhtsog B (2005) Movements and activities of snow leopards in Southwestern Mongolia. *Biol Conser* 124: 527-537.
- Mukherjee S, Goyal SP, Chellam R (1994) Standardization of scat analysis techniques for leopards (*Pantera pardus*) in Gir National Park, Western India. *Mammalia* 58, 139-143
- Murphy WJ, Sun S, Chen ZQ, Pecon-Slattery J, O'Brien SJ (1999) Extensive conservation of sex chromosome organization between cat and human revealed by parallel radiation hybrid mapping. *Geno Res* 9: 1223-1230.
- Namgail T, Wieren SE, Mishra C, Prins HHT (2010) Multi-spatial co-distribution of the endangered Ladakh urial and blue sheep in the arid Trans-Himalayan mountains. *J Arid Environ* 74: 1162-1169.
- Oil MK (1997) Winter home range of snow leopards in Nepal. *Mammalia* 61: 335-360.
- Oli MK (1993) A key for the identification of the hair of mammals of a snow leopard (*Panthea uncia*) habitat in Nepal. *J Zool (London)* 231: 71-93.
- Oli MK, Taylor IR, Rogers ME (1993) Diet of the snow leopard (*Panthera uncia*) in the Annapurna Conservation Area, Nepal. *J Zool (London)* 231: 365-370.
- Oli MK (1994) Snow Leopards and Blue Sheep in Nepal: Densities and Predator: Prey Ratio. *J Mammal* 75: 998-1004.
- Majumder A, Basu S, Sankar K, Qureshi Q, Jhala Y V, Nigam P, Gopal R ( 2012) Home Ranges of the Radio-Collared Bengal tigers (*Panthera tigris tigris* l.) in Pench Tiger Reserve Madhya Pradesh Central Inida. *Wildl Biol Pract* 8(1): 36-49. doi:10.2461/wbp.2012.8.4
- Seidensticker J (1976). On the ecological separation between tigers & leopards. *Biotropica* 8:225–234. DOI:10.2307/2989714
- Smith JLD (1993) The role of dispersal in structuring the Chitwan tiger population. *Behaviour* 124: 165–195.

- Sunquist M E (1981) The social organization of tigers (*Panthera tigris*) in Royal Chitwan National Park. *Smithsonian Contributions to Zoology* 336: 1–98.  
DOI:10.5479/si.00810282.336
- Schaller G B (1977) *Mountain Monarchs: Wild Sheep and Goats of the Himalaya*. The University of Chicago Press: Chicago.
- Schaller GB (1998) *Wildlife of the Tibetan Steppe*. The University of Chicago Press: Chicago.
- Schaller GB, Junrang R, Mingjiang Q (1988) Status of the snow leopard in Qinghai and Gansu provinces, China. *Biol Conser* 45: 179-194.
- Schaller GB, Talipu HL, Hua L, Junrang R, Mingjiang Q, Haibin W (1987) Status of Large mammals in Taxkorgan Reserve, Xinjiang, China. *Biol Conser* 42: 53-71.
- Shehzad W, McCarthy TM, Pompanon F, Purevjav L, Coissac E, Raiz T, Taberlet P (2012) Prey Preference of Snow Leopard (*Panthera uncia*) in South Gobi, Mongolia. *Plos one* 7, e32104. Doi:10.1371/journal.pone.0032104
- Shrestha R, Wegge P (2008) Wild sheep and livestock in Nepal Trans-Himalaya: coexistence or competition? *Environ Conser* 35: 125–136.
- Wolf M, Ale SB (2009) Signs at the top: Habitat features influencing snow leopard (*Uncia uncia*) activity in Sagarmatha National Park, Nepal. *J Mammal* 90: 604-611.



## **Paper II: Blue sheep in the Annapurna Conservation Area, Nepal: Habitat use, population biomass and their contribution to the carrying capacity of snow leopards**

### **Abstract**

The Himalaya region of Nepal provides a habitat for the endangered snow leopard (*Panthera uncia*) and its principal prey species, the blue sheep (*Pseudois nayaur*). The aim of this study was to describe the habitat, the distribution and the population structure of blue sheep, and to estimate their contribution to the carrying capacity of snow leopard in the upper Mustang region of Nepal. Blue sheep were recorded at altitudes from 3209 to 5498 m on slopes with gradients of 16–60° and aspects of 40°NE to 140°SE. A total of 939 blue sheep were counted in the upper Mustang region, and 98 were counted in the Yak Kharka region of Manang District; however, upper Mustang had the lowest population density of blue sheep recorded within their distribution range in Nepal (0.86 blue sheep/km<sup>2</sup>). The results of the study show that a higher density of blue sheep is associated with greater plant species diversity. The most important species present in the blue sheep habitat were *Kobresia pygmaea*, *Artemesia* spp, *Lonicera* spp, *Lancea tibetica*, *Poa* spp, *Astragalus* spp and *Ephedra gerardiana*. It is estimated that the existing blue sheep population biomass of approximately 38 925 kg in the upper Mustang region could support approximately 19 snow leopards (1.6 snow leopards/100 km<sup>2</sup>).

**Key words:** carrying capacity, blue sheep, snow leopards, population density, habitat use.

### **Introduction**

The Himalaya region of Nepal provides prime habitat for the endangered snow leopard (*Panthera uncia*) and its principal prey species, the blue sheep (*Pseudois nayaur*), on which

snow leopard populations are heavily dependent (Rogers 1991, Oli et al. 1993, Aryal et al. 2010a, Lovari et al. 2009). The blue sheep appears to be present in virtually all appropriate mountainous terrain from the Qilian Mountains in the north to the Himalayas in the south (including China, Nepal, India, Pakistan and Mongolia), although detailed population estimates are lacking (Schaller 1977, Oli et al. 1993, Dagleish et al. 2007, Harris 2008, Aryal et al. 2010a). The greatest abundance of blue sheep is found in the Himalayan region of Nepal (Oli et al. 1993, Aryal et al. 2010a).

The presence of snow leopards, which are distributed throughout the northern mountains of Nepal, provides an indicator of a healthy and balanced ecosystem (Schaller 1977, Oli et al. 1993, Harris 2008, Aryal et al. 2010a). To maintain a healthy high altitude Himalayan ecosystem, it is essential that the biomass of blue sheep is maintained (Oli & Rogers 1996). Furthermore, throughout most of its distribution range, the snow leopard enters into conflict with humans because of livestock depredation, and the intensity of this conflict is inversely proportional to the availability of the natural prey (Oli et al. 1994). An understanding of the carrying capacity for predators such as the snow leopard will facilitate the management of human–wildlife conflict and this, in turn, will provide greater understanding of the interaction between prey and predators in the region.

Many factors influence the abundance and distribution of blue sheep. In China and Nepal, they are the target of trophy hunters (Harris 2008). For example, each year, the government of Nepal authorizes the harvesting of blue sheep in the Dhorpatan Hunting Reserve (DHR) by international trophy hunters (DNPWC 2011), but it is currently unknown whether the harvests are sustainable (Aryal et al. 2010a). Blue sheep are well-adapted to a high-altitude mountainous environment; they have physiological modifications in cardiopulmonary hemodynamics, the ability to exist on a diet of sparse graminoids and herbs, and exceptional agility on steep rocky terrain. Similarly, vegetation diversity and habitat patterns largely influence the distribution and

abundance of ungulates like blue sheep (Wang and Hoffman 1987, Sakai et al. 2003, Mishra et al. 2004, Dagleish et al. 2007, Shrestha and Wegge 2008, Aryal et al. 2010a).

In the Annapurna Conservation Area (ACA), an important region for the conservation of the high altitude Himalayan ecosystem, existing studies of blue sheep populations have been concentrated in the Manang District, and have focused on diet and home range (Oli et al. 1993; Oli 1996, Oli 1997, Shrestha and Wegge 2008). The upper Mustang region, by contrast, is more remote than the Manang region, and has a cold desert climate that provides a prime habitat not only for snow leopards and blue sheep, but also for other globally threatened species such as the brown bear. However, partly as a result of its remoteness, there is a lack of information on the distribution, population status and habitat requirements of these species.

In this study, we aimed to acquire detailed information about the population status and habitat use of blue sheep in the upper Mustang region of the Mustang District, and to compare this with the Yak Kharka region of the Manang District. We included in our study a comparison of features of the habitats used by blue sheep in the 2 regions, including the vegetation food base, and estimated the carrying capacity for snow leopards based on the available blue sheep population in the upper Mustang.

## **Method and Materials**

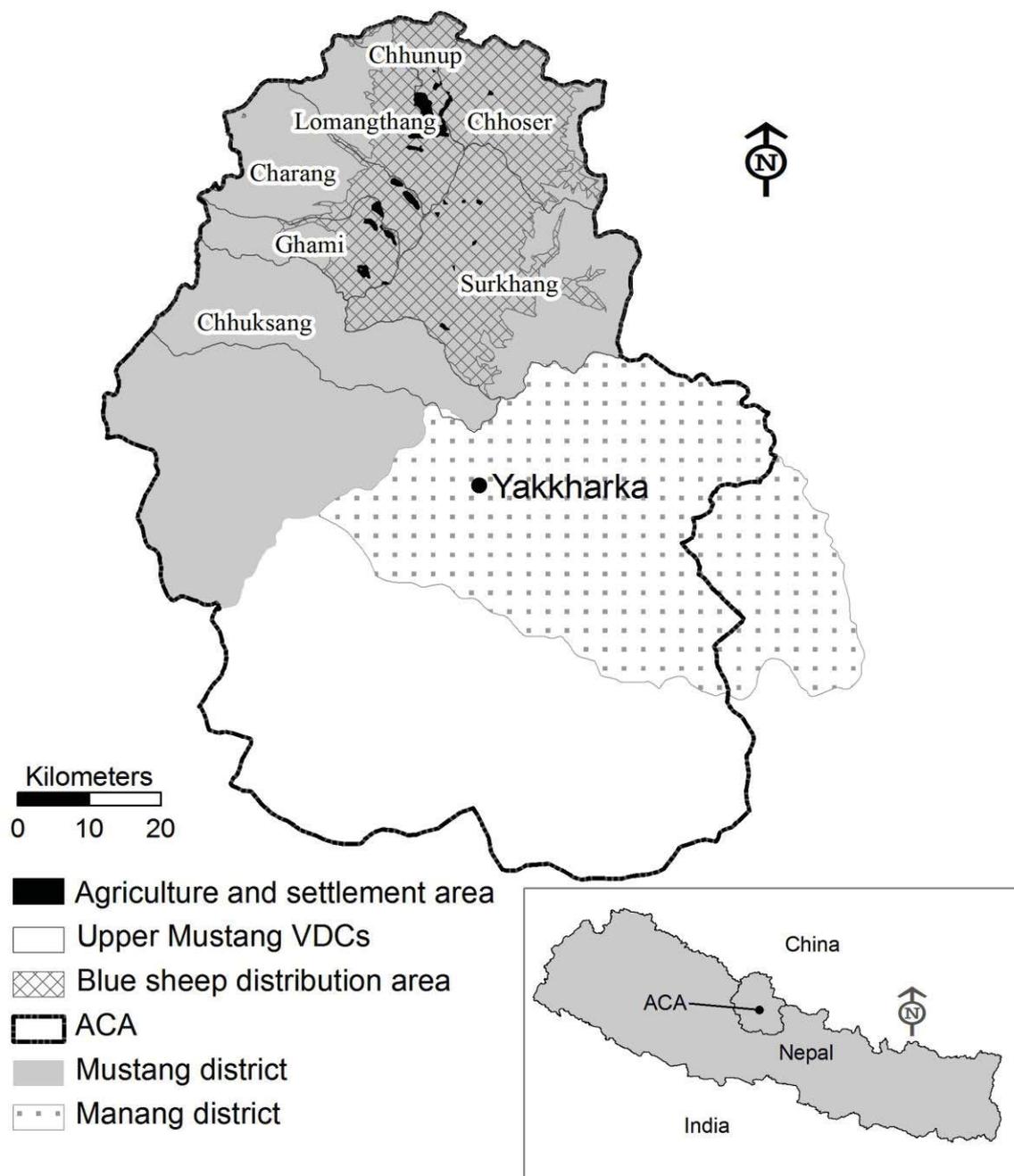
### **Study area**

This study was conducted in the upper Mustang region of the Mustang District and in the Yak Kharka region of Manang District of Nepal (Fig. 1).

In upper Mustang, the research was centred on Lomangthang and its surrounding village development committees (VDCs), including Chhoser, Chhunup, Surkhang, Charang, Ghami and the Samer area of Chhuksang VDC. This region lies in the northern part of the Mustang District

at approximately 83°45' to 84°E and 29°04'12" to 29°18'N. The area can be characterized as a cold desert, desiccated by strong winds and intense solar radiation. The climate is sub-alpine, with temperature ranges of 26.8°C to −5.8°C. The whole area remains under snow for 4–5 months from November to March. Total annual rainfall is less than 200 mm and more than half of the total precipitation occurs as snow during the winter months (Chetri & Gurung 2004, Chetri 2008, Aryal et al. 2012). The region falls in the Dhaulagiri–Annapurna mountain rain-shadow zone, and includes a unique assemblage of rare and endangered species. These include the Tibetan argali (*Ovis ammon hodgsonii*), the Tibetan gazelle (*Procapra picticaudata*), the wild ass (*Equus kiang*) and the blue sheep (*Pseudois nayaur*), as well as several predators: the snow leopard, the lynx (*Lynx lynx isabellinus*), the red fox (*Vulpes vulpes*), the brown bear (*Ursus arctos*) and the grey wolf (*Canis lupus*) (Chetri & Gurung 2004, Chetri 2008, Aryal et al. 2012).

The Yak Kharka region of Manang District, which provides potential habitat for blue sheep and snow leopards (Oli et al. 1993; Oli 1997), lies in the north-west part of the district, covering an area of 2246 km<sup>2</sup> (28°27'–28°54'N and 83°40'–84°34' E) of the Trans-Himalayan region (Fig. 1). The elevation ranges widely (1600 m to Mount Manasalu at 8156 m), and, thus, has diverse climatic conditions.. Approximately 9% of the total land of the district is covered with forest and the remaining land is used for grazing and other purposes (Aryal et al. 2007). The Yak Kharka region is well suited for livestock grazing and the local people also collect a highly valuable medicinal plant from the area, *Cordyceps sinensis*, which is among the world's most expensive medicinal plants (Aryal et al. 2007). The movement of local people, livestock and tourists is significantly higher in this region (Aryal et al. 2007).



**Figure 1** Annapurna Conservation area: 6 VDCs of upper Mustang region of Mustang district and Yak Kharka region of Manang district. ACA, Annapurna Conservation Area; VDC, village development committees.

## Data collection

A habitat survey was conducted during November and December 2009 in the upper Mustang region and during January and February 2010 in the Yak Kharka region. A random sampling method was used to record different parameters from the blue sheep's habitat in the study area. Habitat use plots of  $20 \times 20$  m were laid out in areas that contained indicators of blue sheep. The signs or indicators recognized as evidence of blue sheep were pellets, hair, foot prints, resting sites and direct observation. The following parameters were recorded for each plot: slope, altitude, ground cover, land features, and signs of other ungulates and livestock. In total, 158 plots of  $20 \times 20$  m in size were laid out in the blue sheep habitat of the upper Mustang region, and similarly, 87 were laid out in the Yak Kharka Manang region. In addition, in each  $20 \times 20$  m plot, sub-plots of  $4 \times 4$  m were laid out to survey the shrub layer (woody plants below 3 m in height) and  $1 \times 1$  m sub-plots were laid out to survey herbs (plants up to 1 m in height). For the upper Mustang District,  $n = 158$ ; and for the Yak Kharka region,  $n = 87$ . In other words, in every  $20 \times 20$  m plot, 1 sub-plot was established in a randomly selected corner for herb measurements and 1 sub-plot was laid out in a random corner for shrub measurements. Within these plots, records were made of vegetation height, physical cover (cliffs, hills, broken land, gullies, water bodies, forests, shrubs and grassland), ground cover, signs of other animals, slope, altitude, aspect, and signs of anthropogenic pressures, such as livestock grazing and dung collection. The ground cover by grass was classified into the following percentage-based categories: open (0–25% cover); medium (25–50% cover); good (50–75% cover); and extensive (75–100% cover). Slopes were divided into 4 categories: north-east (NE] =  $(0-112.5^\circ)$ , south-east (SE] =  $112.5-202.5^\circ$ , south-west (SW] =  $202.5-292.5^\circ$  and north-west (NW] =  $292.5-360^\circ$ .

## Biological diversity

Vegetation surveys in the upper Mustang region of the Mustang District and in the Yak Kharka area of the Manang District were used to estimate the species diversity, species richness and evenness in these study areas. Simpson's diversity index was used, which measures the probability that 2 individuals selected at random from a habitat will belong to different species and indicates effective number of different species in the habitats (Rosenzweig 1995, Ravindranath et al. 1997). Simpson's index of Diversity ( $D$ ) is calculated using the following equations:

$$D_s = \sum n_i(n_i - 1) / N(N - 1) \quad (1)$$

$$D = 1 - D_s, \quad (2)$$

where  $D_s$  is the diversity index,  $n_i$  is the number of individuals belonging to a species  $i$  with  $i = 1$  to  $k$  ( $k$  being the total number of species).  $N$  is the total number of individuals of all species. The value of this index ( $D$ ) ranges between 0 (low diversity) and 1 (maximum diversity). This means that a perfectly homogeneous community (i.e. a single species) would have a diversity index score of 0, and a maximally heterogeneous population (where all individuals belong to different species) would have  $D$  score of 1 (assuming infinite categories with equal representation in each category).

The importance value index (IVI) of vegetation was calculated in order to understand the relative importance of different plants in the blue sheep habitat (Aryal 2009, Aryal et al. 2010b). The following formulae were used for calculating the IVI:

$$\text{Frequency} = \text{Number of plots containing the particular species} \times 100 / \text{Total number of plots}$$

*Relative frequency (RF)* = Frequency of any 1 species × 100/Total frequency of all species

*Density* = Total number of individual species in all plots/Total number of plots× area of plots

*Relative Density (RD)* = Density of a species × 100/Total density of all species

*Relative Coverage (RC)* = Coverage of a species × 100/Total coverage

*Importance Value Index (IVI)* = *RF* + *RD* + *RC* (Aryal 2009, Aryal et al. 2010b).

### **Blue sheep density and distribution**

Blue sheep were counted between morning and sunset (08.00 to 18.00 hours) using a fixed-point count method (Schaller 1973, Wegge 1976, Jackson et al. 1996, Aryal et al. 2010). Direct observations, aided by binoculars (8–42×) and a spotting scope (15–45×), were used to make counts from high vantage points, along ridgelines, walking along existing trails and from lower to upper valleys. Horses were used for access, and knowledgeable local people were employed to assist with the surveys. The team was divided into 4 groups of 3 people to count blue sheep in different areas of the VDC. When blue sheep were sighted, they were classified by sex and age into 4 main categories: lambs, yearlings, ewes and rams (Aryal et al. 2010). Rams were further classified into 3 classes (Wegge 1976, Aryal et al. 2010a): Class I (2–3 years; horn length 15–35 cm), Class II (4–7 years; horns curved backward with a length of 30–45 cm) and Class III (7+ years; horns curved and over 45 cm in length).

### **Carrying capacity for snow leopards**

To estimate the maximum number of snow leopards that can be supported by the existing blue sheep population (their primary prey) in the upper Mustang region, we used estimates of blue

sheep biomass, snow leopard home ranges, the potential available habitat and the amount of food required by snow leopards (kg/year).

The parameters for our estimates of snow leopard carrying capacity were derived as follows (Equation 3). The average home range size of 22.6 km<sup>2</sup>/snow leopard was based on calculations of the Nepal snow leopards' home range size of 11.7–38.9 km<sup>2</sup> (Jackson and Ahlborn 1989) and 13.9–22.3 km<sup>2</sup> (Oli 1997). The areas between 3000 and 5500 m above sea level were considered to be the potential habitat for snow leopards in upper Mustang region (Fig. 1). The body mass of male and female blue sheep used for biomass calculations was 60–75 kg and 35–55 kg, respectively (Wang and Hoffmann 1987) and the mean weight for each sex was used to calculate carrying capacity. For yearlings and lambs, the average half weight of female blue sheep was used (Equation 3). It was assumed that the blue sheep birth and death ratio was 2:1, based on Wegge's estimate (1979) that 50% of blue sheep die between birth and 2 years of age (Schaller 1977) in DHR, Nepal. An adult snow leopard requires approximately 1.5 kg food/day, which amounts to 548 kg of meat per year (Schaller 1977).

The ecological sustainable stocking rate (ESSR), which was defined for the purposes of this research as the maximum number of snow leopards (km<sup>2</sup>/animal unit year) that can be supported by the available biomass of blue sheep given inherent biophysical constraints, was used in the study to achieve an ecological goal of sustainable health and proper function of the community population (Alberta 2004, Aryal 2007). A figure of 25% was determined in this study to be appropriate as a “safe use factor,” as described by Alberta (2004) and Aryal (2007) for carrying capacity calculations (Equation 3). A “safe use factor” is defined as the total biomass production of the ecological site that is available for use by animals with the remaining biomass available for ecological sustainability. In our calculations, we allocated 25% of blue sheep numbers or biomass production (carry over) for the snow leopard and considered the remainder as available for the maintenance of ecological functions, for other predators and for

sustained reproduction (Alberta 2004, Aryal 2007). The nature of the environment and human disturbance in the region that had been responsible for the grassland productivity and was directly related to prey and predator population performance was also taken into consideration in calculating ESSR (Equation 3). For this we used the maximum estimated human environmental disturbance coefficient of 25%:

$$\text{Carrying capacity for snow leopards} = \frac{\text{Area (km}^2\text{) (3000–5500 m elevation as a potential area for snow leopards)}}{\text{ESSR (Ecological Sustainable Stocking Rate) } \times \text{Average home range size of snow leopard}}$$

$$\text{ESSR} = \frac{\text{Blue sheep (biomass) kg/per snow leopard need per year}}{\text{Total blue sheep biomass (kg)/km}^2 \times \text{Safe use factor (25\%)} \times \text{(birth and death ratio)} \times \text{Environment and human disturbance factor in the potential habitat}}$$

(3)

## Results

### *Habitat use of blue sheep*

#### *Altitude use*

Blue sheep were recorded across an altitude range of 3209–5498 m in the upper Mustang (mean 4193 m, SD 609m), and 3128–5200 m in Manang (mean 4061 m, SD 627 m) (Fig. 1). Blue sheep made greater use of higher elevations in upper Mustang than in Yak Kharka ( $F = 1.5$ ,  $P < 0.05$ ). In the Yak Kharka region, they were mostly found at elevations spanning 3501–4000 m (29%) and 4001–4500 m (30%), and in upper Mustang from 4000 to 4500 m (26%) and 4500 to

5000 m (29%). Elevations of 3000–3500 m and above 5000 m were not used as frequently as other altitudes (Fig. 2).

#### *Habitat use in relation to aspect, slope and elevation*

Blue sheep were recorded more often in areas with a 16–30° slope (Yak Kharka region of Manang 49% and upper Mustang 71%), and the number gradually decreased in areas with shallower and steeper slopes (Fig. 3). In the Yak Kharka region of Manang, blue sheep were associated with slopes of 0–15° in 31% of sightings, while the equivalent value was 7% in Mustang. There was a trend for blue sheep to use steeper sloped areas (>16°) in the upper Mustang region than in the Yak Kharka region of Manang, but this did not reach statistical significance ( $F = 1.39, P > 0.05$ ). The north-east (NE) aspect was used mainly by blue sheep in the upper Mustang region (50%), while mainly the south-west (SW) aspect was used in the Yak Kharka region of Manang (54%) ( $F = 3.47, P < 0.05$ ) (Fig. 4). The hills were divided into 3 height categories: the upper one-third, the middle one-third and the lower one-third. Blue sheep were mainly recorded in the middle one-third slope position (47%) in the Yak Kharka region of Manang, while they made the most use of the lower one-third slope position (43%) in the upper Mustang region (Fig. 5). The middle one-third (20%) and lower one-third (21%) slope positions were used less in the upper Mustang region and in the Yak Kharka region of Manang ( $F = 0.76, P > 0.05$ ).

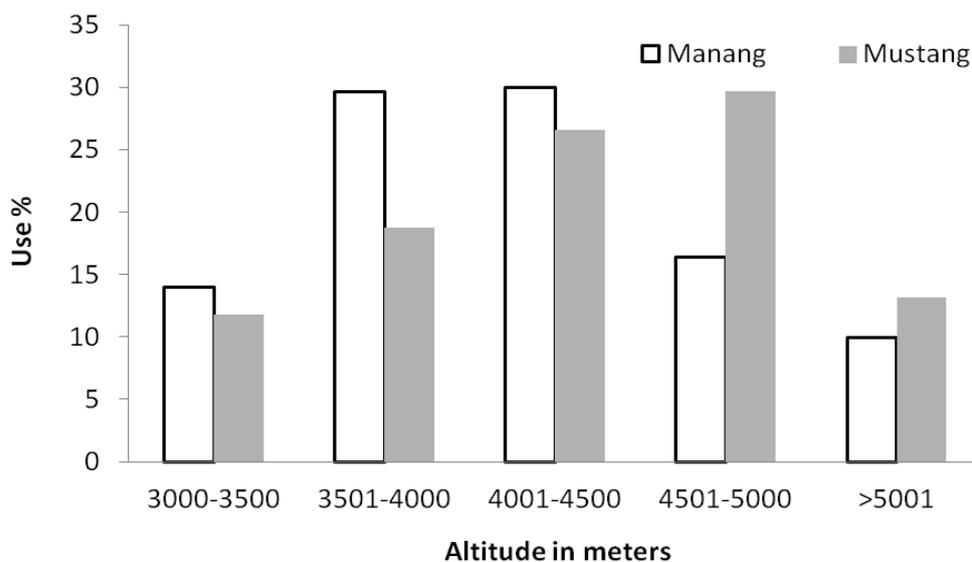
#### *Ground cover*

In the Yak Kharka region of Manang, only 10% of the blue sheep habitat had 76–100% ground cover (Fig. 6). However, areas with higher ground cover (>26%) were significantly more abundant in the Yak Kharka region of Manang compared to the upper Mustang ( $F = 1.43, P < 0.05$ ). Areas categorized as “open” ground cover (0–25%) were used more often by blue sheep

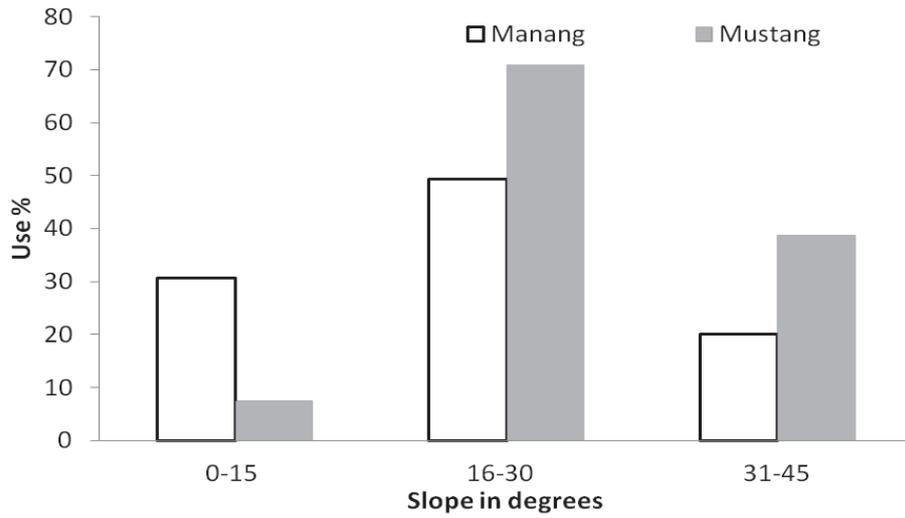
in the upper Mustang region, while areas with 26–50% of ground cover were used more often in the Yak Kharka.

#### *Physical cover in blue sheep habitat*

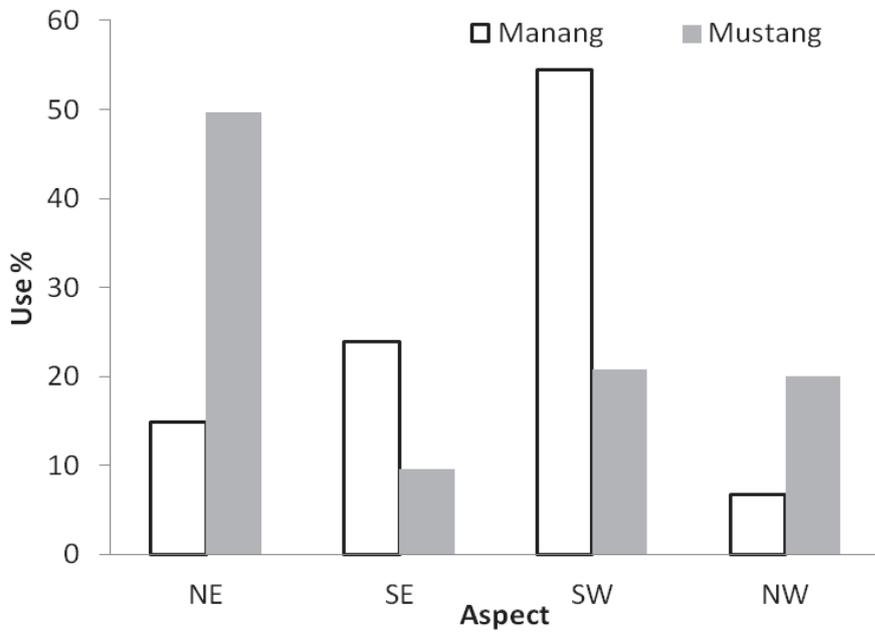
We recorded the cliffs, gullies, brown land, shrub land, ridges and caves surrounding the 50-m radius of each plot. We considered such features relevant, because they potentially provide cover for both predator and prey. The blue sheep mainly used ridges and cliffs, and were less likely to use rocky areas and caves (Fig. 7). The type of habitats used was similar in both study sites ( $F = 0.001, P > 0.05$ ).



**Figure 2.** Altitude used by blue sheep



**Figure 3.** The slope of areas used by blue sheep



**Figure 4.** Aspects used by blue sheep



Figure 5. Hill slope position used by blue sheep

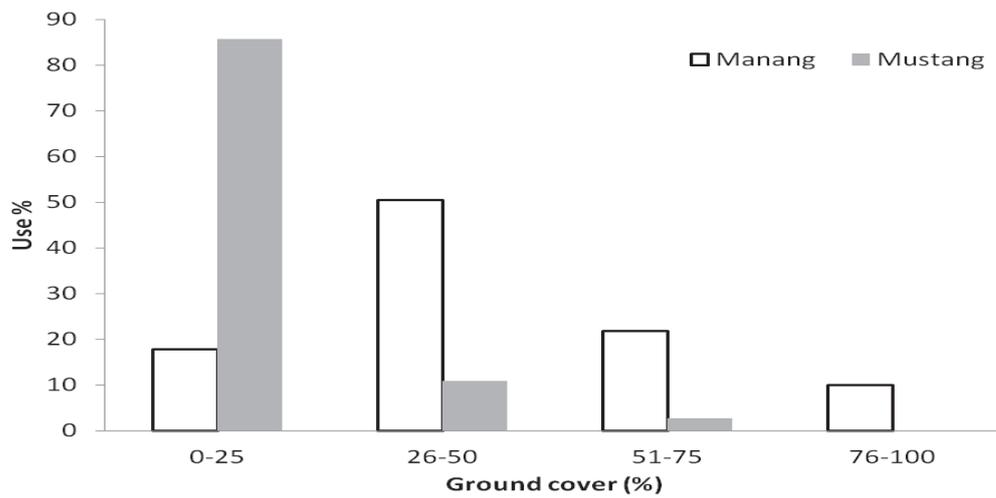
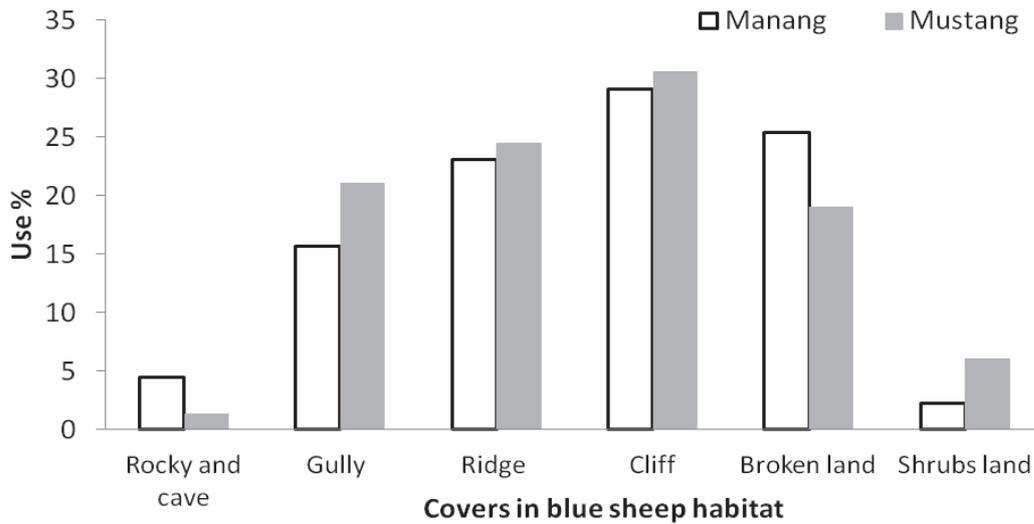


Figure 6. Ground cover used by blue sheep



**Figure 7.** Surrounding habitat feature in blue sheep habitat

*Plant species diversity and the importance value index in the blue sheep habitat*

Plants species diversity was higher in the Yak Kharka region ( $D = 0.924$ ) than in the upper Mustang region ( $D = 0.789$ ), suggesting that the Yak Kharka region has a more heterogeneous species community. The species were equally distributed in the Yak Kharka region ( $F = 1.37$ ,  $P > 0.05$ ). However, significantly higher species richness and frequency were found in the upper Mustang region when compared with the other areas ( $F = 3.15$ ,  $P < 0.05$ ). *Kobresia pygmaea* was the most important (IVI = 38), followed by *Lonicera* spp (IVI = 22), *Artemesia* spp (IVI = 20.94), *Spirea arcuata* (IVI = 15.32), *Caragana* spp (IVI = 14), *Berberis aistata* (IVI = 12), *Potentilla fraticos* (IVI = 11), and *Ephedra gerardiana* (IVI = 8.98) in the Yak Kharka region of the Manang District (Table 1).

In upper Mustang, *Kobresia pygmaea* was the most important (IVI = 58), followed by *Caragana* spp (IVI = 48), *Artemesia* spp (IVI = 22), *Lonicera* spp (IVI = 22), *Poa* spp (IVI = 16.40), *Astragalus* spp (IVI = 14.7), *Lancea tibetica* (IVI = 9.19), *Lonicera* spp (IVI = 8) *Potentilla* spp (IVI = 9) and *Ephedra gerardiana* (IVI = 9.18) (Table 2).

**Table 1.** Important value index (IVI) of vegetation in blue sheep habitat of Yak Kharka region

of Manang District

Species	Relative frequency	Relative density	Relative cover	IVI
<i>Androsce muscoidea</i>	0.76	1.20	0.72	2.68
<i>Aster</i> spp	1.45	1.65	2.20	5.30
<i>Potentilla fraticosa</i>	6.10	2.40	2.59	11.09
<i>Artemesia</i> spp	4.20	9.40	7.34	20.94
<i>Spirea arcuata</i>	10.60	3.10	1.62	15.32
<i>Rhododendron lepidotom</i>	1.09	1.01	1.91	4.01
<i>Ephedra gerardiana</i>	3.09	2.21	3.68	8.98
<i>Carex</i> spp	6.20	8.40	4.80	19.40
<i>Juniperous squamata</i>	1.30	1.09	2.48	4.87
<i>Berberis aristata</i>	8.10	2.61	1.40	12.11
<i>Kobresia pygmaea</i>	15.10	9.60	13.30	38.00
<i>Anaphalis contorta</i>	7.20	4.10	7.10	18.40
<i>Gentianella</i> spp	2.18	0.91	2.67	5.76
<i>Juniperous indica</i>	2.07	1.60	4.14	7.82
<i>Salix</i> spp	0.36	0.53	1.60	2.49
<i>Myricarna squmosa</i>	0.55	0.89	0.17	1.61
<i>Hippopha tibetana</i>	0.36	3.50	1.67	5.53
<i>Clematis tibetiana</i>	0.18	1.20	0.31	1.69
<i>Berberis erythroclades</i>	4.10	1.60	2.71	8.41
<i>Caragana</i> spp	1.80	7.62	4.82	14.24
<i>Selinam wallichianum</i>	0.17	2.30	0.20	2.67

<i>Rhododendron anthopogen</i>	4.10	1.58	1.61	7.29
<i>Saxifraga andersonil</i>	0.35	3.80	4.22	8.37
<i>Contonester microphyllus</i>	6.20	6.10	2.47	14.77
<i>Gentianetla depressa</i>	1.70	2.71	0.63	5.04
<i>Thymus linearis</i>	0.21	1.65	0.68	2.54
<i>Lonicera spp</i>	6.81	6.59	9.40	22.80
<i>Rosa cerocia</i>	0.18	0.42	2.61	3.21
<i>Romix nepalensis</i>	0.47	0.71	1.74	2.92
<i>Thermopsis lanceolata</i>	0.15	1.40	0.68	2.23
<i>Verbascom thpsom</i>	0.36	0.97	0.75	2.08
<i>Oxytropis spp</i>	0.55	2.10	1.31	3.96
<i>Genetiana robusta</i>	0.73	0.66	1.80	3.19
<i>Lentopodiom spp</i>	0.36	0.84	2.40	3.60
<i>Tanije spp</i>	0.36	0.70	0.71	1.77
<i>Astragalus spp</i>	0.18	0.69	1.30	2.17
<i>Polygonatom spp</i>	0.16	1.36	0.89	2.41
<i>Chenopodiom albom</i>	0.15	0.80	0.26	1.21

**Table 2.** Important value index (IVI) of vegetation in blue sheep habitat of upper Mustang region of Mustang district

Species	Relative frequency	Relative density	Relative cover	IVI
<i>Anaphalis spp</i>	2.60	4.60	1.50	8.70

---

<i>Anaphalis triplinervis</i>	0.11	0.19	0.20	0.50
<i>Androsace</i> spp	0.50	0.70	0.06	1.26
<i>Bistorta</i> spp	4.10	7.03	2.58	13.71
<i>Carex</i> spp	11.36	17.20	14.3	42.86
<i>Cortia depressa</i>	1.49	2.60	0.70	4.79
<i>Euphorbia estachyei</i>	5.70	2.50	0.98	9.18
<i>Caragana</i> spp	13.00	16.20	19.5	48.70
<i>Corydalis govaniana</i>	0.62	1.70	0.07	2.39
<i>Clematis</i> sp	3.10	1.60	0.60	5.30
<i>Kobresia pygmaea</i>	15.73	17.60	23.20	56.53
<i>Lancea tibetica</i>	2.40	4.79	2.00	9.19
<i>Pedicularis</i> spp	0.14	0.21	0.70	1.05
<i>Poa</i> spp	6.80	3.20	6.40	16.40
<i>Chesneya nubigena</i>	0.40	0.69	0.50	1.59
<i>Potentilla</i> spp	3.20	1.35	4.62	9.17
<i>Saussurea nepalensis</i>	0.08	0.15	0.04	0.27
<i>Artemisia</i> spp	11.49	6.20	4.60	22.29
<i>Saxifraga</i> spp	3.70	0.70	2.60	7.00

---

<i>Oxytropis</i> spp	1.06	1.89	0.90	3.85
<i>Lincera</i> spp	1.46	2.41	4.40	8.27
<i>Spirea arcuata</i>	0.74	1.27	0.50	2.51
<i>Astragalus</i> spp	8.94	2.60	3.20	14.74
<i>Gentianella</i> spp	0.14	0.27	1.60	2.01
<i>Contonester microphyllus</i>	0.37	0.82	2.50	3.69
<i>Thymus linearis</i>	0.10	0.19	1.30	1.59
<i>Aster</i> spp	0.14	0.25	0.10	0.49
<i>Verbascom thpsom</i>	0.53	1.09	0.35	1.97

### *Blue sheep population*

A total of 939 blue sheep were counted in 67 herds in 6 VDCs of the upper Mustang region and 98 blue sheep were counted in 12 herds in Yak Kharka region and its surrounding area (Table 3). The group sizes were 1 to 58 individuals in the upper Mustang and 4 to 26 in the Yak Kharka region. There was a significant difference in the herd composition (age and sex) in different areas of upper Mustang ( $\chi^2 = 46.2$ ,  $P < 0.001$ ). Blue sheep were distributed across 1089 km<sup>2</sup> of the Mustang, and the Chhoser, Ghami and Chhunup VDCs supported a higher density of blue sheep when compared to other VDCs of the upper Mustang region (in descending order: the Lomangthang, Surkhang, Charang VDCs and Samar area). The Damodar Kund valley of the Surkhang VDC and the Dhalung Chhujung and Samjung regions of the Chhoser VDC provided

a prime habitat for blue sheep. In the upper Mustang region, the blue sheep population density was highest in the Chhoser VDC (1.84 blue sheep/km<sup>2</sup>) and lowest in the Lomangthang VDC (0.51 blue sheep/Km<sup>2</sup>). Of all areas, however, the highest population density was found in the Yak Kharka region (2.09 blue sheep/km<sup>2</sup>) (Table 3). The male : female sex ratio of blue sheep was 1:1.2 and 1: 2.1 in the upper Mustang region and the Yak Kharka region, respectively.

**Table 3.** Blue sheep population parameters in upper Mustang region of Mustang District and Yak Kharka region of Manang District, Nepal

VDC name of upper Mustang	Total number	Adult female	Lamb	Yearling	Total male	Class I	Class II	Class III	Current blue sheep distribution area (km <sup>2</sup> )	Density blue sheep/km <sup>2</sup>
Upper Mustang district										
Chhoser	150	75	16	18	41	4	6	31	80	1.86
Ghami	186	78	24	33	51	8	14	29	107	1.74
Surkhang	269	110	19	47	93	21	25	47	481	0.56
Charang	72	22	8	15	27	3	5	19	80	0.90
Chhunup	103	32	15	17	39	5	16	18	86	1.20
Lomangthang	85	37	8	13	27	4	9	14	166	0.51
Samar <sup>†</sup>	74	21	12	23	18	1	8	9	89	0.83
Total <sup>‡</sup>	939	375	102	166	296	46	83	167	1089	0.86
Manang District										
Yak Kharka	98	49	7	19	23	5	7	11	47 <sup>§</sup>	2.09

<sup>†</sup>Samar lies in Chhuksang village development committees (VDC) of upper Mustang; we only surveyed the surrounding Samar area and did not cover the whole area of Chhuksang VDC area. <sup>‡</sup>The total number of blue sheep in upper Mustang region. <sup>§</sup>Yak Kharka region of Manang District of Nepal. <sup>¶</sup>Approximate survey area in Yak Kharka region

### *Carrying capacity of the upper Mustang for snow leopards*

Our calculations suggested that a total blue sheep biomass of approximately 38 925 kg is available in the upper Mustang region, with the highest biomass per km<sup>2</sup> found in Chhunup and Ghami, followed by the Chhoser, Surkhang and Lomangthang VDCs (Table 4). The blue sheep population was distributed from 3000 to 5500 m elevation, which is the same range over which signs of snow leopards were found in the upper Mustang region. Productivity of this region is also influenced by climate and other environmental factors. In addition, detrimental human activities, such as poaching and livestock grazing, which also influence blue sheep population growth and, hence, carrying capacity for predators, frequently occurred in the blue sheep habitat. Taking these factors into account (Equation 3), our calculations suggested that the blue sheep population in the Upper Mustang region can support a maximum of 19 snow leopards with population density of 1.6 individuals/100km<sup>2</sup> (Table 4). Surkhang VDC can support a maximum of 9 snow leopards, followed by 5 snow leopards in Chhoser VDC and 4 snow leopards in Ghami VDC (Table 4). Local people ( $n = 611$ ) reported that snow leopards frequently killed livestock in the upper Mustang region, and that other prey species were also present, such as marmot, Tibetan argali, the Tibetan gazelle and the wild ass.

**Table 4.** Blue sheep biomass (kg); potential areas of snow leopards distribution and carrying capacity for snow leopards in the upper Mustang region

VDC name	Biomass of blue sheep (kg)					Potential area for snow leopard km <sup>2</sup>	Biomass s/km <sup>2</sup> VDC	Each VDC ESS R	Carrying capacity for snow leopard/km <sup>2</sup>	Carrying capacity for snow leopard/100km <sup>2</sup>	Total carrying capacity in each site
	Female	Lamb	Yearling	Total male	Total in each VDC						
Chhoser	3375	720	810	1845	6750	250	19.71	47.4	0.02	1.7	4.26
								1			
Ghami	3510	1080	1485	2295	8370	107	41.61	14.0	0.02	2.1	2.26
								1			
Surkhang	4950	855	2115	4185	12105	306	16.27	43.5	0.03	3.1	9.35
								5			
Charang	990	360	675	1215	3240	80	9.957	27.0	0.01	0.8	0.65
								6			
Chhunup	1440	675	765	1755	4635	86	47.78	20.3	0.01	1.2	1.01
								4			
Lomangthang	1665	360	585	1215	3825	166	14.32	47.5	0.01	1.0	1.60
								6			
Total	15 930	4050	6435	12510	38 925	995	Maximum carrying capacity for snow leopard				19.13

## Discussion

### *Habitat use by blue sheep*

An earlier study found that in the DHR, blue sheep were confined to a range spanning 3810–4115 m, but within this range used higher and lower elevations equally (Wilson 1981). The

present study found that in the ACA, blue sheep ranged over higher altitudes, exceeding 4200 m, which likely reflects a greater abundance of resources at higher altitudes in ACA. However, our surveys have found that local people claim that over recent years grass resources have diminished in higher mountain and pasture land areas, especially in the winter when the upper region is covered by snow (A. Aryal *et al.*, unpublished data). As a consequence, blue sheep tend to move down to lower elevations to graze on crops in the upper Mustang region. In the Manang region, blue sheep are distributed across the lower areas compared with Mustang, but, nonetheless, higher than DHR. This distribution corresponds with productive land with higher species diversity. Together, these observations suggest that food availability and heavy snow fall are the likely factors that drive the blue sheep population to a lower or higher elevation. However, other factors are also likely to play a role. For example, Wilson (1981) found that females use higher and more rugged terrain in response to disturbances caused by courting males.

There are other differences in habitat use between DHR and ACA. In DHR, Wilson (1981) observed that blue sheep prefer areas with a slope of less than 20°, whereas in the present study we found that in ACA they used areas with a slope of 16–30°. There was a suggestion that in Manang blue sheep selected habitat with shallower slope than Mustang, but this was not statistically significant. Our observations suggest that in ACA, shallower slopes are used predominately for grazing, whereas steeper slopes (31°) and rough terrain are used for resting and avoiding predation. Wilson (1981) also found that in DHR, blue sheep mostly used the south-east and south-west aspects, but this varied according to season. By contrast, our study found that in both Mustang and Manang, the north-east facing slope was predominately used throughout the year. This is likely due to the fact that in upper Mustang the north-eastern aspect provides a colder environment and is a semi-desert, conditions that support a higher biomass of

edible grass. In Manang, the north-eastern facing areas are warmer and support greater vegetation biomass.

Our study suggests that both the species diversity and abundance of grasses influence the population density and distribution of blue sheep. The upper Mustang region covers a larger area than the Manang region, but it has low grass species diversity and, probably for this reason, has a low population density of blue sheep compared with other parts of their distribution range within Nepal.

#### *Blue sheep population densities*

Previous studies estimated densities of blue sheep are 1.8 blue sheep/km<sup>2</sup> in the Barse and Phagune blocks of DHR (Aryal *et al.* 2010), and 2.65/km<sup>2</sup> in Shey Phoksundo National Park (Schaller 1977). Oli (1991) estimates 6.6 to 10.2 blue sheep/km<sup>2</sup> in the Manang District of the Annapurna Conservation area. In the present study we estimate a density of 0.86 blue sheep/km<sup>2</sup> in upper Mustang, which is the lowest density for any site studied to date. Our estimate of blue sheep density in the Manang was more in line with estimates from elsewhere (2.04 blue sheep/km<sup>2</sup>), but, nonetheless, considerably lower than the 6.6–10.2 blue sheep/km<sup>2</sup> estimated for the same region 2 decades ago (Oli 1991). These results suggest both regional and temporal effects on the carrying capacity of blue sheep in Nepal. The apparent decline in the density of these herbivores in Manang between 1991 and the present is alarming. Without longitudinal studies, at present we have no way of determining the extent to which current carrying recorded elsewhere reflects the intrinsic ecological circumstances or human disturbance. It is, however, highly likely that diminishing populations are associated with climate change and other anthropogenic influences, including competition with livestock and poaching, both of which are major factors correlated with blue sheep abundance in the study area.

### *Carrying capacity for snow leopards*

There have been several attempts to calculate carrying capacity of herbivores (East 1984, Fritz and Duncan 1994, Aryal 2007), but comparatively little attention has been given to the carrying capacity of predators. The strong influence not only of prey abundance, but also diversity (Petchey 2000) and population dynamics (Arrow et al. 1995, Petchey 2000) make accurate estimates of predator carrying capacities a challenge. However, given the importance of predators in ecosystems, such estimates are important. In the present study, we estimated the contribution of the main prey species, blue sheep, to the carrying capacity of the main predator, the snow leopard. By comparing this estimate with direct estimates of snow leopard density in ACA, our estimates suggest that blue sheep alone are not sufficient to sustain the observed population densities. Other, relatively minor, prey species (e.g. marmot, woolly hare and pika) in the area no doubt account partially for biomass of snow leopards in ACA, but other predators also subsist on this resource base (e.g. brown bear, wolf, fox and jackal). Further studies are needed to quantify the details of these other trophic interactions within the ecosystem.

There is, however, abundant evidence that a major contributor to the diet of snow leopards is livestock (Oli et al. 1993, Oli et al. 1994, A. Aryal et al. unpublished data). Indeed, elsewhere we have estimated that in the ACA area alone, approximately 500 livestock are lost to snow leopards annually (A. Aryal et al. unpublished data). This presents a serious source of human-wildlife conflict in ACA (Oli et al. 1993, Oli et al. 1994).

Information on the relative contributions of different prey to sustaining the snow leopard population can help to predict how changes in the numbers and proportions of prey can impact on human substance and the ecology of the region. Soil quality and rainfall, which determine vegetation growth and rangeland productivity, have important effects on the carrying capacity of ungulates (Bell 1982; East 1984; Fritz & Duncan 1994), and an increase or decrease in ungulates has a direct impact on the predator population. The upper Mustang region has a very low rainfall

(<200 mm) and the soil is more exposed than other areas in ACA and is very dry. These factors directly affect rangeland productivity and influence the trophic dynamics (Petchey 2000). As a result, the blue sheep biomass changes with climatic and vegetation patterns, which, in turn, affect the population dynamics of the snow leopard. When the population of wild prey is reduced, snow leopards are likely to increase preying on livestock, with a consequent increase in human–snow leopard conflict in the area.

In the present study we used 25% as a “safe use” factor because there are other predators, such as the wolf, lynx, red fox and jackal, in the study areas, and it was assumed that if only 25% of the blue sheep population was consumed by snow leopards, the remaining population would be available for other predators and maintain the ecological balance. Birth : death ratios of 2:1 were used in the study because 50% of blue sheep die between birth and 2 years of age (Schaller 1977, Wegge 1979). On this basis, we estimate that the upper mustang region can sustainably carry 19 snow leopards given the current condition of the environment and the effects of human disturbance. However, changes in any important aspects of the environment (e.g. prey reliability, prey biomass and prey composition (Lande 1993, Petchey 2000) will impact on the carrying capacity for snow leopards. Local people have reported recent increases in livestock depredation due to snow leopards, and this might be indicative of a system undergoing major ecological change. An important priority is to understand these changes, and implement management policies for minimizing the impact on species conservation and human subsistence in the area.

## **Conclusion**

We have presented estimates of the habitat use and resource distribution of blue sheep in the upper Mustang and Manang regions of ACA. These should be taken into consideration in the management of this species. However, other factors must also be taken into consideration. For

example, the relatively low carrying capacity for blue sheep in upper Mustang should not be taken as justification for relegating blue sheep in this region to low conservation status. On the contrary, the fact they provide an essential resource base for key top predators such as the snow leopard makes blue sheep a high conservation priority in this area. Failure to protect this limited resource would likely result in greater predation of livestock, and further escalation of human-predator conflict.

### **Acknowledgments**

We thank the National Trust for Nature Conservation/Annapurna Conservation Area Project (ACAP) for providing permission and necessary support to conduct this research. We thank Mr R. K. Koirala, Dr S.R. Jnawali, Mr R. Lamsal, Mr L.B. Gurung (ACAP Director), Mr N. Lama, Mr N. Dhungana and all upper Mustang Unit Conservation Office staff for their support. We thank the Keidanren Nature Conservation Fund, and the Japan and Massey University Research Fund (New Zealand) for providing financial support for the project. Finally, we thank Mr F. Gurung, Mr. S. Gurung, Mr S. Paudel and Mr B. Adhikari for their support in field survey. DR is part-funded by the National Research Centre for Growth and Development, New Zealand.

### **References**

Alberta (2004). Methodology for calculation carrying capacity and grazing capacity on public rangelands. Rangeland Management Branch, Rangeland Resource Management Program, Alberta, Sustainable resource development. Public land and forestry. Publication Number 1/197. (online). Available from URL: <http://www.srd.alberta.ca/LandsForests/GrazingRangeManagement/documents/CarryingAndGrazingCapacityMethodology.pdf> Assess on 23 July 2012.

- Arrow KB, Bolin R, Costanza P *et al.* (1995). Economic growth, carrying capacity, and the Environment. *Science* **268**, 520–21.
- Aryal A (2007). Blue bull (*Boselaphus tragocamelus*) in Lumbini – A World Heritage site of Nepal. *Tiger Paper/FAO* **34**, 4–9
- Aryal A (2009). Habitat ecology of Himalayan Serow (*Capricornis sumatraensis ssp. thar*) in Annapurna Conservation Area of Nepal. *Tiger Paper/FAO* **36**, 12–20.
- Aryal A, Raubenheimer D, Sathyakumar S, Poudel BS, Ji W, Kunwar KJ, Kok J, Kohshima S and Brunton D (2012). Conservation strategy for brown bear and its habitat in Nepal. *Diversity* **4**(3), 301-317.
- Aryal A, Dutta IC, Dhungel S (2007). Parasitic Fungal on Moth's Larvae: Yarsagumba (*Cordyceps sinensis*), Ecology and Local Economic Contribution in Nepal. *E-Online Bulletin-BRTF* **1**, 01-12. Available from URL: <http://www.brtf.org.np/picture/pdf/Cordyceps%20sinensis%20article.pdf.pdf> Assess on 12 August 2012
- Aryal A, Gastaur S, Menzel S *et al.* (2010a). Estimation of blue sheep population parameters in the Dhorpatan Hunting Reserve, Nepal. *International Journal of Biodiversity and Conservation* **2**, 51–6.
- Aryal A, Raubenheimer D, Subedi S, Kattel B (2010b). Spatial habitat overlap & habitat preference of Himalayan musk deer '*Moschus chrysogaster*' in Sagarmatha (Mt. Everest) National Park, Nepal. *Current Research Journal of Biological Sciences* **2**, 217–25.
- Bell RHV (1982). The effect of soil nutrient availability on the community structure in African ecosystems. In: Huntley BJ, Walker BH. *Ecology of Tropical Savannas* Springer-Verlag, Berlin, pp. 193–216.

- Chetri M (2008). Brown bear (*Ursus arctos*) from Upper Mustang. *Prakriti Newsletter/NTNC* **19–22**. [http://www.ntnc.org.np/sites/default/files/publicaations/newsletter\(1\).pdf](http://www.ntnc.org.np/sites/default/files/publicaations/newsletter(1).pdf) Assess on 12 July 2012.
- Chetri M, Gurung CR (2004). Vegetation composition, species performance and its relationship among livestock and wildlife in the grassland of Upper Mustang, Nepal. In: Zhong JC, Zi XD, Han JL, Chen ZH, eds, *Yak Production in Central Asian Highlands, Proceeding of the Fourth International Congress on Yak*. Sichuan Publishing Group, Sichuan Publication House of Science and Technology, pp. 235–44.
- Dagleish MP, Ali Q, Powell RK, Butz D *et al.* (2007). Fatal sarcoptes scabiei infection of blue sheep (*Pseudois nayaur*) in Pakistan. *Journal of Wildlife Diseases* **43**, 512–17
- DNPWC (2011). Protected Area of Nepal 2068. Department of National Par and Wildlife Conservation, Government of Nepal, Babarmahal, Kathamandu, Nepal. Available from URL: <http://www.dnpwc.gov.np/publications/pustika> Assess on 14 July 2012.
- East R (1984). Rainfall, soil nutrients status and biomass of large African savanna mammals. *African Journal of Ecology* **22**, 245–70.
- Fritz H, Duncan P (1994). On the carrying capacity for large ungulates of African Savanna ecosystems. *Proceedings of Royal Society B: Biological Sciences* **256**, 77–82.
- Harris RB (2008). *Pseudois nayaur*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.1. [Cited 24 October 2011.]. Available from URL: [www.iucnredlist.org](http://www.iucnredlist.org)
- Jackson RM, Ahlborn GG (1989). Snow leopard in Nepal: Home Range and movements. *National Geographical Research* **5**, 161–75.
- Lande R (1993). Risks of population extinction from demographic and environmental stochasticity and random catastrophes. *American Naturalist* **142**, 911–22.

- Lovari S, Boesi R, Minder I, Mucci N, Randi E, Dematteis A, Ale SB (2009). Restoring a keystone predator may endanger a prey species in a human altered ecosystem: the return of the snow leopard to Sagarmatha National Park. *Animal Conservation* **12**, 559-570.
- Mishra C, Van Wieren SE, Ketner P *et al.* (2004). Competition between domestic livestock and wild bharal *Pseudois nayaur* in the Indian Trans- Himalaya. *Journal of Applied Ecology* **41**, 344–54.
- Oli M, Rogers ME (1991). Seasonal pattern in group size and population composition of blue sheep in Manang, Nepal. *Journal of Wildlife Management* **60**, 797–801.
- Oli MK (1997). Home range of Snow leopards in Nepal. *Mammalia* **61**, 355–60.
- Oli MK, Taylor IR, Rogers ME (1993). Diet of the snow leopard (*Panthera uncia*) in the Annapurna Conservation Area, Nepal. *Journal of Zoology (London)* **231**, 365–70.
- Oli MK, Taylor IR, Rogers ME (1994). Snow leopard *Panthera uncia* predation of livestock: An assessment of local perceptions in the Annapurna Conservation Area, Nepal. *Biological Conservation* **68**, 63–8.
- Petchey OL (2000). Prey diversity, prey composition, and predator population dynamics in experimental microcosms. *Journal of Animal Ecology* **69**, 874–82.
- Ravindranath S, Premnath S (1997). Biomass Studies: Field methods for monitoring biomass. Mohan Primlani for Oxford and IBH Publishing, New Delhi, India.
- Rosenzweig M L (1995). *Species Diversity in Space and Time*. Cambridge University Press, New York, NY.
- Sakai A, Matsumoto T, Saitoh M *et al.* (2003). Cardiopulmonary hemodynamics of blue-sheep, *Pseudois nayaur*, as high-altitude adapted mammals. *Japanese Journal of Physiology* **53**, 377–84.
- Schaller G (1977). *Mountain Monarchs: Wild Sheep and Goats of the Himalaya*. University of Chicago Press, Chicago, IL.

- Shrestha R, Wegge P (2008). Wild sheep and livestock in Nepal Trans-Himalaya: Coexistence or competition? *Environmental Conservation* **35**, 125–36.
- Wang X, Hoffman RS (1987). *Pseudois nayaur* and *Pseudois schaeferi*. *Mammalian Species* **278**, 1–6.
- Wegge P (1976). Himalayan shikar reserves; surveys and management proposals. Field Document No. 5. FAO/NEP/72/002 Project, Kathmandu.
- Wegge P (1979). Aspects of the population ecology of blue sheep in Nepal. *Journal of Asian Ecology* **1**, 10–20.
- Wilson P (1981). Ecology and habitat utilisation of blue sheep in Nepal. *Conservation Biology* **2**, 55–74.

## **Paper III: Habitat assessment for blue sheep translocation to maintain a viable snow leopard population in the Mt Everest Region, Nepal**

### **Abstract**

Blue sheep (*Pseudois nayaur*) are the key prey of the endangered snow leopard (*Panthera uncia*) in the Himalayan region of Nepal. However, the snow leopard population has recently expanded back into the Sagarmatha (Mt. Everest) National Park where the blue sheep are currently absent, and evidence suggests that snow leopards depredate livestock. A solution to this prospective human-wildlife conflict is the translocation of blue sheep back into this area. The aims of this study are therefore: (1) to characterize the spatial and environmental factors related to current blue sheep distributions in three areas, Annapurna Conservation Area, Shey Phoksundo National Park, and Kanchanjunga Conservation Area, and (2) to use these characteristics to assess the suitability for blue sheep translocation of two areas, Sagarmatha National Park and Langtang National Park. Blue sheep were found to occur in 14603 km<sup>2</sup> of Nepal, of which only 7343 km<sup>2</sup> (49%) is inside protected areas. Blue sheep preferred alpine meadow, pasture and grassland with mean annual precipitation of between 200 and 1000 mm, and most frequently occurred at elevations between 3300 and 5100 m with soil combinations of Haplumbrepts, Dystrochrepts and Cryumbrepts. Overall, the Sagarmatha National Park was significantly similar to the Kanchanjunga Conservation Area (Bray Curtis Similarity Coefficient > 72%) in terms of vegetation, elevation, precipitation, soil, aspect, and slope. Therefore, the translocation of blue sheep from the Kanchanjunga Conservation Area to the Sagarmatha National Park is recommended in accordance with the main conservation aims of supporting the population of snow leopards and other predators in the park, while minimising human-wildlife conflict.

However, before translocation can proceed, further studies are needed on human disturbance and grass biomass at specific release sites, and decisions need to be made on the number of blue sheep to be relocated.

**Keywords:** snow leopard; blue sheep; translocation; habitat preferences; distribution; similarity; Mt. Everest (Sagarmatha) National Park

## **Introduction**

The snow leopard (*Panthera uncia*) is an endangered species with a distribution that spans 11 countries (Jackson et al. 2008, IUCN 2011). The world's population of the snow leopard has declined by at least 20% over the past sixteen years due to habitat and prey loss, snow leopard–human conflict, poaching and persecution (Koshkarev and Vyrypaev 2000, McCarthy et al. 2003, Jackson et al. 2008, IUCN 2011). Nonetheless, it is estimated that 300–500 snow leopards still remain in Nepal (Jackson et al. 2008, IUCN 2011).

The blue sheep (*Pseudois nayaur*) is a species with a conservation status of 'Least Concern' because of its widespread distribution and presumed large population size (Harris 2008). Blue sheep populations are distributed throughout Bhutan, China, northern India, northern Myanmar, Nepal, and northern Pakistan (Harris 2008). Some sources have stated that this species also exists in Tajikistan (Grubb 2005), but there is no such recent evidence (Harris 2008). Blue sheep are widely distributed throughout the Himalayan region of Nepal (Schaller 1977, Wilson 1981, Oli 1994, Aryal et al. 2010), and they are the main prey species of the snow leopard in the high altitude biomes of Eurasia (Oli et al. 1993). Therefore, blue sheep can be an indicator of possible snow leopard presence and are crucial for a long-term viability of snow leopard populations in the Himalayas.

Recently, the snow leopard population has expanded back into the Sagarmatha (Mt. Everest) National Park (Ale 2007, Lovari et al. 2009). While this is positive in terms of snow leopard conservation, there is evidence that snow leopards depredate livestock in the area, potentially setting up a conflict between human and snow leopard populations, allegedly because of the low numbers of natural prey species and absence of blue sheep in the park. It has thus been suggested that blue sheep should be translocated to the park before the losses of livestock exceed the tolerance threshold of the local people (Ale 2007, Lovari et al. 2009). However, many studies have emphasized that habitat quality, spatial and temporal heterogeneity, environmental change over time, land use and human disturbance may be the main reasons for a success or failure of any given translocation attempt (Griffith et al. 1989, Wolf et al. 1996, IUCN 1998, Lomolino and Channell 1998, Sekercioglu et al. 2008, Chapron et al. 2009, Osborne and Seddon 2011). Therefore, the main objective of this study is to use the spatial environmental factors associated with the current blue sheep distribution to assess the suitability of potential sites for translocation and thus provide information for conservation decisions.

Remote sensing data are widely used for habitat analysis of wildlife (Pendleton et al. 1998) and are of sufficient resolution for coarse estimates of species–area relationships and habitat assessments. Moreover, they are less expensive and logistically challenging than detailed ground-based surveys (Mack et al. 1997). The Geographic Information System (GIS) based data about spatial distribution and availability of preferred habitats can be used to facilitate the protection and restoration of critical habitats, and hence this approach has broad applicability in conservation biology and wildlife management (Manel et al. 1999, Jaberg and Guisan 2001). In this study we have taken a GIS approach combined with ground-based surveys to assess connectivity, corridors, distribution ranges, and habitat preference of blue sheep throughout Nepal. The specific aims of this study are to (1) quantify the overall distribution range, connectivity, and corridors for blue sheep populations throughout Nepal, (2) assess the

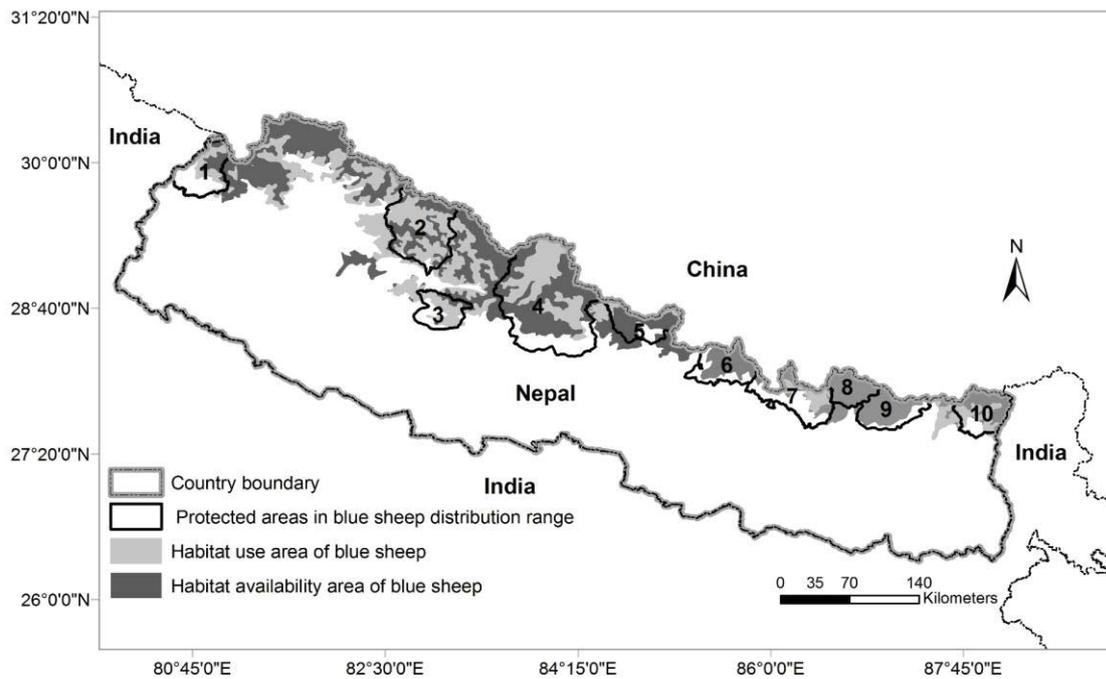
feasibility in terms of habitat suitability of translocating blue sheep back into the Mt. Everest region, and (3) provide wildlife managers with detailed and current distribution patterns of blue sheep populations throughout Nepal within and outside protected areas.

## **Material and Methods**

### ***Study area***

The study was conducted throughout the high mountain region of Nepal from December 2009 to June 2011 (Figure 1). Nepal is situated on the southern slopes of the central Himalayas and occupies a total area of 147,181 km<sup>2</sup>. The country is located between latitudes 26°22' and 30°27' N and longitudes 80°40' and 88°12' E. Hills and high mountains cover approximately 86% of the total land area and the remaining 14% are the flatlands of the Terai region (<300 m). Altitude varies from approximately 60 m (Terai) to 8,848 m (Mount Everest/Sagarmatha) above sea level, the highest point in the world (NBS 2002).

The high mountain region of Nepal is the meeting place of two major geographical regions of the world – the Palaearctic region to the north and the Indo-Malayan region to the south. This area contains thirty eight major ecosystems and is relatively less diverse in flora or fauna than lower altitudes of the country due to adverse environmental conditions. However, this area is characterized by a large number of endemic species (NBS 2002).



**Figure 1.** Blue sheep distribution range in Nepal and the current study area. Potential blue sheep habitats (used and available areas) in Nepal and protected areas within the blue sheep distribution range. Protected areas of Nepal include: 1 – Appi Nappa Conservation Area (ANCA), 2 – Shey Phoksundo National Park (SPNP), 3 – Dhorpatan Hunting Reserve (DHR), 4 – Annapurna Conservation Area (ACA), 5 – Manasalu Conservation Area (MCA), 6 – Langtang National Park (LNP), 7 – Gaurishankar Conservation Area (GCA), 8 – Sagarmatha (Mt. Everest) National Park (SNP), 9 – Makalu Barun National Park (MBNP), and 10 – Kanchanjung Conservation Area (KCA).

All areas potentially suitable for blue sheep were identified throughout the country. We selected three protected areas with blue sheep present: Annapurna Conservation Area (ACA), Shy Phoksundo National Park (SPNP), and Kanchanjunga Conservation Area (KCA), and two areas without blue sheep: Lantang National Park (LNP) and Mt. Everest (Sagarmatha) National Park (SNP). We compared habitat parameters (vegetation, soil, elevation, aspect, slope, precipitation) of all those areas to investigate the suitability of translocating blue sheep to either SNP or LNP

(Figure 1). For further information on these protected areas see Aryal and Subedi (2011), Aryal et al. (2012), and Aryal et al. (2012a).

### ***Remote sensing data***

The spatial data (raster and vector layers) used for this study included physiographic data, vegetation types, elevation, soil types, contour lines, mean annual precipitation, and administrative boundaries (available from Department of Survey, Government of Nepal and ICIMOD- <http://geoportal.icimod.org>). In addition, raster layers of the study were downloaded from the USGS databases sourced from [http://edcns17.cr.usgs.gov/NewEarth\\_Explorer/](http://edcns17.cr.usgs.gov/NewEarth_Explorer/) for reference. We used Arc GIS software (version 9.3, ESRI Inc., Redlands, California, USA) for analysis of these layers and for the formation of digital elevation models. Contour lines with 20 m intervals were used to show aspect, slope, and elevation in the models, and the 3D Analyst extension of ArcGIS was used to convert the contour lines to a raster surface. Slope was reclassified into seven categories using 10° intervals ( $1 \leq 10^\circ$  to  $7 \geq 60^\circ$ ). Aspect was reclassified into eight classes (north, northeast, east, southeast, south, southwest, west, and northwest). Precipitation gradient is represented by intervals of 200 mm mean annual precipitation, and elevation by 300 m intervals. We also used five classes of soil types categorized by the Department of Survey, Government of Nepal: (1) Dystrochrepts, Haplumbrepts, Haplustalfs, (2) glaciated mountain, (3) Haplumbrepts, Dystrochrepts, Cryumbrepts, (4) Dystrochrepts, Haplustalfs, Rhodustalfs, and (5) Dystrochrepts, Haplustalfs-calcareous. All raster surfaces were converted to vector files to calculate the area of each class and for further analysis.

### ***Potential and current blue sheep distributions***

We used vegetation, elevation, physiographic, slope, and aspect layers to delineate the potential blue sheep distribution habitats throughout the country. We determined the potential blue sheep habitat based on: (1) habitats within high mountain areas (physiographic layers), with either existing pasture areas, shrublands, grasslands or areas more than 500 m below the tree line, and (2) previous studies and literature about blue sheep distribution and potential areas. Further, potential areas were divided into habitat use and habitat availability categories (as describe below). Landscapes of blue sheep distribution were further classified based on the country's development region (NBS 2002). Landscape connectivity was analysed using Arc GIS by overlapping features, including vegetation pattern, human settlement, agricultural land, geographical barriers, precipitation zones, aspect, and slope patterns. Current blue sheep distribution areas were verified through intensive presence and absence surveys (interviews and habitat surveys) within these potential sites from November 2009 to June 2011 and at sites referenced by previous studies on blue sheep occurrences throughout Nepal (Wegge 1976; Wilson 1981, Austegard and Haugland 1993, Oli 1994, Wegge 1991, Karki and Thapa 2006, Thapa 2006, Aryal et al. 2010). Questionnaires were distributed to local people, protected area staff, students and scientists (n = 162) working within potential blue sheep distribution areas. A questionnaire contained four main questions: *Do you know of any blue sheep habitat in your area? If yes, are there currently any blue sheep present? If yes, where (which Village Development Committees (VDC)) and when did you last see blue sheep in your area? Do you know the current status and survival threats for blue sheep?* Following this questionnaire survey 5 to 10 randomly selected sites were visited to confirm the presence or absence of blue sheep in the area. Presence or absence was determined by direct sightings, carcasses or pellets of blue sheep and interviews with local people from 2009 to 2011. Topographic maps (1:50000 scale) were used during each interview to determine current blue sheep sightings in the interviewee's

local area. The GPS (Geographical Positioning System) points of areas with blue sheep present were recorded whenever possible during the surveys.

### ***Habitat preference of blue sheep***

All information was combined to delineate a potential (available, 'A') blue sheep distribution area and the current (used 'U') distribution area of blue sheep by using Arc GIS software and to overlay these distribution layers with selected habitat parameters. We clipped U and A separately with all attribute layers (vegetation, elevation, slope, aspects, precipitation, and soil), calculated each attribute area, and applied the Ivlev's electivity index (IEI) (Ivlev 1961, Krebs 1989, Aryal 2009, Aryal et al. 2010). The Ivlev's electivity index indicates a value from -1 to +1, with positive values indicating preference, negative values indicating avoidance, and 0 indicating random use. The following formula was used to calculate the habitat preference of blue sheep:  $IEI = (U\% - A\%)/(U\% + A\%)$  (Ivlev 1961, Krebs 1989, Aryal 2009, Aryal et al. 2010, 2010a). A two-way ANOVA test was used to compare blue sheep preferences for different habitat parameters with the null hypothesis stating that all habitats are used in proportion to their availability (U as a dependent variable and A as an independent variable).

### ***Feasibility of blue sheep translocation to the Mt. Everest region***

We compared similarity in terms of slope, aspect, precipitation, vegetation, elevation, and soil type between the protected areas with blue sheep present (ACA, KCA, and SPNP) and the protected areas with blue sheep absent (SNP and LNP) to determine the suitability of the latter sites for blue sheep. Each classification area was calculated using Arc GIS. We also used field verification data and interview data to confirm the presence or absence of blue sheep in all areas. We compared ecological and biophysical parameters of areas with and without blue sheep by using univariate and multivariate analyses in Primer & Permanova + (Anderson et al. 2008). We

calculated the similarity matrix using the Bray Curtis coefficient (Bray and Curtis 1957). We used non-metric Multi-Dimensional Scaling (MDS) ordination to visually assess site differences (Anderson et al. 2008). We first compared habitat features of presence/absence separately to understand how they were similar (Bray Curtis Coefficient Similarity 'S' = 0 to 100%). Then we combined all parameters to calculate an overall similarity measure (S = 0 to 100%) and defined the measure as follows: 0 to 25% (low feasibility for blue sheep translocation), 26 to 50% (medium feasibility for blue sheep translocation), 51 to 75% (high feasibility for blue sheep translocation), and 76 to 100% (blue sheep translocation highly recommended).

## **Results**

### ***Distribution and connectivity for blue sheep in the Himalayas***

#### *Potential distribution*

The potential blue sheep habitats were divided into four landscape categories: (1) western landscape (western boundary to the Manaslu Conservation Area (MCA), 28322 km<sup>2</sup>); (2) Langtang landscape (within the LNP, 1227 km<sup>2</sup>); c) Sagarmatha landscape (covering the Gaurishakhar Conservation Area (GCA) to the Makalu Barun National Park (MBNP), including the SNP, 3747 km<sup>2</sup>; and (4) eastern landscape (Sagarmatha to the Kachanjunga Conservation Area (KCA), 2135 km<sup>2</sup> (Fig. 1). The total potential area for blue sheep throughout Nepal's high mountain region covered 35433 km<sup>2</sup>. The potential blue sheep habitats totalled 19394 km<sup>2</sup> inside protected areas and 16039 km<sup>2</sup> outside protected areas (Fig. 1, Table 1).

The blue sheep population within the western landscape had excellent connectivity without barriers to movement (Fig. 1). However, there was no connectivity of the blue sheep population between the western landscape and the Langtang landscape, where 50 km of the unsuitable habitat (<1500 m elevation with dense forest) separate the two areas. Increased human

settlement and expansion of agricultural land in Thuman, Briddin, Goljung, Tipling, Sertung, and Lapa VDCs were also the reasons for the loss of connectivity between these landscapes (Fig. 1). Similarly, Langtang and Sagarmatha landscapes lacked connectivity for blue sheep populations although there were scattered potential habitats in between. No connectivity was found between Kanchanjunga and Sagarmatha landscapes as three major villages (Keemathanka, Chepuwa, and Hatiya) and their associated human disturbance formed a barrier. Nonetheless, the development of a corridor (13 × 20 km) could potentially increase the connectivity of populations between the landscapes (Fig. 1).

**Table 1.** Potential and current blue sheep distribution areas within and outside the protected areas of Nepal.

Area	Potential area (km <sup>2</sup> )	Current presence (km <sup>2</sup> )	Protected area size (km <sup>2</sup> )	Population status
Western landscape	28322.5	12777		
Appi Nappa Conservation Area (ANCA)	1035.3	533.2	1903	Unknown
Shey Phoksundo National Park (SPNP)	3555	1867	3555	Common
Annapurna Conservation Area (ACA)	6286.3	31479	7629	Common
Manasalu Conservation Area (MCA)	1403.6	154	1663	Unknown
Dhorpatan Hunting Reserve (DHR)	803.6	610.9	1325	Common
Langtang landscape	1227.3	0		
Langtang National Park (LNP)	1151.9	0	1710	Absent
Sagarmatha landscape	3747.4	831.6		
Sagarmatha National Park (SNP)	1156.1	0	1148	Absent
Gaurishankar Conservation Area (GCA)	1167.8	484.2	2179	Unknown
Makalu Barun National Park(MNP)	1316.9	0	1500	Absent

Eastern landscape	2135.9	994.5		
Kanchanjunga Conservation Area (KCA)	1517.95	546	2035	Common

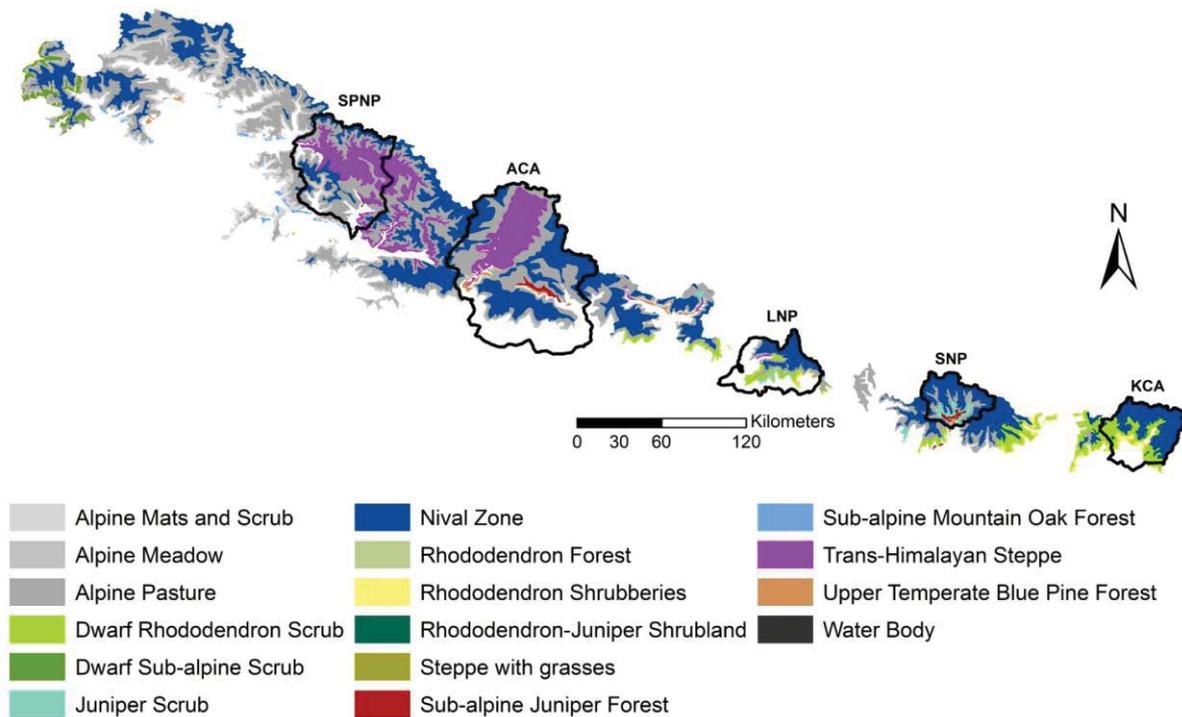
### *Current blue sheep distribution*

At present, blue sheep can be found in 14603 km<sup>2</sup> of Nepal, and merely 7343 km<sup>2</sup> of this area lies inside protected areas (Table 1). Blue sheep were found to be present in a 12777 km<sup>2</sup> area of the western landscape, 484 km<sup>2</sup> area of the Sagarmatha landscape, and 994 km<sup>2</sup> area of the eastern landscape (Fig. 1, Table 1). Blue sheep were distributed in the Appi Nappa Conservation Area (ANCA), ACA, MCA, Dhorpatan Hunting Reserve (DHR), KCA, SPNP, and Gauri Shankar Conservation Area (GSCA) (Table 1). Blue sheep were absent in the Langtang landscape and, more specifically, within the SNP (Table 1).

### *Habitat preferences of blue sheep*

The following is a breakdown for blue sheep habitat preference based on individual habitat parameters measured in this study.

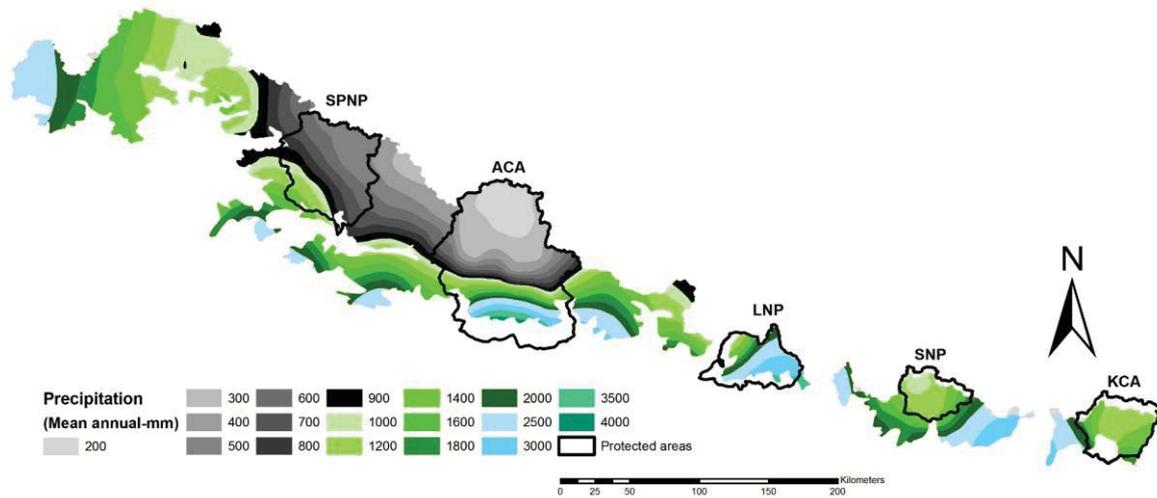
*Vegetation:* Blue sheep preferred the alpine meadow (IEI = 0.77), alpine pasture (IEI = 0.84), alpine mats and scrubs (IEI = 0.54), and steppe with *Euphorbia royleana*, grasses and *Artemisia* spp. (IEI = 1). These areas were used significantly more than expected based on availability ( $F = 2.89$ ;  $p = 0.001$ ) (Appendix 1, Fig. 2). However, blue sheep also used some transitional areas close to forests in western and eastern regions of the country, dwarf rhododendron scrubs (IEI = 0.84) (Appendix 1). Blue sheep generally used habitats well above the tree line; however, in winter blue sheep also used the tree line and lower elevations.



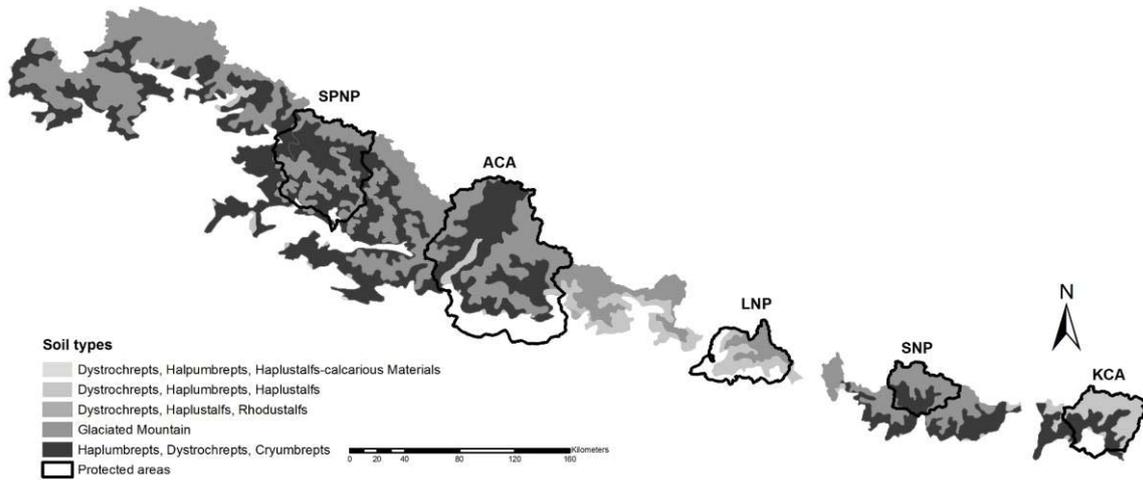
**Figure 2.** Vegetation composition in the blue sheep potential distribution area. Protected areas with blue sheep present were SPNP, ACA and KCA, and protected areas with blue sheep absent were LNP and SNP).

*Precipitation:* Blue sheep generally preferred areas with a mean annual precipitation of 200–1000 mm and avoided areas with >1000 mm ( $F = 3.71, p = 0.02$ ) (Appendix 1). However, blue sheep used areas with < 700 mm mean annual precipitation on the western side of the MCA and areas with ~1000 mm mean annual precipitation in the eastern landscape (KCA) (Appendix 1, Fig. 3a).

*Soil types:* Blue sheep preferred areas with soil combinations of Haplumbrepts, Dystrochrepts and Cryumbrepts (IEI = 0.87), whereas other soil combination types were generally avoided (Appendix 1). Blue sheep did not use soil combinations which included Dystrochrepts, Haplustalfs and Rhodustalfs (IEI = -1) or Dystrochrepts and Haplustalfs-Calcarious (IEI = -1) (Appendix 1, Fig. 3b).



3(a)

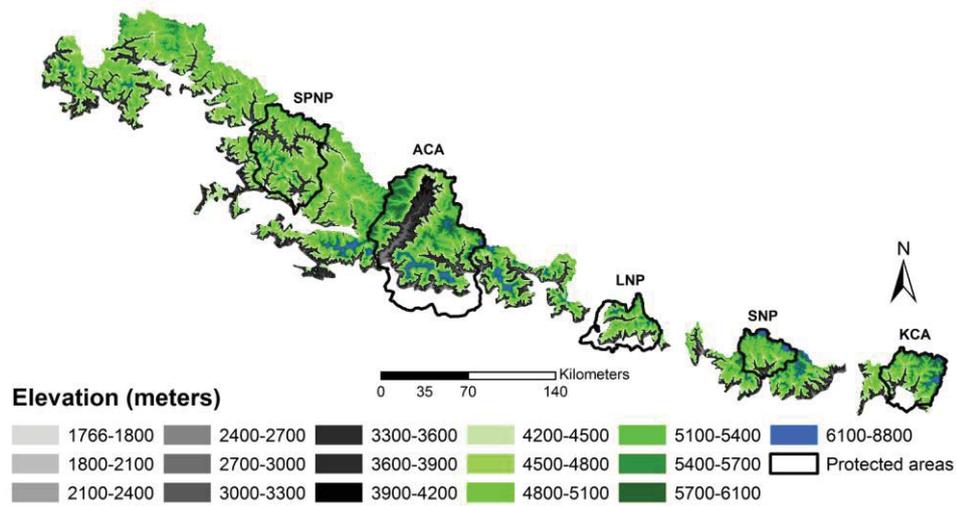


3(b)

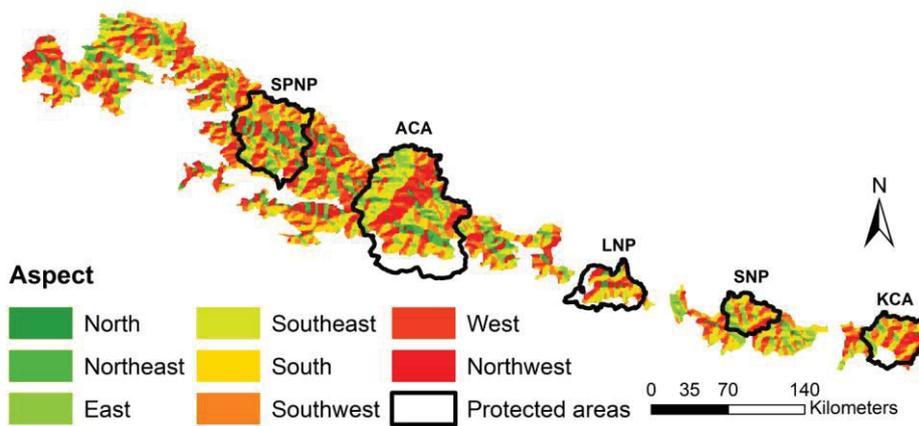
**Figure 3.** Mean annual precipitation (a) and soil types (b) in the potential blue sheep distribution area.

*Altitude:* Blue sheep preferred elevations between 3300 and 5100 m (Appendix 1) and randomly used elevations between 5100 and 5400 m (IEI = 0) ( $F = 1.94$   $p = 0.003$ ). Nonetheless, blue sheep did use elevations from 2800 to 5700 m throughout its distribution range (Appendix 1). Higher elevations were used in the eastern parts of the blue sheep distribution and lower elevations in the lower parts of the country (Appendix 1, Fig. 4a)

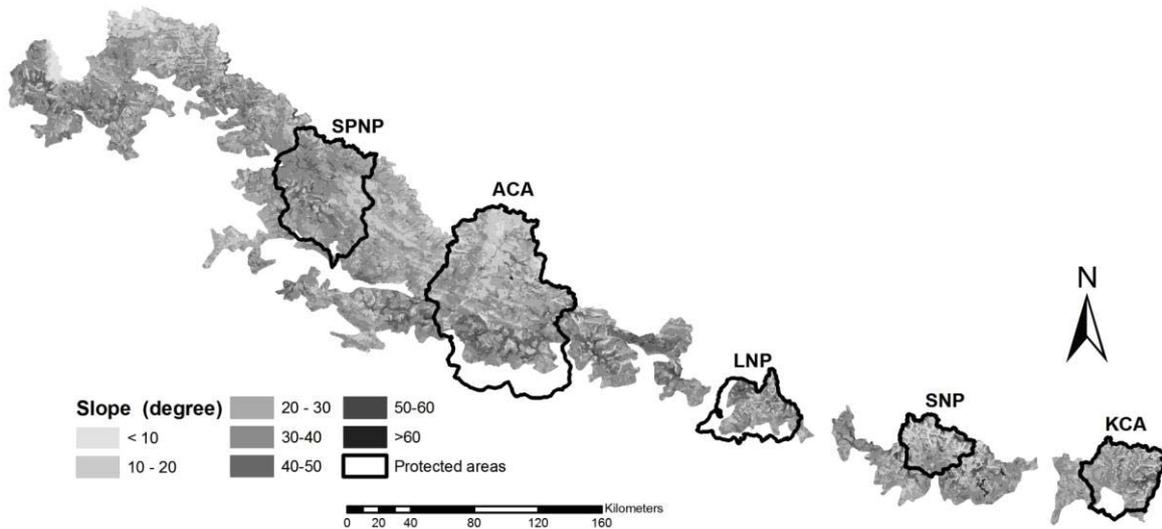
*Aspect and slope:* Blue sheep preferred northeast to southwest aspects (IEI = 0.31) and avoided north (IEI = -0.13); west (IEI = -0.10) and northwest (IEI = -0.54) aspects (Appendix 1, Figure 4b). Blue sheep also preferred >20–40° slopes and randomly used 40–60° slopes (IEI = 0). Blue sheep avoided flatter areas (<10°; Appendix 1, Fig. 4c).



(a)



(b)



(c)

Figure 4. Elevations (a), aspects (b) and slopes (c) in the blue sheep potential distribution area.

*Possibilities for translocation of blue sheep to the Sagarmatha NP and biophysical comparisons*

Protected areas with sheep (KCA, ACA and SPNP) and without sheep (SNP and LNP) were compared in terms of land features and biophysical parameters (aspect, slope, elevation, precipitation, and vegetation). The findings were as follows:

*Vegetation:* The nival zone (> 5000 m) and alpine pasture land were available in the SNP and LNP, and these are similar to areas where blue sheep are present (Appendix 1). The SNP was more ecologically similar to the KCA (Bray Curtis Similarity 'S' = 54.25%) and less similar to the SPNP (Bray Curtis Similarity 'S' = 37.95%) and ACA (Bray Curtis Similarity 'S' = 27.7%) (PERMANOVA, Pseudo F = 1.7,  $p = 0.31$ ; Fig. 2, Table 2, Appendix 2).

*Precipitation:* The precipitation patterns in the SNP were most similar to those in the KCA (Bray Curtis Similarity 'S' = 72.18%), followed by the SPNP (Bray Curtis Similarity 'S' = 28%) and AACA (Bray Curtis Similarity 'S' = 19.03%) (PERMANOVA, Pseudo F = 0.75,  $p = 0.71$ , Fig.

3a, Table 2, Appendix 2 and 3). Precipitation in the LNP was similar to that in the ACA (Bray Curtis Similarity 'S' = 25.16%), KCA (Bray Curtis similarity 'S' = 21.13%), and SPNP (Bray Curtis Similarity 'S' = 5.87%) (Table 2, Appendix 2).

*Soil:* Combinations of the following soil types: (a) glaciated mountain, (b) Haplumbrepts, Dystrochrepts and Cryumbrepts, and (c) Dystrochrepts, Haplumbrepts and Haplustalfs, were found in similar ratios in the areas with and without blue sheep (Appendix 3). The soil types in the LNP were most similar to the soils in the SPNP (Bray Curtis Similarity 'S' = 49.9%), KCA (Bray Curtis similarity 'S' = 29.88%), and ACA (Bray Curtis Similarity 'S' = 30.97%) compared with other areas. Besides, the soil types in the SNP were more similar to the soils in the SPNP (Bray Curtis similarity 'S' = 49.91%), ACA (Bray Curtis Similarity 'S' = 31.06%) and KCA (29.15%) than to those in other areas (PERMANOVA, Pseudo F = 1.7  $p = 0.28$ ; Table 2, Fig. 3b, Appendix 2).

*Elevation:* The elevation of the SNP was most similar to that of the KCA (Bray Curtis Similarity 'S' = 78.83%), SPNP (Bray Curtis Similarity 'S' = 35.62%) and ACA (Bray Curtis Similarity 'S' = 31.34%) (PERMANOVA, Pseudo F = 1.7,  $p = 0.28$ ; Fig. 3, Appendix 2). The elevation of the LNP was similar to that of the KCA (Bray Curtis Similarity 'S' = 70.86%), ACA (Bray Curtis Similarity 'S' = 17.27%) and SPNP (Bray Curtis Similarity 'S' = 23.68%) (Table 2, Appendix 2).

*Aspect:* The aspect in protected areas with and without blue sheep was similar (Appendix 3); however, the aspect in the SNP was most similar to that in the KCA (Bray Curtis Similarity 'S' = 86.42%), ACA (Bray Curtis Similarity 'S' = 30.95%) and SPNP (Bray Curtis Similarity 'S' = 49.79%) (PERMANOVA, Pseudo F = 3.2,  $p = 0.19$ , Fig. 4, Table 2, Appendix 2). Further, the aspect in the LNP was more similar to that in the KCA (Bray Curtis Similarity 'S' = 86.18%), SPNP (Bray Curtis Similarity 'S' = 49.61%), and ACA (Bray Curtis Similarity 'S' = 30.82%) than in other areas.

*Slope:* Slopes were equally distributed in all protected areas with the presence or absence of blue sheep (Appendix 3). The slopes in the SNP were most similar to those in the KCA (Bray Curtis similarity ‘S’ = 82.80%), SPNP (Bray Curtis Similarity ‘S’ = 48.8%), and ACA (S = 31.56%). The slopes of the LNP were similar to those of the KCA (Bray Curtis Similarity ‘S’ = 83.9%), ACA (Bray Curtis Similarity ‘S’ = 30.61%), and SPNP (Bray Curtis Similarity ‘S’ = 47.96%) (PERMANOVA, Pseudo F = 3.16, Figure 4c,  $p = 0.21$ , Table 2, Appendix 2).

Table 2. Calculation of Bray Curtis Similarity ‘S’ values for biophysical parameters (vegetation, soil, aspect, slope, precipitation, and elevation) of protected areas with blue sheep present or absent.

Vegetation parameters matrix				
	ACA	KCA	LNP	SNP
KCA	25.17			
LNP	23.14	48.77		
SNP	27.75	54.25	65.16	
SPNP	66.00	24.14	34.23	37.95
Soil parameters matrix				
KCA	20.78			
LNP	30.97	40.90		
SNP	31.06	29.15	77.42	
SPNP	71.17	21.88	49.82	49.91
Aspect parameters matrix				
KCA	38.791			
LNP	30.82	86.18		
SNP	30.95	86.42	98.87	

SPNP	71.16	60.69	49.61	49.79
Slope parameters matrix				
KCA	39.24			
LNP	30.61	83.90		
SNP	31.56	82.80	86.96	
SPNP	72.80	59.67	47.96	48.80
Precipitation parameters matrix				
KCA	19.02			
LNP	25.16	21.13		
SNP	19.03	72.18	18.20	
SPNP	36.24	17.24	5.87	28
Elevation parameters matrix				
KCA	26.08			
LNP	17.27	70.86		
SNP	31.34	78.83	56.61	
SPNP	77.23	32.07	23.68	35.62
Overall biophysical parameters matrix and their value in%				
KCA	28.00			
LNP	25.21	58.03		
SNP	29.05	70.08	67.24	
SPNP	67.93	35.94	33.95	40.85

## **Discussion**

### ***Blue sheep distribution, connectivity and corridors***

Protected areas suitable for blue sheep were distributed throughout the Himalayan region of Nepal. High Mountain and high Himal physiographical areas represent approximately 60% of total protected areas (Shrestha et al. 2010). However, 50.3% of the potential habitat of blue sheep lies outside these protected areas. Indeed, currently blue sheep occupy only 41% of the total potential habitat (35433 km<sup>2</sup>) in Nepal.

The highest level of connectivity covering 80% of the potential blue sheep habitat was within the western landscape, followed by the Sagarmatha and Langtang landscapes (Table 1). Landscape connectivity enhances population viability for many species, and until recently most continental species lived in well-connected landscapes (Gilpin and Soule 1986, Noss 1987, Hunter 1996, Meffe and Carroll 1997). Connectivity breakdown was identified between western and Langtang landscapes, Sagarmatha and Kanchanjung landscapes due to human disturbance (agriculture and settlement) and expanses of unsuitable habitats. Beier and Noss (1998) reported that urbanization and other human activities often break natural connections among landscapes. Connectivity between landscapes could potentially be improved by connecting landscapes through wildlife corridors for blue sheep and other species. Such plans have multiple benefits and would improve the movement of blue sheep and their predators and reduce genetic inbreeding and demographic stochasticity. However, such corridors might also promote connection and spread of diseases, catastrophic disturbances, exotic species and other prey species and predators in the region (Simberloff et al. 1992, Hess 1994, Beier and Noss 1998).

### ***Habitat preference***

Blue sheep occupied ecological areas in the alpine pasture, nival zone and Trans-Himalayan steppe. Similar areas are still available to blue sheep in the region, and they could potentially

extend their range in these habitats. Therefore, larger blue sheep populations can be supported. It was originally believed that blue sheep use only elevations above the tree line, but the present study has determined that they also use some transitional zones between the tree line and grassland communities and occasionally move below the tree line, particularly in winter (Figure 2). However, in general blue sheep avoid forested habitats and are more frequently found near cliffs with escape cover, grassland and scrubs (Schaller 1977, Kinloch 1892, Oli 1996). It thus seems that they use transition areas between alpine meadows, shrub land and the tree line of higher Himalaya areas to escape from predators, to forage and to avoid adverse weather conditions.

Blue sheep prefer areas with low precipitation (Figure 3), but they nonetheless occur throughout a wide range of precipitation levels (200 to 1000 mm annual precipitation). Precipitation is the main factor responsible for the growth of vegetation in the higher Himalaya areas. Higher precipitation (>400 mm per year) supports good regeneration of plant species so there is more grass available for blue sheep per area unit.

Of five soil categories, the Haplumbrepts, Dystrochrepts and Cryumbrepts soil combination was found to be optimal for blue sheep because this combination supports the vegetation preferred by blue sheep. A total of 13541.3 km<sup>2</sup> area of this soil combination was used by blue sheep. Additionally, blue sheep were recorded across smaller areas with Dystrochrepts, Haplumbrepts, Haplustalfs and glaciated mountain soil combinations (Appendix 1, Fig. 3b).

Blue sheep may occupy elevation levels between 2800 and 5700 m, but occur more frequently at 3300 to 5100 m (Fig. 4a). The tree line in the eastern part of Nepal (27°N) lies at 4400 m, while it is only at 3500 m in the western part (30°N) of the country. Typically, blue sheep occur within higher elevations on the eastern side than on the western side of the country. Our results are similar to those of Wilson (1981) who stated that blue sheep used areas between 3960 and 4570

m, but in contrast with the results obtained by Namgail (2006) who reported that blue sheep avoid <4000m elevations.

Southern and eastern aspects of mountains are warmer and support a higher diversity of plants than western and northern aspects are. Although blue sheep used all aspects, we found they preferred southern and eastern aspects, thus supporting the findings by Wilson (1981). In contrast to Wilson's (1981) observation that blue sheep preferred areas with <20° slopes, our study revealed that blue sheep had lower preference for extreme slopes (either low or high) and we found a relationship between activity and slope: lower slopes (<20 to 40°) were used for grazing, and 40–50° slope areas were used for resting. Our results suggest that slopes of >60° were probably used for refuge from predators, adverse weather conditions and human disturbance (Fig. 4). Blue sheep are able to utilise steep slopes because of their relatively short and muscular legs which provide agility in rugged terrain (Bleich 1999; Geist 1999). However, our findings differ with those of Namgail, Fox, and Bhatnagar (2004) who argued that blue sheep avoided >40° slopes and moderate slopes of 11–30°.

### ***Translocation possibility of blue sheep***

The Trans-Himalayan steppe, alpine pasture, nival zone and dwarf rhododendron scrubs are the main ecological areas important for blue sheep distribution, and these can be used as indicators of a potential blue sheep habitat. The ACA (1279 km<sup>2</sup>) and SPNP (1047 km<sup>2</sup>) have large areas of the Trans-Himalayan steppe which support blue sheep populations. The KCA has significant areas of dwarf rhododendron scrubs (399 km<sup>2</sup>) and nival zone vegetation (968 km<sup>2</sup>) which support large blue sheep populations by providing grazing resources.

Since soil quality is a vital component of habitat quality and in turn underpins biodiversity, it is important to ensure that this ecological factor is understood and taken into account when designing conservation management plans for animals in various areas (Rantalainen et al. 2005).

The present study found that soil types suitable for the preferred vegetation (Dystrochrepts, Haplumbrepts and Haplustalfs) are present within and between the Appi Nappa Conservation Area (ANCA) and ACA of the western landscape but absent within and between the MCA and LNP. Nevertheless, blue sheep do occur in the MCA. However, blue sheep do not occur in the areas of the Sagarmatha and eastern landscapes where such soils occur. The soil combination associated with blue sheep presence occurred within the KCA, and we conclude that these three soil types appear responsible for supporting grassland vegetation and as a consequence blue sheep populations.

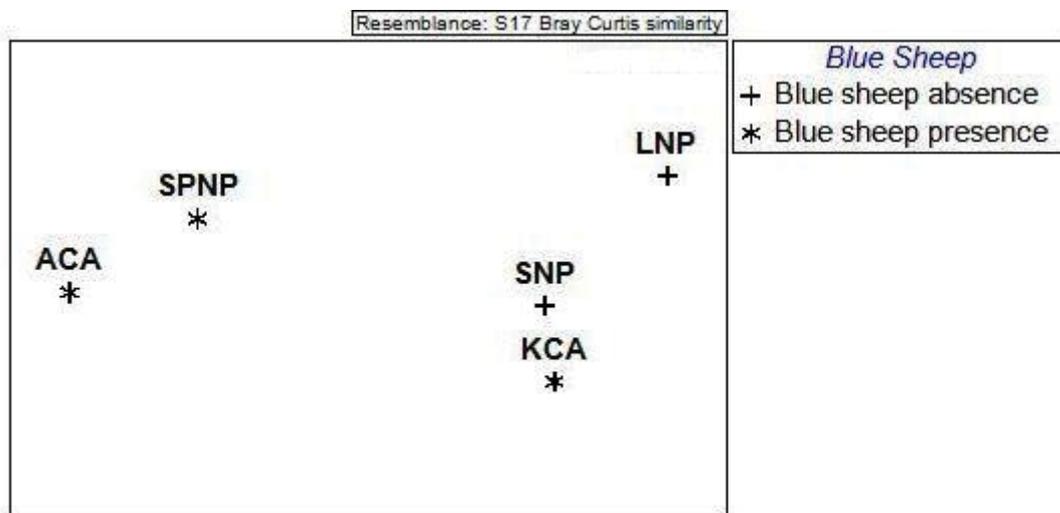
The alpine pasture, nival zone, grassland, soil types, aspect, slopes, elevation and precipitation area of the SNP are similar to the habitats where blue sheep are currently present. Therefore, it can be expected that a blue sheep population could be successfully established there. Overall, according to our analysis, the SNP was most similar (Bray Curtis Similarity 'S' > 72%) to the KCA and less similar to other areas with blue sheep present (Bray Curtis Similarity 'S' < 25%) (PERMANOVA, Pseudo F = 1.9,  $p = 0.21$ ; Fig. 5, Appendix 2). It is noteworthy that the present study revealed that the sites with blue sheep had substantial variations in mean annual precipitation, so it appears that blue sheep are tolerant to a wide range of precipitation levels. Based on vegetation systems, soil combinations, aspect and slope, the SNP, apart from being very similar to the KCA, appears to be comparable to three of the existing blue sheep home ranges.

The translocation of animals between similar habitats is likely to lead to higher survival rates than could be expected in less similar or quite different areas. Furthermore, long-distance geographic translocation tends to decrease survival and alters the behaviour of animals (Reinert and Rupert 1999). On the basis of the parameters included in this study it is recommended that translocation from the KCA to the SNP is the best option for conservation success. Lovari et al. (2009) also reported that higher elevations of the SNP could be suitable for blue sheep. Despite a

lack of substantiated evidence, it appears likely that blue sheep were present in the SNP area historically (Fig. 1, Harris 2008, IUCN 2008 – global blue sheep distribution map). A blue sheep population has been re-established in the areas near to the SNP, such as Lamobogar, and on the south-western slopes of the KCA (Schaller 1977, Wegge 1991). These two isolated ranges adjoin the Tibetan border and SNP and contain viable blue sheep populations. Also, blue sheep currently occur in a site in China (Qomolangma National Nature Preserve, Tibet), which adjoins the northern border of the SNP. Hence, the Tibetan population dwelling across the northern border and to the east and west from the SNP may potentially cross over into the SNP in the same way that the snow leopards have returned. Populations of blue sheep were present in the western part of the SNP, in the Gauri Shankar Conservation Area (GCA) (Figure 1). However, *Kobresia pygmaea*, a grass distributed through the Tibetan Plateau, including the SNP in Nepal (Miehe et al. 2008), is one of the preferred forage plants of blue sheep (Shrestha et al. 2005, Shrestha and Wegge 2008), but there is no evidence of this grass between the area presently inhabited by blue sheep and the SNP (Miehe et al. 2008). Therefore, the fragmentation of occurrence of *Kobresia pygmaea* grassland may restrict the presence or movements of the blue sheep population into the SNP. However, the availability of *Kobresia pygmaea* grassland in this park (Miehe et al. 2008) indicates that the area may support a blue sheep population if these animals are translocated to the region.

A comprehensive knowledge of the spatial distribution and spatial arrangement of preferred habitats is essential for developing a species conservation management plan (Gibson et al. 2004). The present study has provided detailed spatial distributions and habitat preferences of blue sheep throughout the Himalayas which can provide baseline information for the development of management strategies. Such resources can be used to facilitate protection, management, and restoration of critical habitats, and hence they have broad applicability in conservation biology and wildlife management (Jaberg and Guisan 2001, NBS 2002). We recommend the

translocation of blue sheep to the Mt. Everest region with the main conservation aim of supporting the population of snow leopards and other predators and helping to reduce human–wildlife conflict (Hodder and Bullock 1997, Lovari et al. 2009). However, a detailed analysis is still required of human disturbance, grass biomass and the effects of climate change to determine specific release sites. Moreover, a decision would also need to be made about the number of founder blue sheep that would be required before translocation should proceed (Griffith et al.1989, Wolf et al. 1996, IUCN 1998, Sekercioglu et al. 2008, Seddon et al. 2011).



**Figure 5.** Non-metric Multi-Dimensional Scaling (MDS) graph of overall similarity of parameters (vegetation, elevation, aspect, soil, slope, precipitation) in protected areas with blue sheep present and absent (2D stress=0.25).

### Acknowledgements

We thank the Department of National Park and Wildlife Conservation/Ministry of Forest and Soil Conservation Nepal; National Trust for Nature Conservation/Annapurna Conservation Area Project (ACAP) for providing permission and necessary support to conduct research, and Dr S.R. Jnawali, Mr R.P. Lamsal, Mr N. Lama (officer in charge of ACAP) and Mr L.B. Gurung

(ACAP Director) for provided support and encouragement. We thank Mr K. Thapa (WWF Nepal), Prof. Dr S. Lovari (Italy) and Dr K.A. Parker (New Zealand) for their initial comments and suggestions to improve the manuscript. We thank the Massey University Research Fund for providing financial support for the study. Finally, we thank Mr M. Delaney, Mr F. Gurung, Mr S. Gurung, Mr S. Paudel and Mr B. Adhikari for their support in field.

## References

- Ale, S.B. 2007. Ecology of the snow leopard and the Himalayan tahr in Sagarmatha (Mt. Everest) National Park, Nepal. PhD Thesis. Chicago, Illinois: University of Illinois at Chicago.
- Anderson, M.U., R.N. Gorley, and K.R. Clarke. 2008. *PERMANOVA + FOR PRIMER: Guide to software and statistical methods*. Plymouth, UK: PRIMER-E.
- Aryal, A. 2009. Habitat ecology of Himalayan serow (*Capricornis sumatraensis* ssp. *thar*) in Annapurna Conservation Area of Nepal. *Tiger Paper/FAO* 36, no. 4: 12–20.
- Aryal, A., and A. Subedi. 2011. Conservation and potential habitat of Himalayan musk deer (*Moschus chrysogaster*) in the protected areas of Nepal. *International Journal of Conservation Sciences* 2, no. 2: 127–141.
- Aryal, A., S. Gastaur, S. Menzel, T.B. Chhetri, and J. Hopkins. 2010. Estimation of blue sheep population parameters in the Dhorpatan Hunting Reserve, Nepal. *International Journal of Biodiversity and Conservation* 2, no. 3: 051–056.
- Aryal, A., D. Raubenheimer, S. Subedi, and B. Kattel. 2010a. Spatial habitat overlap & habitat preference of Himalayan musk deer (*Moschus chrysogaster*) in Sagarmatha (Mt. Everest) National Park, Nepal. *Current Research Journal of Biological Sciences* 2, no. 3: 217–225.
- Aryal, A., J. Hipkins, W. Ji, D. Raubenheimer, and D. Brunton. 2012. Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (in press).

- Aryal, A., D. Raubenheimer, S. Sathyakumar, B.S. Poudel, W. Ji, K.J. Kunwar, J. Kok, S. Kohshima, and D. Brunton. 2012a. Conservation strategy for brown bear and its habitat in Nepal. *Diversity* 4: 301–317.
- Austegaard, G.O., and S. Haugland. 1993. Trophy hunting in Nepal: a case study on blue sheep in Dhorpatan Shikar Reserve. A thesis submitted in partial fulfilment of the requirements for the M. Sc. Degree. Agriculture University of Norway.
- Beier, P., and R.F. Noss. 1998. Do habitat corridors provide connectivity? *Conservation Biology* 12, no. 6: 1241–1252.
- Bleich, V.C. 1999. Mountain sheep and coyotes: pattern of predator evasion in a mountain ungulate. *Journal of Mammalogy* 80: 283–289.
- Bray, J.R., and J.T. Curtis. 1957. An ordination of upland forest communities of southern Wisconsin. *Ecological Monographs* 27: 325–349.
- Chapron, G., R. Wielgus, P.Y. Quenette, and J.J. Camarra. 2009. Diagnosing mechanisms of decline and planning for recovery of an endangered brown bear (*Ursus arctos*) population. *PLoS ONE* 4, no. 10: e7568. doi:10.1371/journal.pone.0007568.
- Geist, V. 1999. Adaptive strategies in American Mountain Sheep: effects of climate, latitude and altitude, Ice age evolution and neonatal security. In *Mountain sheep of North America*, ed. R. Valdez, and P.R. Krausman, 190–208. Tucson: University of Arizona Press.
- Gibson, L.A., B.A. Wilson, D.M. Cahill, and J. Hill. 2004. Spatial prediction of rufous bristle bird habitat in a coastal heath land: A GIS-based an approach. *Journal of Applied Ecology* 41: 213–223.
- Griffith, B., J.M. Scott, J.W. Carpenter, and C. Reed. 1989. Translocation as a species conservation tool: status and strategy. *Science* 245: 477–480.

- Grubb, P. 2005. Artiodactyla. In *Mammal Species of the World. A Taxonomic and Geographic Reference* 3rd ed, ed. D.E. Wilson, and D.M. Reeder, 637–722. Baltimore, USA: Johns Hopkins University Press.
- Harris, R.B. 2008. *Pseudois nayaur*. In *IUCN 2010. IUCN Red List of Threatened Species*. Version 2010.4. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 19 March 2011.
- Hess, G. 1994. Conservation corridors and contagious disease. A cautionary note. *Conservation Biology* 8: 256–262.
- Hodder, K.H., and J.M. Bullock. 1997. Translocations of native species in the UK: implications for biodiversity. *Journal of Applied Ecology* 34: 547–565.
- Hunter, M.L. 1996. *Fundamentals of conservation biology*. Cambridge, Massachusetts: Blackwell Science.
- International Union for Conservation of Nature [IUCN] 1998. *Guidelines for re-introductions*. Switzerland and Cambridge, UK: IUCN/SSC Re-introduction Specialist Group, IUCN, Gland.
- International Union for Conservation of Nature [IUCN] 2008. *Pseudois nayaur*. In *IUCN 2011. IUCN Red List of Threatened Species*. Version 2012.1
- International Union for Conservation of Nature [IUCN] 2011. IUCN Red List of Threatened Species. Version 2011.1.<[www.iucnredlist.org](http://www.iucnredlist.org)>.Downloaded on 24 October 2011.
- Ivlev, V.S. 1961. *Experimental ecology of the feeding of fishes*. New Haven: Yale Univ. Press.
- Jaberg, C., and A. Guisan. 2001. Modelling the distribution of bats in relation o landscapes structure in a temperate mountain environment. *Journal of Applied Ecology* 38: 1169–1181.
- Jackson, R., D. Mallon, T. McCarthy, R.A. Chundaway, and B. Habib. 2008. *Panthera uncia*. In *IUCN 2011. IUCN Red List of Threatened Species*. Version 2011.1. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 25 October 2011.

- Karki, J., and B. Thapa. 2006. *Status of Blue sheep and Himalayan tahr in Dhorpatan Hunting Reserve*. Nepal: Department of National Park and Wildlife Conservation.
- Kinloch, A.A.A. 1892. *Large game shooting in Tibet, the Himalayas, Northern and Central India*. Third ed. Calcutta: Thacker and Spink.
- Koshkarev, E.P., and V. Vyrypaev. 2000. The snow leopard after the break-up of the Soviet Union. *Cat News* 32: 9–11.
- Krebs, C.J. 1989. *Ecological methodology*. New York, New York, USA: Harper and Row.
- Lomolino, M.V., and R. Channell. 1998. Range collapse, re-introductions, and biogeographic guidelines for conservation. *Conservation Biology* 12, no. 2: 481–484.
- Lovari, S., R. Boesi, I. Minder, N. Mucci, E. Randi, A. Dematteis, and S.B. Ale. 2009. Restoring a keystone predator may endanger a prey species in a human altered ecosystem: the return of the snow leopard to Sagarmatha National Park. *Animal Conservation* 12: 559–570.
- Mack, E.L., L.G. Firbank, P.E. Bellamy, S.A. Hinsley, and N. Veitch. 1997. The comparison of remotely sensed and ground-based habitat area data using species-area models. *Journal of Applied Ecology* 34, no. 5: 1222–1228.
- Manel, S., J.M. Dias, S.T. Buckton, and S.J. Ormerod. 1999. Alternative methods for predicting species distribution: an illustration with Himalayan river birds. *Journal of Applied Ecology* 36: 734–747.
- McCarthy, T.M., P.M. Allen, J. Fox, G. Chapron, R.M. Jackson, C. Mishra, and S. Theile. 2003. *Snow leopard survival strategy*. Seattle: ISLT.
- Meffe, G.K., and C.R. Carroll. 1997. Conservation reserves in heterogeneous landscapes. In *Carroll and Contributors. Principles of conservation biology* 2<sup>nd</sup> Edition, ed. G.K. Meffe. Massachusetts: C.R. Sinauer Associates, Sunderland.
- Miehe, G. 1989. Vegetation patterns on Mount Everest as influenced by monsoon and föhn. *Vegetation* 79: 21–32.

- Miehe, G., S. Miehe, K. Kaiser, L. Jianquan, and X. Zhao. 2008. Status and dynamics of the *Kobresia pygmaea* ecosystem on the Tibetan Plateau. *Journal of the Human Environment* 34, no. 4: 272–279.
- Namgail, T. 2006. Winter habitat partitioning between Asiatic Ibex and blue sheep in Ladakh, Northern India. *Journal of Mountain Ecology* 8: 7–13.
- Namgail, T., J.L. Fox, and Y.C. Bhatnagar. 2004. Habitat segregation between sympatric Tibetan argali (*Ovis ammon hodgsoni*) and Blue sheep (*Pseudois nayaur*) in the Indian Trans-Himalaya. *Journal of Zoology* 262: 57–63.
- Nepal Biodiversity Strategy [NBS] 2002. His Majesty's Government of Nepal, Supported by GEF and UNDP.
- Noss, R.F. 1987. Corridors in real landscapes: a reply to Simberloff and Cox. *Conservation Biology* 1: 159–164.
- Oli, M.K. 1994. Snow leopards and blue sheep in Nepal: densities and predator-prey ratio. *Journal of Mammalogy* 75, no. 4: 998–1004.
- Oli, M. 1996. Seasonal patterns in habitat use of blue sheep *Pseudois nayaur* (Artiodactyla, Bovidae) in Nepal. *Mammalia* 60, no. 2: 187–193.
- Oli, M.K., I.R. Taylor, and M.E. Rogers. 1993. Diet of the snow leopard (*Panthera uncia*) in the Annapurna Conservation Area, Nepal. *Journal of Zoology* (London) 231: 365–370.
- Osborne, P.E., and P.J. Seddon. 2011. Selecting suitable habitats for reintroductions: variation, change and the role of species distribution modelling. In *Reintroduction Biology: Integrating Science and Management*, ed. J.G. Ewen, D.P. Armstrong, K.A. Parker, and P.J. Seddon. First Edition. Blackwell Publishing Ltd.
- Pendleton, G.W., K. Titus, K. DeGayner, C.J. Flatten, and R.E. Lowell. 1998. Compositional analysis and GIS for study of habitat Selection by Goshawks in Southeast Alaska. *Journal of Agricultural, Biological and Environmental Statistics* 3, no. 3: 280–295.

- Rantalainen, M.L., H. Fritze, J. Haimi, T. Pennanen, and H. Setälä. 2005. Colonisation of newly established habitats by soil decomposer organisms: the effect of habitat corridors in relation to colonization distance and habitat size. *Applied Soil Ecology* 28: 67–77.
- Reinert, H.K., and R.R. Rupert. 1999. Impacts of translocation on behaviour and survival of timber rattlesnakes, *Crotalus horridus*. *Journal of Herpetology* 33, no. 1: 45–61.
- Schaller, G. B. 1977. *Mountain monarchs: Wild sheep and goats of the Himalaya*. Chicago: University of Chicago Press.
- Seddon, P.J., W.M. Strauss, and J. Innes. 2011. Animal translocations: What are they and why do we do them? In *Reintroduction Biology: Integrating Science and Management*. First Edition, ed. J.G. Ewen, D.P. Armstrong, K.A. Parker, and P.J. Seddon. Blackwell Publishing Ltd.
- Sekercioglu, C.H., S.H. Schneider, J.P. Pay, and S.R. Loarie. 2008. Climate change, elevational range shifts and bird extinctions. *Conservation Biology* 22: 140–150.
- Shrestha, R., and P. Wegge. 2008. Wild sheep and livestock in Nepal Trans-Himalaya: Coexistence or competition. *Environmental Conservation* 35: 125–136.
- Shrestha, R., P. Wegge, and R. Koirala. 2005. Summer diets of wild and domestic ungulates in Nepal Himalaya. *Journal of Zoology* 266: 111–119.
- Shrestha, U.B., S. Shrestha, P. Chaudhary, and R.P. Chaudhary. 2010. How representative is the protected areas system of Nepal? *Mountain Research and Development* 30, no. 3: 282–294.
- Simberloff, D., J.A. Farr, J. Cox, and D.W. Mehlman, 1992. Movement corridors; conservation bargains or poor investments? *Conservation Biology* 6: 493–504.
- Thapa, K. 2006. *Study on status and distribution of the snow leopard and blue sheep including people interaction: A case study from Kanchanjunga conservation area, Taplejung and*

*Shey Phoksundo National Park, Dolpa, Nepal*. Report submitted to WWF Nepal program, Kathmandu.

Wegge, P. 1976. Himalayan Shikar Reserves; surveys and management proposals. *Field Document No. 5. FAO/NEP/72/002 Project*, Kathmandu. 96 pp.

Wegge, P. 1991. Survey of Kanchanjunga area in NE Taplejung district of Nepal. *WWF Project report*. 4102. Gland, Switzerland: World Wide Fund for Nature.

Wilson, P. 1981. Ecology and habitat utilisation of blue sheep in Nepal. *Conservation Biology* 2: 55–74.

Wolf, C.M, B. Griffith, C. Reed, and S.A. Temple. 1996. Avian and mammalian translocations: update and reanalysis of 1987 survey data. *Conservation Biology* 10: 1142–1154.

**Appendix 1.** Biophysical parameters (vegetation, precipitation, soil, elevation, aspect and slope) of areas used by and potentially available for blue sheep and the values of Ivlev's electivity index (IEI).

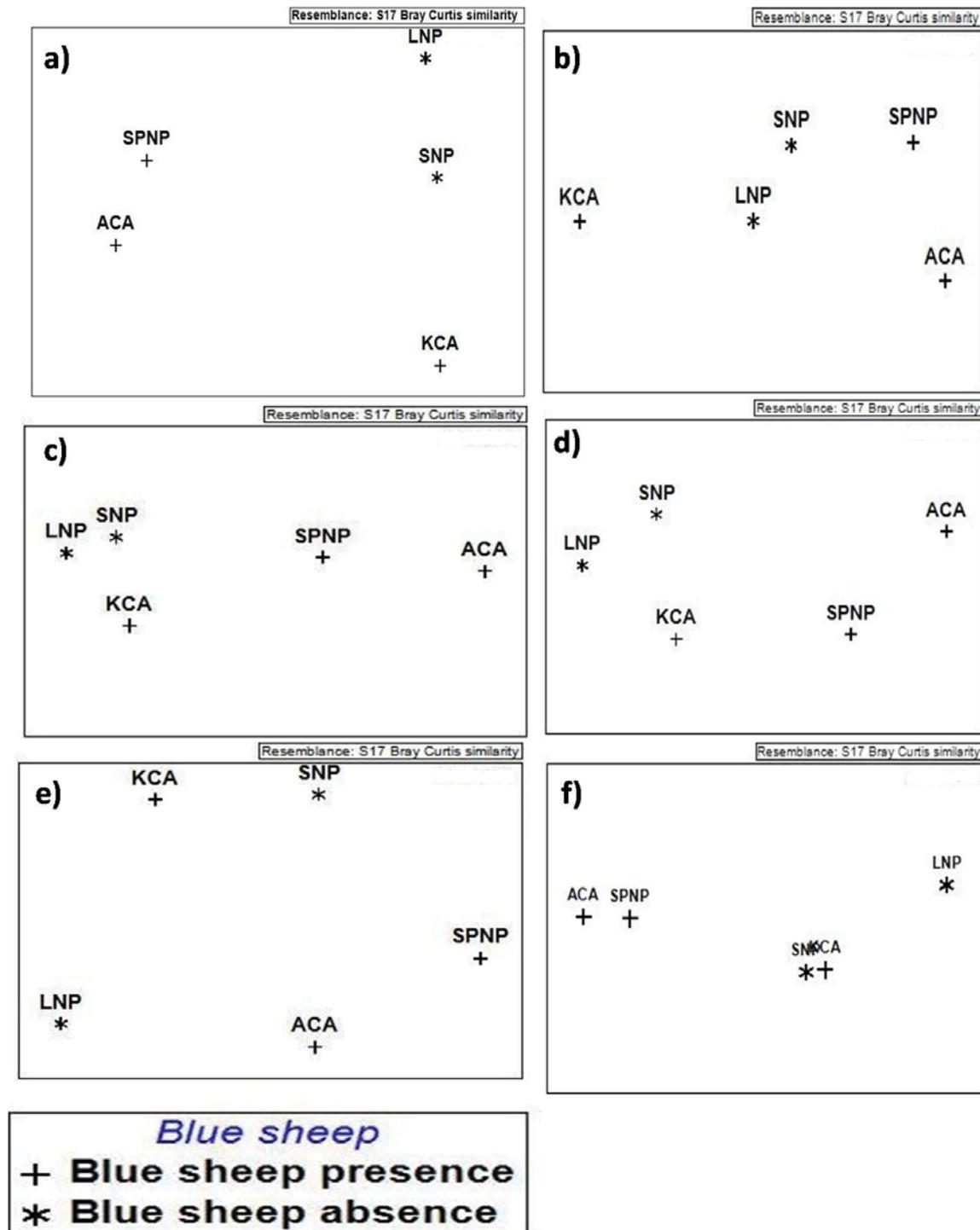
Biophysical parameters	Used area (km <sup>2</sup> )	Available area (km <sup>2</sup> )	Used (%)	Available (%)	IEI
<b>Vegetation</b>					
Alpine mats and scrub	1405.3	613.8	10.99	0.29	0.95
Alpine meadow	784.2	149	6.13	0.07	0.98
Alpine pasture	4823.8	7026.6	37.71	3.29	0.84
Birch-rhododendron	0	964	0	0.45	-1
Blue pine-birch forest	0	135.5	0	0.06	-1
Blue pine-spruce forest	0	48.9	0	0.02	-1
Deciduous walnut-maple-alder	0	38.8	0	0.02	-1
Dwarf rhododendron scrub	529.5	775.9	4.14	0.36	0.84
Dwarf sub-alpine scrub	259.7	60.5	2.03	0.03	0.97

Juniper scrub	15.7	155.6	0.12	0.07	0.25
Nival zone	1334.4	9700.2	10.43	4.54	0.39
Pine-spruce-fir forest	0	4.9	0	0	-1
Rhododendron shrubberies	161.2	218.7	1.26	0.1	0.85
Spruce forest	0	6.3	0	0	-1
Steppe with <i>Euphorbia royleana</i> , grasses and <i>Artemisia</i>	456	0.2	3.56	0	1
Sub-alpine juniper forest	65.6	48.3	0.51	0.02	0.92
Sub-alpine mountain oak forest	9	231	0.07	0.11	-0.21
Temperate juniper forest	21	416	0.16	0.19	-0.08
Trans-Himalayan steppe	2451.7	669.6	19.17	0.31	0.97
Upper temperate blue pine forest with grassland	90.12	130	0.7	0.06	0.84
Water body	4.5	0	0.04	0	1
<b>Mean annual precipitation (mm)</b>					
200	855.3	400	6.63	1.24	0.68
300	546.2	600	4.23	1.87	0.39
400	438.8	948	3.4	2.95	0.07
500	756.4	1568.9	5.87	4.88	0.09
600	863.3	1644.7	6.69	5.11	0.13
700	781.6	1494.1	6.06	4.64	0.13
800	651.3	1254.1	5.05	3.9	0.13
900	870.5	1639.3	6.75	5.1	0.14
1000	844.7	1993.2	6.55	6.2	0.03
1200	1441.9	4459.9	11.18	13.86	-0.11
1400	1136.9	3766.9	8.81	11.71	-0.14
1600	960.2	2912.2	7.45	9.05	-0.1

1800	743.3	2272.8	5.76	7.07	-0.1
2000	673.3	2336.8	5.22	7.26	-0.16
2500	1076.1	3405.4	8.34	10.59	-0.12
3000	181.2	827.2	1.41	2.57	-0.29
3500	66.3	206.8	0.51	0.64	-0.11
3500>	9.9	437	0.08	1.36	-0.89
<b>Soil types</b>					
Dystrochrepts, Haplumbrepts, Haplustalfs	95.3	3602.04	0.67	17.01	-0.92
Glaciated mountain	617.8	16110.4	4.33	76.07	-0.89
Haplumbrepts, Dystrochrepts, Cryumbrepts	13541.4	1426.8	95	6.74	0.87
Dystrochrepts, Haplustalfs, Rhodustalfs	0	30.6	0	0.14	-1
Dystrochrepts, Haplustalfs- calcareous	0	8.8	0	0.04	-1
<b>Elevation (m)</b>					
1766–1800	0	0.1	0	0	-1
1800–2100	2.1	2.3	0.01	0.01	-0.04
2100–2400	10.7	15.7	0.03	0.05	-0.18
2400–2700	80.9	103.5	0.26	0.33	-0.12
2700–3000	227.9	314.9	0.74	1.01	-0.15
3000–3300	584.9	780	1.9	2.5	-0.14
3300–3600	1244.1	1157.8	4.04	3.72	0.04
3600–3900	2523.3	2064.2	8.19	6.63	0.11
3900–4200	3488.7	3011.3	11.32	9.67	0.08
4200–4500	4313.5	3873.4	14	12.44	0.06

4500–4800	4713.9	4723.4	15.3	15.17	0
4800–5100	7182.1	7155.2	23.31	22.97	0.01
5100–5400	4065.1	4135.3	13.19	13.28	0
5400–5700	1753.7	2639.2	5.69	8.47	-0.2
5700–6100	622.1	1162.6	2.02	3.73	-0.3
6100–8800	1.1	6.3	0	0.02	-0.7
<b>Aspects</b>					
North	396.4	1414.5	3.12	4.04	-0.13
Northeast	2023	2911.9	15.94	8.32	0.31
East	1948.7	2734.2	15.36	7.82	0.33
Southeast	1810.2	2615.2	14.26	7.48	0.31
South	1863.7	2780.7	14.69	7.95	0.3
Southwest	1998.9	2881.5	15.75	8.24	0.31
West	819.6	2739.6	6.46	7.83	-0.1
Northwest	1830.3	16904.5	14.42	48.32	-0.54
<b>Slope</b>					
< 10 degree	1262.9	4350	3.49	27.17	-0.77
10–20 degree	3263.9	5851.9	9.01	36.55	-0.6
20–30 degree	5570.3	2307.7	15.38	14.41	0.03
30–40 degree	6082.4	1653.6	16.8	10.33	0.24
40–50 degree	2097.9	1008	5.79	6.3	0
50–60 degree	257.5	120.3	0.71	0.75	0
> 60 degree	17672.5	651.1	48.81	4.07	0.85

**Appendix 2.** Non-metric Multi-Dimensional Scaling (MDS) analysis graph of vegetation (a), soil (b), aspect (c), slope (d), precipitation (e), and elevation (f) in protected areas with blue sheep present and absent.



**Appendix 3.** Biophysical parameters (area in km<sup>2</sup>), i.e. vegetation, precipitation, soil, elevation, aspect, and slope in a blue sheep distribution potential habitat in protected areas with blue sheep present (KCA, ACA, SPNP) and absent (SNP and LNP).

Biophysical parameter (area km <sup>2</sup> )	KCA	SNP	LNP	ACA	SPNP
<b>Vegetation</b>					
Alpine mats and scrub					126
Alpine meadow				92	
Alpine pasture		282	221	2199	1460
Birch-rhododendron forest			63	37	151
Blue pine-birch forest				52	70
Juniper scrub		87	40		
Dwarf rhododendron scrub	399		150		
Larch forest	22				
Mixed broad-leaved forest	7				
Mixed blue pine-oak forest				15	
Nival zone	968	725	489	2139	594
Rhododendron forest			52		
Rhododendron shrubberies	109				
Spruce forest				1	
Sub-alpine juniper forest		38			
Sub-alpine juniper forest				68	
Temperate juniper forest				3	7
Trans-Himalayan steppe			9	1279	1047
<b>Precipitation (mm)</b>					

200		1139			
300		1436			
400	18	511			
500	915	350			
600	685	345			
700		294			
800	405	253			
900	332	196			
1000	231	154	1	192	1
1200	247	277	56	506	589
1400	106	214	61	170	352
1600		146	49	68	147
1800		117	66	17	56
2000		110	144		12
2500		291	358		1
3000		263	315		
3500		138	27		
3500>		37			
<hr/>					
Soil					
<hr/>					
Glaciated mountain	1606	2871	504	765	
Haplumbrepts, Dystrochrepts, Cryumbrepts	1866	3148	647	389	546
Dystrochrepts, Haplumbrepts, Haplustalfs	264		1	971	
Dystrochrepts, Haplumbrepts, Rhodustalfs	1				
<hr/>					
Elevation (m)					
<hr/>					

1766–1800		0.1			
1800–2100		2			
2100–2400		9			
2400–2700		64		0.3	2
2700–3000	5	131	2	2	12
3000–3300	32	226	9	10.08	27
3300–3600	91	379	23	26	49
3600–3900	212	544	51	49	84
3900–4200	506	661	84	117	131
4200–4500	886	904	117	223	175
4500–4800	1541	1076	248	329	187
4800–5100	3969	4909	669	436	231
5100–5400	1200	1755	490	233	142
5400–5700	193	1078	295	206	81
5700–6100	63	612	169	141	40
6100–8800	18	304	190	122	33
<hr/>					
Aspect					
<hr/>					
North	92	75	72	220	433
Northeast	181	154	157	460	830
East	185	142	137	435	753
Southeast	190	130	128	414	730
South	184	141	140	422	808
Southwest	185	155	162	447	828
West	192	142	142	432	745
Northwest	199	135	131	420	748

---

Slope class					
< 10 degree	717	150	78	177	181
10–20 degree	1455	316	194	638	243
20–30 degree	1851	436	307	1031	274
30–40 degree	1571	424	329	1260	263
40–50 degree	627	183	194	483	161
50–60 degree	152	41	47	61	65
> 60 degree	10	4	2	1	6

---

## Chapter Four

### Small mammals and their distribution and ecology

#### Summary

This chapter describes the ecology of two small mammals, which are some of the least understood species despite their significant role in providing an alternative diet for existing predators in the ecosystem. The chapter consists of two parts:

- 1) The hispid hare (*Caprolagus hispidus*) from the lowlands of Nepal's tropical region, and
- 2) The Himalayan marmot (*Marmota himalayana*) from the high mountain region of Nepal.

The first part investigates the seasonal foraging behaviour of the Himalayan marmot, the soil nutrients, and plant diversity in the upper Mustang region of Nepal (Paper *I* below). The second part analyzes the diet and habitat use of hispid hare before and after a grassland fire in Shuklaphanta Wildlife Reserve (SWR) in Nepal (Paper *II* below). The study, it is recommended that the timing of grass burning is changed to either before or after the hispid hare breeding season to reduce the direct (burning, destruction of nests) and indirect (increased risk of predation) effects of existing grassland management strategy on hare populations. Population management strategies and a field based conservation captive breeding program are suggested to maintain a viable population of the hispid hare in SWR.

*This chapter contains two papers as follows:*

- I. Aryal, A., D. Brunton, W. Ji, J. Rothman and D. Raubenheimer (**In prep.**). Habitat Characteristics of the Himalayan Marmot (*Marmota himalayana*) in upper Mustang, Nepal.

II. Aryal, A., D. Brunton, W. Ji, H. Yadav, B. Adhikari, D. Raubenheimer. 2012. Diet and habitat use of hispid hare *Caprolagus hispidus* in Shuklaphanta Wildlife Reserve Nepal. *Mammal Study* 37 (2): 147-154. (With cover page photo coverage).

# **Paper I: Habitat Characteristics of the Himalayan Marmot (*Marmota himalayana*) in upper Mustang, Nepal**

## **Abstract**

The Himalayan marmot (*Marmota himalayana*), which occurs throughout the Himalayan alpine mountain ecosystem, plays an important role as an ‘ecosystem engineer’ through soil modification resulting from its extensive burrowing. Despite its potentially important ecological role, *M. himalayana* is one of the least studied species in the Himalayas. In this study we investigated the seasonal foraging behaviour, diet, nutritional composition of foods, and the soil properties and plant diversity associated with marmot habitat in the upper Mustang region of Nepal. Marmots were found to inhabit warmer valleys close to water sources in areas between 3200m and 5300m above sea level. Their burrows were found mostly in the eastern slopes of valleys, and plant diversity was higher in the marmot habitat than paired areas unoccupied by marmots. Seventeen species of plants, including *Primula* spp, *Potentilla fruticosa*, *Kobresia pygmaea*, *Anaphalis contorta*, *Lonicera spinosa* and *Corex* spp were recorded in marmot scats over three seasons (summer, autumn and spring); and the relative frequency of plants found in the marmot presence habitat and in the scats were not significantly different. Soil pH, organic matter and organic carbon were not significantly different in habitat occupied by marmots compared to areas where marmots were absent. Phosphorus ( $P_2O_5$ ) levels were significantly higher and potash ( $K_2O$ ) levels significantly lower in marmot burrow habitat. Sandy loam was the dominant soil type (71%) in marmot burrow habitat. Marmot hibernation occurred from the end of November to the end of February when the mean monthly temperature was below 5 °C and precipitation < 10mm.

**Key words:** *Ecosystem engineer, marmot, plant diversity, forage plants, soil nutrients, diet.*

## Introduction

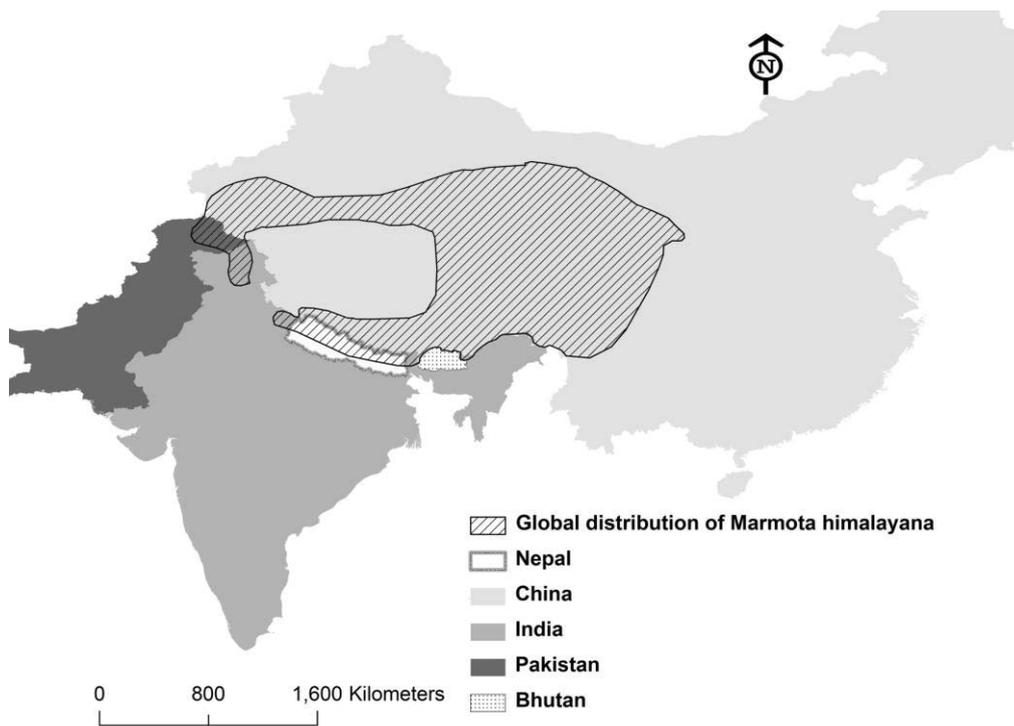
The Himalayan marmot (*Marmota himalayana*) is native to the higher Himalayan regions of China, Nepal, Pakistan and India (between 3500 and 5200m, Fig. 1) (Roberts 1997, Molur *et al.* 2005, Smith and Xie 2005). The potential global marmot distribution area is estimated to be 2,432,970 km<sup>2</sup> (Fig. 1) (Molur and Shrestha 2008; IUCN 2011), of which about 84,934 km<sup>2</sup> is estimated to be the potential habitat in Nepal (Fig. 1).

Although the Himalayan marmot is classified as a species of ‘least concern’ under the IUCN (World Conservation Union) (Molur and Shrestha 2008, IUCN 2012), it is undoubtedly an important component of Himalayan ecosystems. A small burrowing herbivore, the Himalayan marmot (*Marmota himalayana*) is regarded as an ecosystem engineer because its burrows maintain soil fertility and plant diversity in mountain ecosystems (Brown and Heske 1990, Nikol’skii and Ulak 2005, Bagchi 2005, Nikol’skii and Ulak 2006). It is also an important food source for endangered predators such as the snow leopard (*Paranthera uncia*) and the brown bear (*Ursus arctos*) in this region. More than 50% of the total diet of the brown bear and about 20% of the snow leopard diet consists of marmot (Oli *et al.* 1994, Aryal *et al.* 2010, Aryal *et al.* 2012a). Himalayan marmots are, however, considered pests in parts of the Asian highlands and in some areas are frequently subject to lethal control measures (Jing *et al.* 1991, Zhong *et al.* 1991, Smith and Foggin 1999, Bagchi *et al.* 2006, Xu *et al.* 2006). They are also harvested for fur, meat and illegal trade, and in some countries may be over-harvested. Harvesting and lethal controls are considered the major causes of the decline in the marmot population (Bagchi *et al.* 2006, Murdoch *et al.* 2009).

Marmots are distributed in the rangelands of the upper Mustang region in Nepal where they are the main prey species for the brown bear (Aryal *et al.* 2012a). Consequently, the presence of marmots is often an indicator of brown bear presence in the region (Aryal *et al.* 2010, Aryal *et al.* 2012a). Livestock prefer to graze in Himalayan marmot habitat (Nikol’skii and Ulak 2005),

although the reason for this is unknown (Jing et al. 1991, Zhong et al. 1991, Nikol'skii and Ulak 2005, Bagchi et al. 2006). Despite its ecological importance, the Himalayan marmot is one of the least studied species in the region, with little known about its ecology, behaviour and the potential impact of climate change (Gromov et al. 1965, Zimina 1978, Bibikov 1989, Heptner and Naumov 1992, Elli et al. 1999, Gombobaatar et al. 2001, Nikol'skii and Ulak 2005, Nikol'skii and Ulak 2006).

The aim of this study was to understand the seasonal foraging ecology, dietary composition, and the characteristics associated with marmot habitat in the upper Mustang region (inside the Annapurna Conservation Area, ACA), Nepal. Such knowledge can advance the overall understanding of this species and its habitat, and may contribute to improving species management at local and regional level.



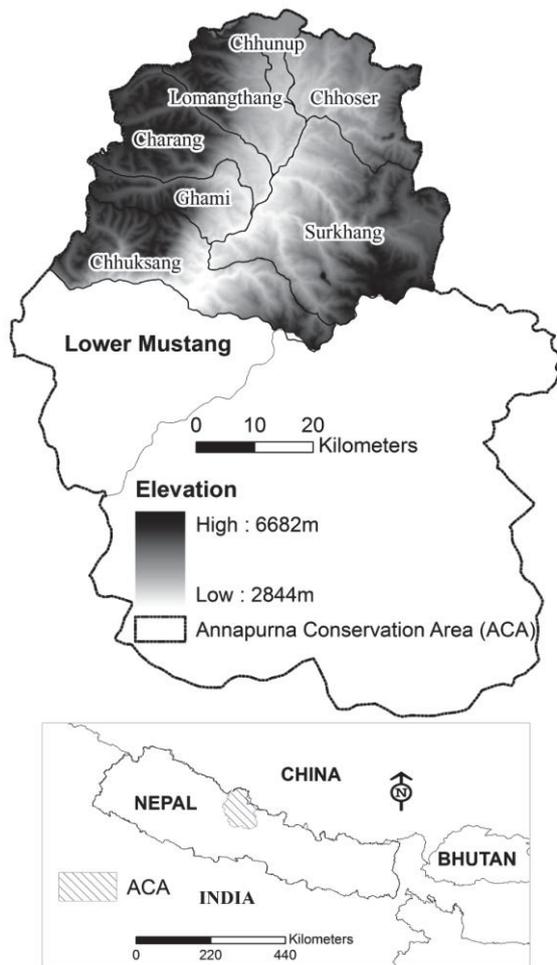
**Figure 1.** Global distribution of *Marmota himalayana* (Molur and Shrestha 2008; IUCN 2011)

## Materials and Methods

### Study area

Upper Mustang lies in the Mustang district of the Annapurna Conservation Area, Nepal (Fig. 2). Upper Mustang covers approximately 2500 km<sup>2</sup> and is divided into seven village development committees (VDC) (Fig. 2). This region has a cold desert environment with low rainfall (< 200mm/year) (Chetri and Gurung 2004, ACAP 2010). Agriculture, livestock farming and tourism are the main sources of income and only 8% of the local population is self-sufficient based on their own agricultural products (Chetri and Gurung 2004, ACAP 2010).

This region represents a typical high alpine mountain ecosystem and supports rangeland grasses and wildlife including the snow leopard, lynx (*Lynx lynx isabellinus*), brown bear, grey wolf (*Canis lupus*), Tibetan argali (*Ovis ammon hodgsonii*), Tibetan gazelle (*Procapra picticaudata*), wild ass (*Equus kiang*), blue sheep (*Pseudois nayaur*) and Himalayan marmot (Chetri and Gurung 2004, ACAP 2010, Aryal et al. 2012a).



**Figure 2.** Study area and Digital Elevation Model (DEM) of upper Mustang region. The map illustrates the upper Mustang inside the Annapurna Conservation Area of Nepal.

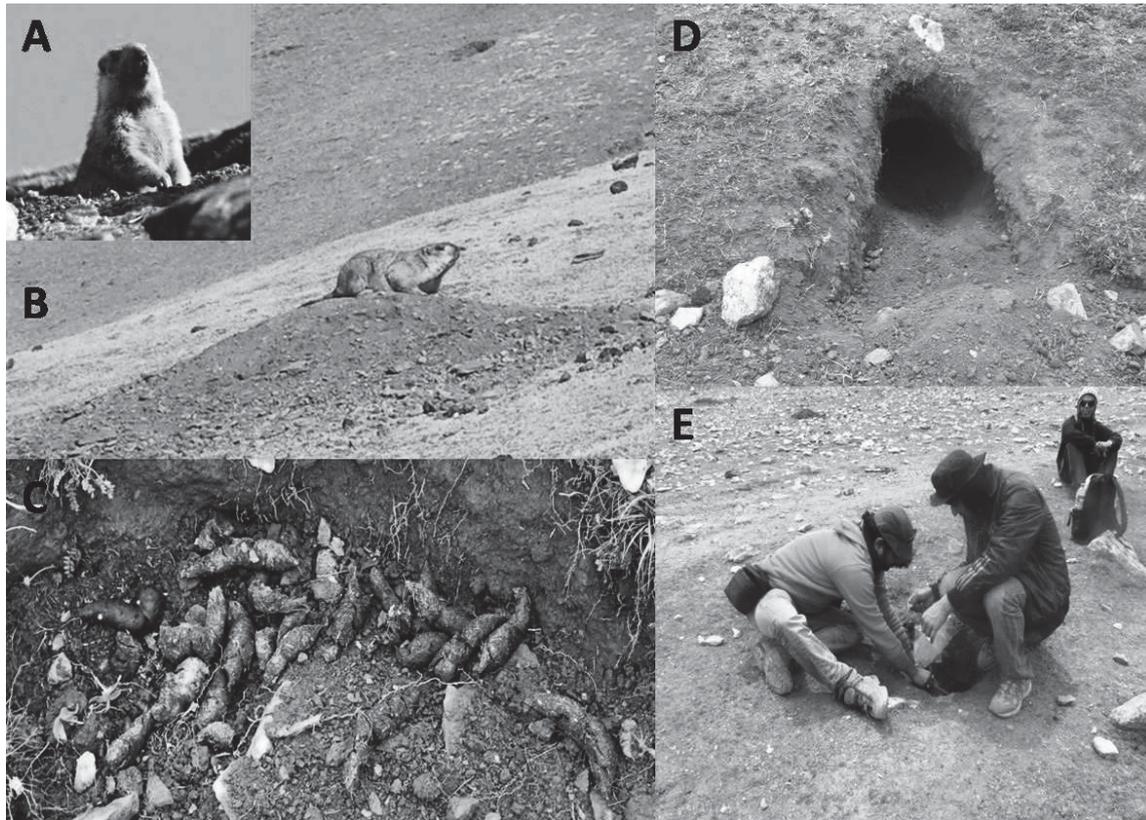
### **Marmot distribution**

Each VDC in the upper Mustang region was visited and interviews were conducted with local people about the marmot habitat, distribution, and population trends in the area. We asked open questions to local people (especially herders): *Where do marmots live in your area? What are the population trends of marmots (increasing, decreasing or unknown)? Do local people kill marmot?* A field survey was then conducted and data collected of habitat variables (namely, scats, burrows, GPS points, soil samples and sample plots of plants) from locations with marmot scats and burrows. The areas visited were located between an elevation of 2900m and 5500m

(Fig. 2). Vantage points and ridges were used to scan the valley and search for marmots and their burrows. Aspect, slope, surrounding habitat, and distance to water resources from the burrows were recorded. Careful observations were undertaken to identify the age of the burrows, and whether or not they were currently used by marmots e.g. presences of fresh soil excavations.

### **Diversity of plant species**

A vegetation survey following Kent and Coker (1995) was conducted during spring in habitats where marmot burrows were either present or absent and a total 156 plots were laid out. When the burrows of marmots were discovered, vegetation survey plots of 1m x 1m were laid out near (<5m) the burrows; these were called 'used' habitat. Other plots were then laid 200-300m away in a random direction where marmot burrows were absent; these were called 'available' habitat (Fig. 3). In the period between August and November, prior to marmot hibernation, the vegetation composition of each plot was record to estimate relative frequency and plants diversity. Vegetation was identified using a reference guide of the plants of the upper Mustang (Chetri et al. 2006), and unidentified plants were sent to the Central Botanical Garden in Godawari, Lalitpur, Nepal for identification. Chi-square ( $\chi^2$ ) test was used to test for differences in the frequency of plants between marmot occupied and available habitats, and Simpson's diversity index (D) was used to estimate the plant diversity in both categories of habitat (Rosenzweig 1995, Ravindranath et al. 1997). Bray Curtis Similarity (Bray and Curtis 1957) was calculated for marmots 'used' and 'available' habitats. Pielou's evenness [ $J' = H'/\log(s)$ - where H is Brillouin:  $=\text{Log}(N!/\text{PROD}(N_i!))/N$ ; S= total species, and N= total individuals] was used to test how evenly the individuals were distributed among the different species in marmot present and absent habitat (Anderson et al. 2008). Primer software was used for these analyses (Bray and Curtis 1957, Anderson et al. 2008).



**Figure 3.** Himalayan marmot (A and B); scats of Himalayan marmot (C); the marmot burrow (D); soil collection from marmot burrow (E).

### **Soil nutrient analysis**

Seventy eight samples (200-300g) were collected from soil dug by marmots around their burrows. An additional 78 soil samples were collected from ‘available’ habitat (as described above) where marmots’ burrows were absent (Fig. 3).

All soil samples were analyzed in the Regional Soil Lab (RSL), Pokhara, Nepal. Nitrogen (N %) content was analyzed using the Kjeldahl distillation method (Bremner 1960, Bradstreet 1965, Jones 1991). Phosphorus ( $P_2O_5$ ) content was analyzed using the Oslen's bicarbonate method (Delgado and Torrent 1997, Kleinman et al. 2001, Horta and Torrent 2007), and potash ( $K_2O$ ) content by using the Flame photometer method (Alban and Kellog 1959, Poluektv 1961, Tung et

al. 2009). Organic matter (OM) and organic carbon (OC) [ $OC (\%) = OM (\%) * 0.58$ ] were analyzed by the Black and Waley method (Walkley 1947, Schumacher 2002, Howard and Howard 2009). Soil pH was analyzed by the electrode method (Gillman and Sumpter 1986, Lee and Yang 2000) and soil texture by the hydrometer method (Day 1965, Gee and Bauder 1979, ASTM 1985, Gee and Bauder 1986). Chi-square ( $\chi^2$ ) test was used to test the significance of different soil nutrients contained in used and available habitats.

### **Temperature and precipitation patterns in the marmot habitat**

Monthly temperature and rainfall data from 2010-2011 were obtained from the meteorological stations of Chhoser and Lomangthang in the upper Mustang region within 2-9 km from the study area. Mean monthly temperature and precipitation were calculated. The marmot hibernation activities in the Lomangthang VDC (Panga area) of upper Mustang (Fig. 2) were observed by the team (researcher and two assistants) from October 2010 to February 2011. Once a week, we visited marmot colonies in Panga area of Lomangthang and special note was taken of when hibernation began and when marmots emerged. The weeks of the month they commenced and finished their hibernation were also recorded; and these activities were compared to mean monthly temperature and precipitation.

### **Diet analysis**

Micro-histological analysis was used to estimate the frequency of plant species found in marmot scats (Sparks and Malechek 1968, Shrestha et al. 2005, Giri et al. 2011, Aryal et al. 2012b). It is possible that some plant species were completely digested and consequently no remains were found in scats. Nevertheless, the methods are adequate to rank each plant species in terms of its occurrence in the diets of herbivores (McInnis et al. 1983). Marmot scats (n=203) found in and around marmot burrows from the upper Mustang region were collected in three different seasons

[summer (July 2010), autumn (October-November 2010) and spring (May 2011)] (Fig. 3C). Microscope slides were prepared from each scat sample for identification of plants remains (Sparks and Malechek 1968).

The samples were processed in the laboratory following Giri et al. (2011) and Aryal et al. (2012b). Scat samples were initially washed in distilled water with 2% alcohol. They were then ground and sieved (1mm-0.3mm) and washed with 5% potassium hydroxide to remove the black color from the plant fragment remains. Samples were passed through Ethanol (C<sub>2</sub>H<sub>6</sub>O) and finally dehydrated with Xylene (C<sub>8</sub>H<sub>10</sub>) (Giri et al. 2011, Aryal et al. 2012b). A permanent slide of each sample fragment was prepared for observation under microscopes. Microscope (100x and 400x) cell structure photographs were then taken to compare with plant fragment structure references of the region. Reference fragment photographs of each plant species found in the marmot habitat were prepared (Giri et al. 2011, Aryal et al. 2012b). Twenty fragments were randomly chosen from each slide to compare with reference slides and to calculate the frequency of occurrence. Fragments that could not be identified to the species level were grouped as unidentified. The relative frequency percentage of each plants species in the scats was calculated (Sparks and Malechek 1968, Aryal et al. 2012b). A chi-square ( $\chi^2$ ) test was used to investigate significant differences in plants species occurrence in marmot scats between and within seasons.

## **Results**

### *Marmot distribution*

Himalayan marmots were found to be distributed throughout upper Mustang (Chhuksang, Lomangthang, Surkhang, Ghami, Chhoser, and Chhunup) from 3200m to 5300m above sea level (Fig. 1). Marmot burrows were found in valleys with eastern slopes (61%), north-east slopes

(10%), south-east slopes (21%), south-west slopes (5%), and north-west slopes (3%). Most of the marmot burrows (86%) were found near (<700 meters) water sources (such as streams or rivers or ponds) and only 14 % of burrows were observed > 700 meters from water sources. Livestock grazing activities were observed in and around the marmot colonies visited. Out of total 82 respondents, 69 (84%) agreed that the population of marmots has declined over the past ten years and 16% of the respondents were unable to comment on population trends. All respondents stated that there were no illegal hunting activities to kill marmot for meat or other purposes in this region.

### **Plant diversity in marmot habitat (present and absent habitat)**

Seventy eight plots were laid out in habitat used by marmots and another 78 in ‘available’ habitat to measure plant diversity. Forty-two plant species were recorded in marmot habitats and thirty four plant species were found in habitats where marmots were absent (Table 1). The most frequently occurring plants in habitats where marmots were present were *Anaphalis* spp (6.5%) *Potentilla* spp (6.2%), *Kobresia* spp (6.2%), *Lancea tibetica* (5.4%), and *Carex* spp (4.3%). In habitats where marmot burrows were absent, the most frequently occurring plants were *Caragana* spp (13.7%) and *Artemisia* spp (10.5%) (Table 1). There was, however, no statically significant difference in the frequency of occurrence of plants species in marmot present and absent habitat ( $\chi^2= 1.1$ ,  $df=1$ ,  $p=0.28$ ; Table 1). However, the plant species diversity was higher and more heterogeneous in the marmot present habitat ( $D=0.96$ ) than in the marmot absent habitat ( $D=0.93$ ). Plant frequencies had 42% similarity (Bray Curtis similarity ‘S’) between the two types of habitat. Species were distributed more evenly in habitats where marmots were present (Pielou’s evenness= 0.91) than absent (Pielou’s evenness= 0.84) (Table1).

**Table 1:** Plants relative frequency on marmot present and absent habitat before the marmot hibernation i.e. August-November 2010.

<b>Marmot habitat</b>	<b>present</b>	Relative Frequency (%)	<b>Marmot absent habitat</b>	Relative Frequency (%)
<i>Agrostis</i> spp		1.4	<i>Allium</i> spp	7.8
<i>Ajuga</i>		1.7	<i>Anaphalis</i>	1.0
<i>Allium</i> spp		4.6	<i>Androsace</i>	1.1
<i>Anaphalis</i> spp		6.5	<i>Anemone rupicola</i>	1.0
<i>Androsace</i>		1.7	<i>Arabdiopsis</i>	0.1
<i>Anemone rupicola</i>		3.5	<i>Artemisia</i> spp	10.5
<i>Astragalus</i> spp		1.6	<i>Bistorta macrophylla</i>	3.8
<i>Artemisia</i> spp		3.6	<i>Caragana</i> spp	13.7
<i>Aster</i> spp		0.3	<i>Carex</i> spp	7.8
<i>Caragana</i> spp		2.6	<i>Clematis tibetina</i>	0.7
<i>Carex</i> spp		4.3	<i>Cortia depressa</i>	0.6
<i>Clematis tibetina</i>		1.2	<i>Cotoneaster</i> spp	1.1
<i>Cortia depressa</i>		0.3	<i>Cynathus microphyllus</i>	0.4
<i>Cotoneaster</i> spp		1.7	<i>Delphinium</i> spp	1.4
<i>Cynathus microphyllus</i>		0.3	<i>Erigeron</i> spp	3.5
<i>Delphinium</i> spp		4.9	<i>Euphrasia</i> spp	0.1
<i>Deschampsia</i> spp		3.3	<i>Herminium eluthiei</i>	1.7
<i>Erigeron</i> spp		0.6	<i>Kobressia</i> spp	6.0
<i>Euphrasia himalayca</i>		0.6	<i>Lancea tibetica</i>	2.9
<i>Euphrasia</i> spp		5.2	<i>Leontopodium himalayanum</i>	4.5

---

<i>Gentiana</i> spp	2.0	<i>Lonicera</i> spp	9.4
<i>Hallenia elliptica</i>	0.4	<i>Medicago falcata</i>	0.4
<i>Iris</i> spp	1.9	<i>Oxytropis</i> spp	0.6
<i>Juncus thomsoni</i>	1.2	<i>pedicularis nodosa</i>	1.1
<i>Kobresia</i> spp	6.2	<i>Pendicularis longiflora</i>	0.4
<i>Lancea tibetica</i>	5.4	<i>Plantago himalaica</i>	2.2
<i>Leontopodium</i>	2.0	<i>Poa</i> spp	3.4
<i>himalayanum</i>			
<i>Lonicera</i> spp	3.0	<i>Potentilla</i> spp	1.3
<i>Medicago falcata</i>	1.7	<i>Primula rosea</i>	4.3
<i>Oxytropis</i> spp	2.8	<i>Rhodiola amabilis</i>	0.8
<i>pedicularis nodosa</i>	2.0	<i>Rhododendron</i> spp	5.7
<i>Pendicularis longiflora</i>	0.3	<i>Sedum ewersii</i>	0.3
<i>Plantago himalaica</i>	0.4	<i>Thalictrum</i> spp	0.3
<i>Poa</i> spp	2.8	<i>Viola biflora</i>	0.1
<i>Polygonatum</i> spp	0.1		
<i>Potentilla</i> spp	6.2		
<i>Primula</i> spp	6.5		
<i>Rheum australe</i>	0.9		
<i>Rhodiola amabilis</i>	0.3		
<i>Saussurea</i> sp	0.3		
<i>Sedum ewersii</i>	3.0		
<i>Thalictrum</i> spp	0.3		

---

### *Soil nutrient in marmot habitats*

In the process of burrow construction, marmots excavate the soil from underground to the surface and, in so doing, mix the soil nutrients of different soil strata. The two habitat types were found to have a similar soil pH (an average of ~ 7) and nitrogen (an average ~0.20%) level, but the phosphorus (P<sub>2</sub>O<sub>5</sub>) level was significantly higher in marmot burrow habitats (average 32.04 kg/ha) when compared with areas where the marmots burrows were absent (average 14.8 kg/ha) ( $\chi^2= 3.4$ , df=1, p=0.06) (Table 2). The potash (K<sub>2</sub>O) level was significantly lower in marmot burrow habitats (256 kg/ha) than where marmot burrows were absent ( $\chi^2= 4.3$ , df=1, p=0.036) (Table 2). Organic matter (OM) in marmot burrow habitats was not significantly different from the habitat in which marmot burrows were absent ( $\chi^2= 3.4$ , df=1, p=0.06; Table 2).

Most of the marmot burrows were found in sandy loam soil (72%), followed by silt loam (14%) and silt clay loam (14%). Sandy loam soil is looser and therefore easier for marmots to dig and make burrows.

**Table 2:** Nutrients in soil sampled from areas where marmots were present and absent. Min. = minimum, Max.= maximum, SE = standard error.

	<b>N</b>	<b>Range</b>	<b>Min.</b>	<b>Max.</b>	<b>Mean</b>
<b>Habitat without burrows</b>					
<b>pH</b>	78	2.38	5.82	8.20	7.20
<b>N%</b>	78	0.66	0.04	0.70	0.23
<b>P2O5</b>	78	35.00	0.00	35.00	14.88
<b>Kg/ha</b>					
<b>K2O</b>	78	666.30	1.70	668.00	318.03

---

<b>Kg/ha</b>					
<b>OM%</b>	78	6.40	0.70	7.10	3.14
<b>OC%</b>	78	3.70	0.40	4.10	2.01
<b>Habitat with burrows</b>					
<b>pH</b>	78	1.80	5.90	7.70	7.07
<b>N%</b>	78	0.64	0.06	0.70	0.20
<b>P2O5</b>	78	86.00	1.00	87.00	32.04
<b>Kg/ha</b>					
<b>K2O</b>	78	407.40	74.60	482.00	243.37
<b>Kg/ha</b>					
<b>OM%</b>	78	3.00	1.30	4.30	2.48
<b>OC%</b>	78	1.88	0.52	2.40	1.35

---

*Temperature and precipitation pattern in marmot habitat*

We observed that marmots hibernated for three months from the end of November to February when the mean monthly temperature dropped below 5 °C. Marmots were more frequently appeared outside of the burrows when mean monthly temperatures were between 10 to 18°C (from April to September, Fig. 4). Precipitation also predicted the marmot hibernation period, with amounts exceeding 10mm corresponding with increased marmot activity (Fig. 5).

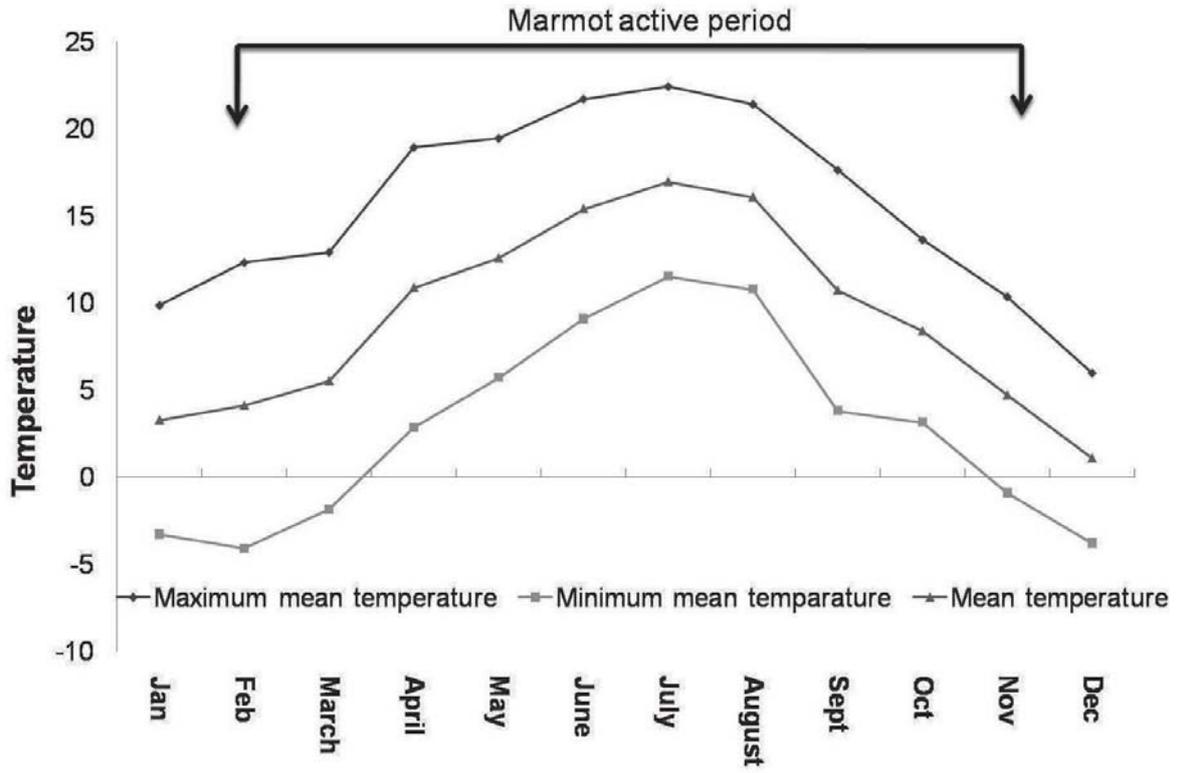
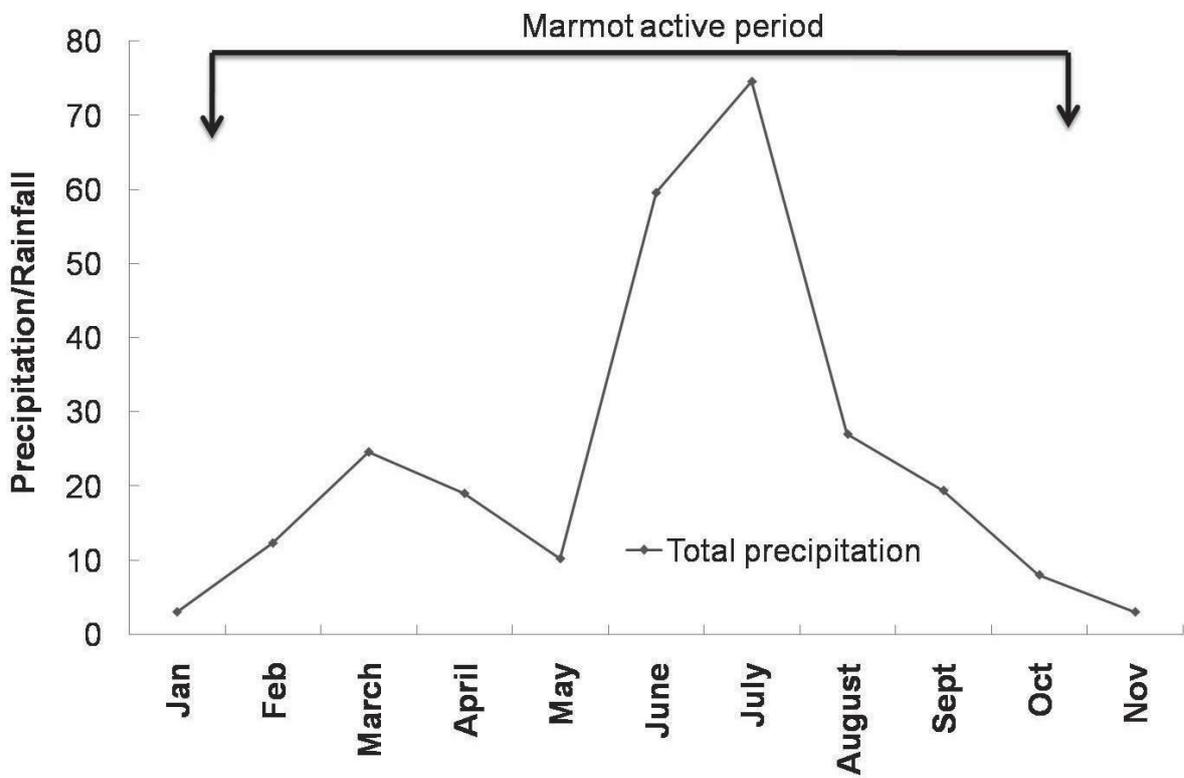


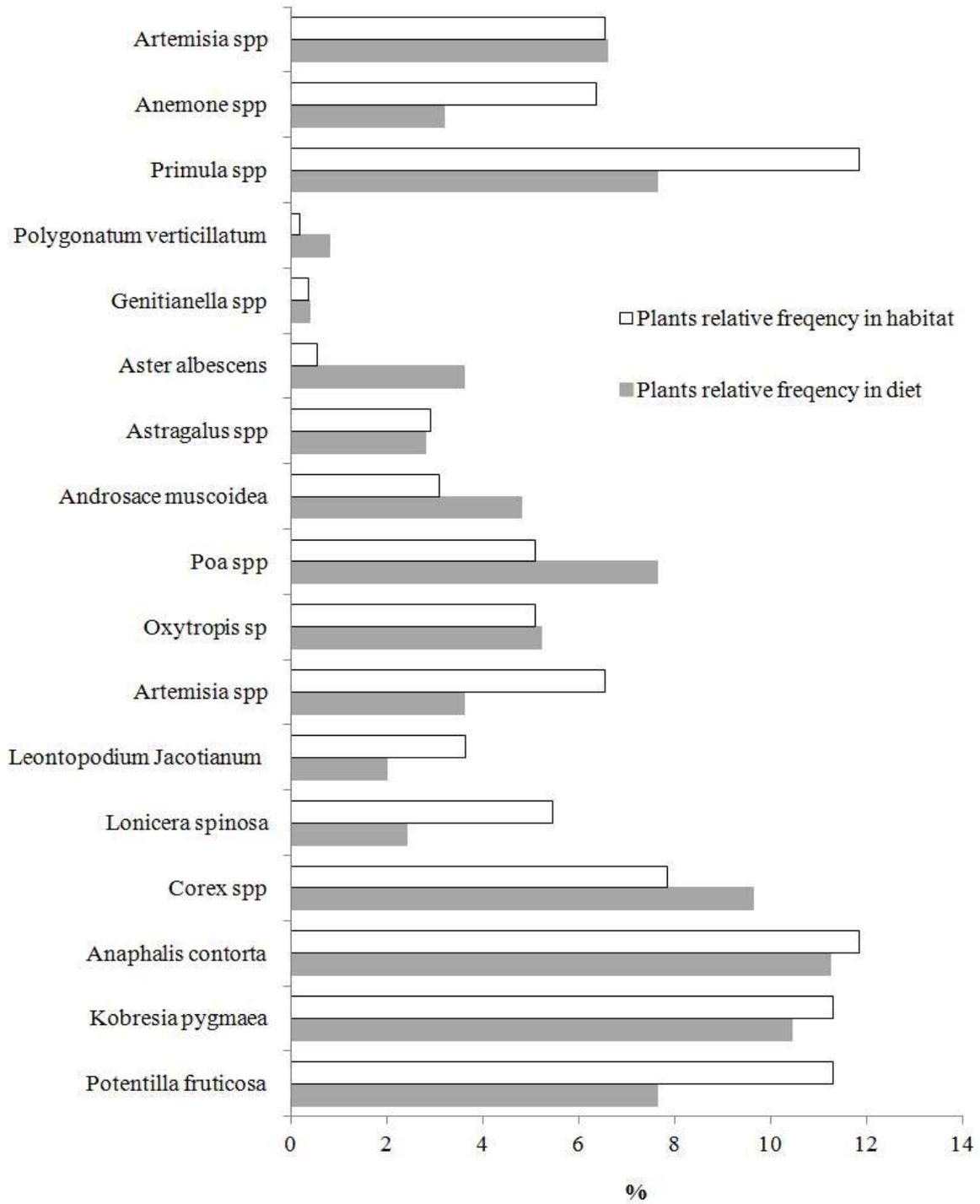
Figure 4: Temperature patterns and hibernation patterns of marmots (2010-2011)



**Figure 5:** Precipitation patterns and hibernation patterns of marmots (2010-2011)

*Foods identified in the scat of marmot*

Two hundred and three fresh marmot scat samples (summer: 69, autumn: 73 and spring: 61) were collected from the upper Mustang region. At least 17 species of plants such as *Primula* spp, *Potentilla fruticosa*, *Korbresia pygmaea*, *Anaphalis contorta*, *Lonicera spinosa* and *Corex* spp were mostly found in marmot scats throughout three seasons (summer, autumn and spring) (Table 3). Plants species occurring in the scats were not significantly different in each seasons (Summer-  $\chi^2=7.3$  df=12, p=0.96; Autumn-  $\chi^2=4$ , df=16, p=0.9; Spring-  $\chi^2=4$ , df=14, p=0.9) and also not significantly different among the three seasons ( $\chi^2= 1.3$ , df=2, p=0.5) (Table 3). The marmots choose feeding species which were found in both habitat presence and absence (see table 1). Similarly, the relative frequency of plants found in the marmot presence habitat and in the scats were not significantly different ( $\chi^2= 0.059$ , df=1, p=0.81; Fig. 6).



**Figure 6:** Plants relative frequency occurrence in marmto diet and marmto habitat before hibernation, August-November 2010.

**Table 3:** Plants identified in marmot scats in three seasons (summer, autumn, spring) in upper Mustang region, Nepal .

	<b>Summer (July) (scats= 69)</b>	<b>Autumn (October- November) (scats=73)</b>	<b>Spring (May) (scats= 61)</b>	<b>Total Frequency for all three seasons</b>	<b>Relative for all</b>
<b>Vegetation</b>	<b>Frequency (%)</b>	<b>Frequency (%)</b>	<b>Frequency (%)</b>	<b>Frequency (%)</b>	
<i>Primula spp</i>	14.98	3.21	13.67	10.62	
<i>Potentilla fruticosa</i>	11.34	7.63	12.66	10.54	
<i>Kobresia pygmaea</i>	9.31	10.44	10.85	10.20	
<i>Anaphalis contorta</i>	6.07	11.24	10.15	9.16	
<i>Corex spp</i>	4.86	9.64	6.33	6.94	
<i>Anemone spp</i>	7.69	3.21	4.22	5.04	
<i>Lonicera spinosa</i>	8.50	2.41	4.22	5.04	
<i>Leontopodium</i>					
<i>Jacotianum</i>	6.48	2.01	5.63	4.70	
<i>Artemisia sp.</i>	6.48	3.61	3.52	4.54	
<i>Oxytropis sp.</i>	-	5.22	3.12	2.78	
<i>Poa spp</i>	-	7.63	1.00	2.88	
<i>Androsace muscoidea</i>	-	4.82	2.11	2.31	
<i>Cordyialis spp</i>	0.81	1.20	3.22	1.74	
<i>Astragalus spp</i>	0.40	2.81	1.71	1.64	
<i>Aster albescens</i>	4.26	3.61	5.33	4.40	
<i>Genitianella spp</i>	2.63	0.40	-	1.01	
<i>Polygonatum</i>	-	0.80	-	0.27	

---

*verticillatum*

*Unidentified*                      16.16                      20.07                      12.27                      16.17

---

## **Discussion**

Marmots distribution reported Himalayan range across the Nepal (Fig. 1, Molur and Shrestha 2008, IUCN 2011), however, we believed their distribution appears limited to the western regions inside and outside of the protected areas of the country. We assumed that marmots might be distributed across a < 20,000km<sup>2</sup> area in Nepal (Fig. 1). Marmot colonies were distributed in all VDCs of the upper Mustang region; however, they were distributed in specific habitats in limited areas near to water resources and warmer valley slopes. A questionnaire survey of local people suggests that the population of marmots has been in decline. The survey also indicated that there is no illegal marmot harvesting in upper Mustangs, and people in this region do not have negative attitude towards marmots. However, in China and Mongolia, marmot populations have been in decline due to over-harvesting, illegal trade and lethal control due to the perception that they are pests (Smith and Foggin 1999, Batbold 2002, Xu et al. 2006, Bagchi et al. 2006, Murdoch et. al. 2009).

Marmots have previously been documented in the Himalayan region (subalpine and alpine mountain belts) at higher elevations between 3000 and 5500m (Schweinfurth 1957, Walter and Breckle 1991, Nikol'skii and Ulak 2005, Nikol'skii and Ulak 2006); and 3500 to 5200 m (Roberts 1997, Molur *et al.* 2005, Smith and Xie 2005). In this study, marmots were also recorded at elevations between 3200 and 5300m. Climate is changing in the Himalaya region (Sharma and Tsering 2009) and this change might influence to the distribution and behaviour of

marmot in the region. Hence, detail further study on the impact of climate change on marmot in the Himalayan region should be undertaken.

Himalayan marmots hibernate in the winter and are active during the other seasons (Nikol'skii and Ulak 2005, Nikol'skii and Ulak 2006). The first emergence of marmots from hibernation is influenced by climatic factors, such as temperature, snow cover and elevation (Inouye et al. 2000, Blumstein et al. 2004, Blumstein 2009 ). This study reported that marmot hibernated early November and emerged in early February; however, the role of changing climate on hibernation patterns and marmot activities in the future is uncertain. The marmots' emergence from hibernation is also influenced by social factors of the animal, such as mating and reproductive competition (Blumstein 2009). Additionally, the male marmot leaves their social group after the mating season in search of new habitat in the surrounding areas to start new burrows (Salsbury and Armitage 1994). Ambient temperature plays a significant role in marmot activities, for example, if the temperature is between 22-25<sup>0</sup>C it causes heat stress which reduces marmot activities outside the burrow (Turk and Arnold 1988, Melcher et al. 1990, Semenov et al. 2001, Nikol'skii and Ulak 2006). Therefore further field base study should be carried to understand the impact of climate change on the marmot activities in the regions.

The present study found that marmot preferred soils with low potash and high phosphorous content for burrows; such habitat features in marmot habitat might be the help to maintain plants diversity. *Primula* spp, *Potentilla fruticosa*, *Salsola neplalensis*, *Lonicera spinosa*, *Anaphalis contorta*, *Kobresia pygmaea* and *Corex* spp are widely distributed plant species in the upper Mustang region and also comprise a significant contribution to marmot diet. A different composition of plants species was found in each season, and this was related to plant availability, distribution patterns and the influence of the existing average temperature and precipitation patterns.

The burrowing activities of small mammals, such as marmots, have an influence on plant community diversity (Zahler et al. 2004, Van Staalduinen and Werger 2007). Small mammals such as pika and marmots are often considered to be pests in grassland areas because they potentially contribute towards grassland degradation. However, they also have positive effects on plant-soil interaction, plant diversity, dominance hierarchies, and defoliation (Detling and Painter 1983, Brown and Heske 1990, Aho et al. 1998, Reichman and Seabloom 2002, Bagchi et al. 2006). Livestock (goats and sheep) were observed grazing in marmot colonies and fed on *Corex* spp, *Potentilla* spp, *Poa* spp, in the region (Shrestha and Wegge 2008). Nikol'skii and Ulak (2005) reported that livestock prefer to graze in the Himalayan marmot habitat. In conclusion, the present research has found that marmot colonies tend to maintain higher plant diversity and influence soil formulation processes and nutrient cycles. Further studies are required to understand the complex association between marmot presence, plant diversity and livestock grazing and the impacts that climate change may have on marmot activity and role within grassland ecosystems.

### **Acknowledgement**

We thank the National Trust for Nature Conservation/Annapurna Conservation Area Project for providing permission and necessary support to conduct this research. We thank Mr. Mark Delaney, Mr. R. K. Koirala, Dr. S.R. Jnawali, Mr. R. Lamsal, Mr. L.B. Gurung (ACAP Director); Mr. N. Lama (ACAP), Mr. N. Dhungana (ACAP) and all upper Mustang Unit Conservation office's staffs for their support. We thank Massey University Research Fund for providing financial support for the project. Finally we thank Mr. F. Gurung, Mr.S. Gurung for field support and in particular Mr. B. Adhikari for his support in lab work (diet analysis).

## References

- ACAP (2010). Annual Report upper Mustang Unit Conservation Office. Annapurna Conservation area, UCO, Lomanthang, Mustang, Nepal. 89 pp
- Alban L A, Kellog M (1959). Methods of soil analysis as used in the OSC soil testing laboratory. Oregon Agr. Exp. Sta. Misc. Paper 65. 8 pp.  
[http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/4116/SR%20no.%2065\\_ocr.pdf?sequence=1](http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/4116/SR%20no.%2065_ocr.pdf?sequence=1)
- Anderson MU, Gorley RN Clarke KR (2008). PERMANOVA+ FOR PRIMER: Guide to software and statistical methods. PERIMER-E: Plymouth, UK.
- Aryal A, Brunton D, Ji W *et al.* (2012b). Diet and Habitat Use of Hispid hare *Caprolagus hispidus* in Suklaphanta Wildlife Reserve, Nepal. *Mammal Study* 37 (2), In press.
- Aryal A, Hipkins J, Ji W, *et al.* (2012a). Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (2), *In Press*
- Aryal A, Kreigenhofer B (2009). Summer diet composition of the Common Leopard *Panthera pardus* (Carnivora: Felidae) in Nepal. *Journal of Threatened Taxa* 1, 562-566.
- Aryal A, Sathyakumar S, Schwartz CC (2010). Current status of the Brown bear in Manasalu Conservation Area Nepal. *Ursus* 21, 109-114.
- ASTM (American Society for Testing and Materials) (1985). *Standard test method for particle-size analysis of soils D 422-63 (1972)*. 1985 Annual Book of ASTM Standards 04.08:117-127. American Society for Testing Materials, Philadelphia.

- Bagchi S, Namgail T, Ritchie ME (2006). Small mammalian herbivores as mediators of plant community dynamics in the high-altitude arid rangelands of Trans-Himalaya. *Biological Conservation* 127, 438–442.
- Batbold J (2002). *The problems of management of marmots in Mongolia*. In Holarctic Marmots as a Factor of Biodiversity, Proceedings of the Third International Conference on Marmots, Cheboksary, Russia (eds K.B. Armitage & V.Y. Rumiantsev), pp. 68–75. ABF Publishing House, Moscow, Russia.
- Blumstein DT (2009). Social Effects on Emergence from Hibernation in Yellow Bellied Marmots. *Journal of Mammalogy* 90, 1184-1187.
- Blumstein DT, Im S, Nicodemus A *et al.* (2004). Yellow-bellied marmots (*Marmota flaviventris*) hibernate socially. *Journal of Mammalogy* 85, 25–29.
- Bradstreet RB (1954). *The Kjeldahl Method for Organic Nitrogen*. *Annal Chemistry* 26, 185-187.
- Bray JR, Curtis JT (1957). An ordination of upland forest communities of southern Wisconsin. *Ecological Monographs* 27, 325-349.
- Brown JH, Heske EJ (1990). Control of desert–grassland transition by a keystone rodent guild. *Science* 250, 1705–1707.
- Chetri M (2008). Brown bear (*Ursus arctos*) from upper Mustang. Prakriti Newsletter/NTNC. Jan-June 2008 Issue: 19–22.
- Chetri M, Chapagain NR, Neupane BD (2006). *Flowers of Mustang - A field guide for the identification of Flora of Mustang*. National Trust for Nature Conservation, Annapurna

Conservation Project, Upper Mustang Biodiversity Conservation Project, Kathmandu, Nepal.

Chetri M, Gurung CR (2004). Vegetation Composition, species performance and its relationship among livestock and wildlife in the grassland of Upper Mustang, Nepal. In: Jincheng, Z., Xiangdong, Z., Jianlin, H. & Zhihua, C. (Eds.), Yak Production in Central Asian Highlands, Proceeding of the Fourth International Congress on Yak. Sichuan Publishing Group, Sichuan Publication House of Science and Technology: 235–244.  
Chicago Press.

CITES (2009). Appendix I, II and III. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Geneva. Switzerland.

Day PR (1965). Particle fractionation and particle-size analysis p. 545-567. In C.A. Black et al (ed.) Methods of soil analysis, Part 1. *Agronomy* 9, 545-567. Raubenheimer D, Simpson S., Sánchez-Vázquez J, Huntingford F, Kadri S, Jobling M. (2012). Nutrition and Diet Choice.p. 150-182. In *Aquaculture and Behavior*, Edited by Felicity Huntingford, Malcolm Jobling and Sunil Kadri. Blackwell Publishing Ltd. .

Delgado A, Torrent J (1997). Phosphate-rich soils in the European Union: estimating total plant-available phosphorus. *European Journal of Agronomy* 6, 205–214.

Elli SDH, Tsengeg P, Whitlock P *et al.* (1999). Predators as prey at a golden eagle *Aquila chrysaetos eyrie* in Mongolia. *Ibis* 141, 139–158.

Gee GW, Bauder JW (1979). Particle size analysis by hydrometer: a simplified method for routine textural analysis and a sensitivity test of measured parameters. *Soil Science Society of American Journal* 43, 1004-1007.

- Gee GW, Bauder JW (1986). *Particle-size Analysis*. P. 383 - 411. In A.L. Page (ed.). *Methods of soil analysis, Part 1, Physical and mineralogical methods*. Second Edition, Agronomy
- Gillman GP, Sumpter EA (1986). Modification to the compulsive exchange method for measuring exchange characteristics of soils. *Australian Journal of Soil Research* 24, 61 - 66
- Giri S, Aryal A, Koirala RK *et al.* (2011). Feeding Ecology and Distribution of Himalayan Serow (*Capricornis thar*) in Annapurna Conservation Area, Nepal. *World Journal of Zoology* 6, 80-85
- Gombobaatar S, Sumiya D, Shagdarsuren O *et al.* (2001). *Diet studies of saker falcon (Falco cherrug) in Mongolia*. In *Proceedings of the 2nd International Conference on the Saker Falcon and Houbara Bustard* (eds E. Potapov, S. Banzragch, N. Fox & N. Barton), pp. 116–127. Middle East Falcon Research Group, Ulaanbaatar, Mongolia.
- Heptner VG, Naumov NP (eds) (1992). *Mammals of the Soviet Union*. Vol. 2, Part 1A. E.J. Brill, New York, USA
- Horta MC, Torrent J (2007). The Olsen P method as an agronomic and environmental test for predicting phosphate release from acid soils. *Nutrient Cycling in Agroecosystem* 77, 283–292.
- Howard PJA, Howard DM (1990). Use of organic carbon and loss-on-ignition to estimate soil organic matter in different soil types and horizons. *Biology and Fertility of Soils* 9, 306-310.

- Inouye DW, Barr B, Armitage KB *et al.* (2000). Climate change is affecting altitudinal migrants and hibernating species. *Proceedings of the National Academy of Sciences* 97, 1630–1633.
- IUCN (2011). *IUCN Red List of Threatened Species*. Version 2011.2. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 23 February 2012.
- Jing Z, Fan N, Zhou W, *et al.* (1991). Integrated management of grassland rodent pest in Panpo area. *Chinese Journal of Applied Ecology* 2, 32–38.
- Jones CG, Lawton JH, Shachak M (1994). Organisms as ecosystem engineers. *Oikos* 69, 373–386.
- Jones CG, Lawton JH, Shachak M (1997). Positive and negative effects of organisms as physical ecosystem engineers. *Ecology* 78, 1946–1957.
- Jones JB (1991). *Kjeldahl Method for Nitrogen Determination*. Athens, GA: Micro-Macro Publishing.
- Kent M, Coker P (1995). *Vegetation description and analysis*. A practical approach. John Wiley and Sons Inc. USA.
- Kleinman PJA, Sharpley AN, Garley K, Jarrel *et al.* (2001). Inter laboratory comparison of soil phosphorus extracted by various soil test methods. *Communication in Soil Science and Plant Analysis* 32, 2325–2345.
- Lee HH, Yang JW (2000). A new method to control electrolytes pH by circulation system in electro kinetic soil remediation. *Journal of Hazardous Materials* 77, 227–240.

- Melcher JC, Armitage KB, Porter WP (1990). Thermal Influences on the Activity and Energetics of Yellow-Bellied Marmots (*Marmota flaviventris*), *Physiological Zoology* 63, 803–820.
- Molur S, Shreshtha TK (2008). *Marmota himalayana*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 23 February 2012.
- Molur S, Srinivasulu C, Srinivasulu B *et al.* (2005). *Status of non-volant small mammals: Conservation Assessment and Management Plan (C.A.M.P) workshop report*. Zoo Outreach Organisation / CBSG-South Asia, Comibatore, India.
- Murdoch JD, Munkhzul T, Buyandelger S *et al.* (2009). Sibirica as a keystone species? Observations and implications of burrow use by corsac foxes *Vulpes corsac* in Mongolia. *Oryx* 43, 431–434.
- Nikol'skii AA, Ulak A (2005). The Range of the Himalayan Marmot (*Marmota himalayana*, Rodentia, Sciuridae) in Nepal, at the Southern Limit of Genus *Marmota* Distribution, *Zoologichesky Zhurnal* 84, 282–284.
- Nikol'skii AA, Ulak A (2006). Key Factors Determining the Ecological Niche of the Himalayan Marmot, *Marmota himalayana* Hodgson (1841), *Russian Journal of Ecology* 37, 46–52.
- Oli M (1994). Snow leopards and Blue sheep in Nepal: densities and predator-prey ratio. *Journal of Mammalogy* 75, 998-1004.
- Poluektov NS (1961). Techniques in flame photometric analysis. Van Nostrand Reinhold, 219 pp.

Ravindranath S, Premnath S (1997). *Biomass Studies : Field methods for monitoring biomass.*

Mohan primlani for oxford and IBH publishing Co.Pvt.Ltd. New Delhi, India.

Roberts TJ (1977). *The Mammals of Pakistan.* Ernest Benn, London, UK.

Rosenzweig M L (1995). *Species Diversity in Space and Time.* Cambridge University Press, New York, NY.

Salsbury CM, Armitage KB (1994). Home-range size and exploratory excursions of adult, male yellow-bellied marmots. *Journal of Mammalogy* 75, 648–656.

Schumacher BA (2002). *Methods for the determination of total organic carbon (TOC) in soils and sediments.* Ecological Risk Assessment Support Center Office of Research and Development US. Environmental Protection Agency. 25 pp.  
<http://www.epa.gov/esd/cmb/research/papers/bs116.pdf>

Sharma E, Tsering K (2009) Climate change in the Himalayas: The vulnerability of biodiversity. *Sustainable Mountain Development* 55, 10-12.

Shrestha R, Wegge P (2008). Wild sheep and livestock in Nepal Trans-Himalaya: Coexistence or competition. *Environmental Conservation* 35, 125–136

Shrestha R, Wegge P, Koirala R (2005). Summer diets of wild and domestic ungulates in Nepal Himalaya. *Journal of Zoology* 266, 111–119.

Shrestha TK (1997). *Mammals of Nepal (with Reference to those of India, Bangladesh, Bhutan and Pakistan)*, Katmandu: R.K. Printers. Nepal.

Smith A, Xie Y (2008). *The Mammals of China.* Princeton University Press, Princeton, New Jersey.

- Smith AT, Foggin JM (1999). The Plateau Pika (*Ochotona curzoniae*) is a keystone species for biodiversity on the Tibetan plateau. *Animal Conservation* 2, 235–240.
- Sparks DR, Malechek JC (1968). Estimating percentage dry weight in diets using a microscopic technique. *Journal of Range Management* 21, 264–265.
- Tung PG, Yusoff MK, Majid NM *et al.* (2009). Effect of N and K Fertilizers on Nutrient Leaching and Groundwater Quality under Mature Oil Palm in Sabah during the Monsoon Period. *American Journal of Applied Sciences* 6, 1788-1799.
- Türk A, Arnold W (1998). Thermoregulations as a Limit to Habitat Use in Alpine Marmot (*Marmota marmota*). *Oecologia*, 76, 544–548.
- Van Staalduinen MA, Werger MJA (2007), Marmot disturbances in Mongolian steppe vegetation. *Journal of Arid Environments* 69, 344–351.
- Walkley A (1947). A Critical Examination of a Rapid Method for Determination of Organic Carbon in Soils - Effect of Variations in Digestion Conditions and of Inorganic Soil Constituents. *Soil Science* 63, 251-257.
- Xu A, Zhigang J, Chunwang L *et al.* (2006). Summer food habits of brown bears in Kekexili Nature Reserve, Qinghai–Tibetan plateau, China. *Ursus* 17, 132–137.
- Zahler P, Lkhagvasuren B, Reading RP *et al.* (2004). Illegal and unsustainable wildlife hunting and trade in Mongolia. *Mongolian Journal of Biological Sciences* 2, 23–31.
- Zhong W, Zhou Q, Sun C *et al.* (1991). The design for the ecological management of Brandt's vole pest and its application. *Acta Theriologica Sinica* 11, 204–212.

## **Paper II: Diet and Habitat Use of Hispid Hare *Caprolagus hispidus* in Shuklaphanta Wildlife Reserve, Nepal**

### **Abstract**

Hispid hare *Caprolagus hispidus* is one of the less studied endangered small mammal species in the world. Hispid hare distribution includes the tropical grassland ecosystem in Nepal. Grassland fire is one of the management regimes used in this region and its impact on biodiversity is controversial. We investigated the diet and habitat use of hispid hare before and after a grassland fire at Shuklaphanta Wildlife Reserve (SWR) in Nepal. Fecal pellets were used for micro-histological analysis to understand hispid hare diet. We laid out sampling plots in areas where we encountered hispid hare sign and recorded habitat and vegetation information. We also looked for signs of hare presence along systematically positioned transect lines and used these data to assess the population status of hispid hare. Population density of hispid hare was 5.76 individuals/km<sup>2</sup> and we estimated a population size of 219 ± 40 hispid hare within the 41 km<sup>2</sup> grasslands of SWR. Hispid hare primarily used tall grassland habitat. Nineteen plant species were identified in hispid hare pellets with *Saccharum spontaneum* and *Imperata cylindrica* having the highest frequency of occurrence. There were no significant differences in the distribution of plant species in the pellets before and after the fire; however a significantly higher diversity of plants were recorded in hispid hare diet after the fire. We recommend a change to the timing of grass burning to either before or after the hispid hare breeding season to reduce the direct (burning, destruction of nests) and indirect (increased risk of predation) negative effects of such grassland management on hare populations. Population management strategies and a field based conservation captive breeding program should be implemented immediately to maintain a viable population of hispid hare in SWR.

**Key words:** diet, grasslands, hispid hare, fire, Shuklaphanta Wildlife Reserve (SWR), *Saccharum* spp, *Imperata cylindrica*.

## **Introduction**

The hispid hare (*Caprolagus hispidus*) is an endangered lagomorph species distributed throughout the grasslands of Nepal and India (Aryal and Yadav 2010, IUCN 2010). These grasslands also support a range of other endangered animal species, including tiger (*Panthera tigris*), rhino (*Rhinoceros unicornis*) and Bengal florican (*Eupodotis bengalensis*) (IUCN 1993, IUCN 2010). Grassland habitats are universally one of the most threatened ecosystems (Bhatta 1999). In Nepal, grasslands are important not only for biodiversity conservation but also to local people for farming and resources such as fuel and grass for thatch roofing (Bhatta 1999). Increasing agricultural pressure and the use of grassland burning to promote grass growth has resulted in the reduction of available habitat for grass-dependent wildlife (Bhatta 1999, Aryal and Yadav 2010).

Grassland of Shuklaphanta Wildlife Reserve (SWR) supports a small population of hispid hare (Aryal and Yadav 2010). Annual grass harvest and burning practices are part of current grassland management by local people and protected area authorities in Nepal (Lehmkuhl et al. 1988, Saetre 1993, Brown 1997, Peet et al.1999, Bhatta 1999). However, the effect of current grassland management practices on local small mammal communities is not known and has not been taken into consideration in management planning. Nonetheless, a few studies of small mammals and grasslands in SWR have been carried out to investigate aspects of the ecology, biology and threats to grassland and its dependent species (Bell 1987, Bell 1986, Bhatta and Shrestha 1977, Peet et al. 1997, Yadav 2005). Fire and associated increases in temperature within habitats influence patterns of animal distributions and potentially has biological consequences and negative impacts on breeding success and food availability.

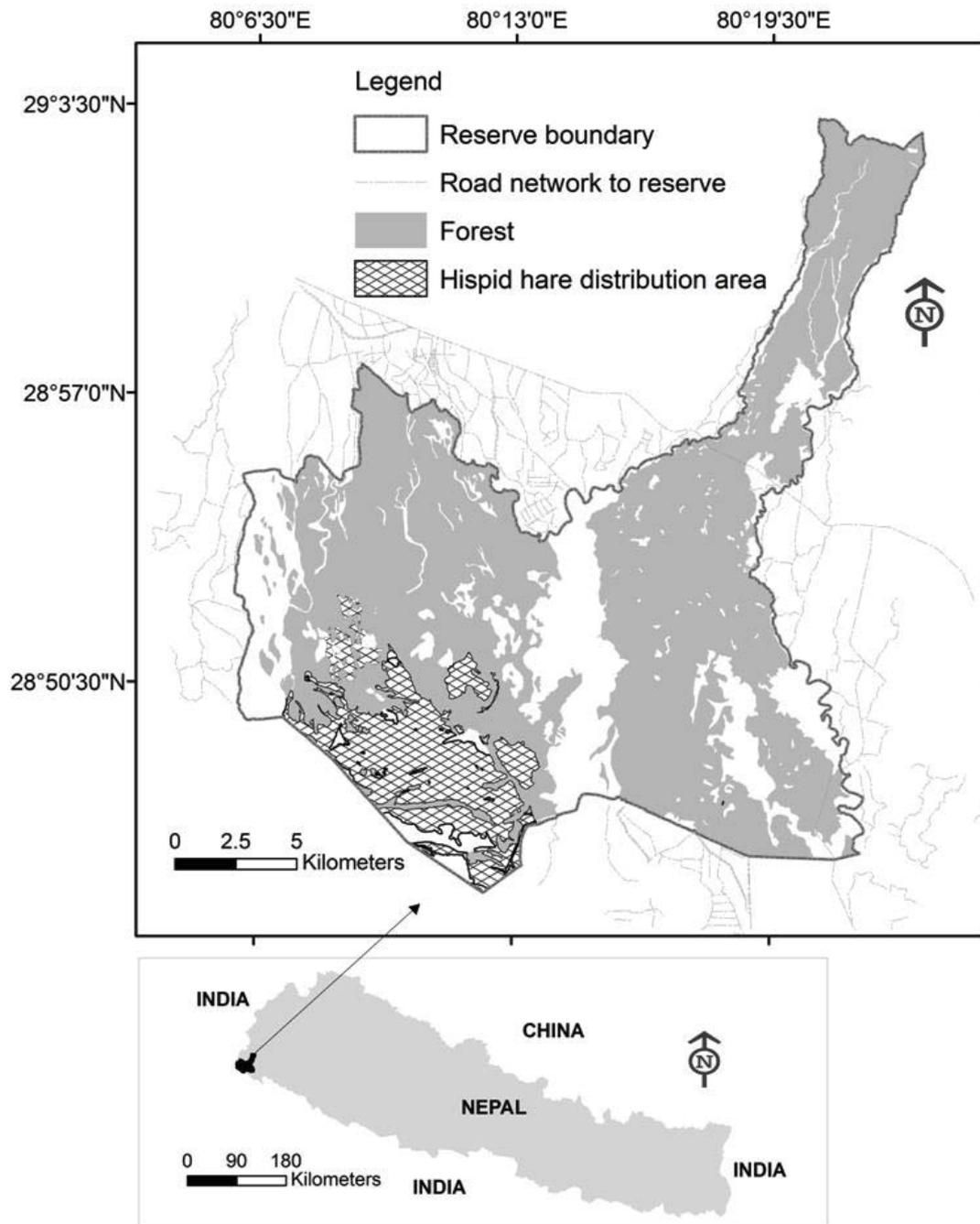
However, very little is known about the influence of fire on the vegetation component of diet selection by hares (Aryal and Yadav 2010)

Maheswaran (2002) reported that hispid hares prefer tall grassland to short or recently burnt patches and states that there is a lack of information on hare diet and habitat use. Indeed, more information on foraging behavior and habitat use is needed for many species in this region, including hispid hare, to understand the impact of human activities on native small mammal communities. The aim of this study was to investigate the diet and habitat use of hispid hare before and after a fire and provide a population size estimate in the SWR. This knowledge is important for understanding how hispid hares respond to such disturbances and how grassland management can be improved to benefit both local people and biodiversity in this grassland ecosystem.

### **Method and Materials**

The study was carried out before and after grassland fire in the Shuklaphanta Wildlife Reserve (October-November 2009 and April-May 2010 respectively). The SWR (latitude 28° 49'-28 ° 57' N and longitude 80° 07'- 80° 15'E) is situated in the southern part of Far-Western Nepal in the Kanchanpur district (Fig. 1). It covers an area of 305 km<sup>2</sup>, 16.1% of which is grasslands (DNPWC 2003). These grasslands are suitable habitat for a large herd of swamp deer (*Cervus duvauceli*) (DNPWC 2003); an initial 155 km<sup>2</sup> reserve was established in 1976. In 1981 it was extended towards the north-east section and upper Syali River and extended by 150 km<sup>2</sup>. The reserve is bounded by protected forest of the Kanchapuir district in the east and north, Lagga Bagga, a national forest in India, in the south, and the Mahakali River in the west. The aquatic and terrestrial habitats of SWR contain more than 665 plant species belonging to 438 genera and 118 families, which is the highest diversity reported for any protected area in Terai (DNPWC 2003). The climax vegetation is dominated by a canopy layer of Sal (*Shorea robusta*) and

includes other associated plants such as *Terminalia alata*, *Terminalia bellirica* and *Lagestromea paraviflora*. SWR has provided prime habitat for swamp deer, hog deer (*Axis porcinus*), spotted deer (*Axis axis*) and many endangered species such as hispid hare, tiger, rhino and elephant (*Elaphus maximus*) (Aryal and Yadav 2010).



**Figure 1.** The study area: Shuklaphanta Wildlife Reserve- Hispid hare distribution is indicated as the hatched area on the map.

### *Distribution of hispid hare*

Interviews were conducted with park staff, NTNC-SCP ( National Trust for Nature Conservation-Suklaphanta Conservation Program) staff, people in the Buffer Zone area (surrounding the village area of the reserve), and associated field staff and biologists to gather information on the distribution of hispid hare ( $n = 153$ ). Sites with 41 km<sup>2</sup> of potential hare habitat (defined in Aryal and Yadav 2010) were then surveyed for the presence of hispid hare and their pellets collected. The potential habitats of hispid hare were identified on the basis of presence/absence of hispid hare pellets, nesting sites, feeding sites and on sightings using camera traps (Aryal and Yadav 2010). The initial survey area is described in Aryal and Yadav (2010), and presence absence surveys were conducted throughout the reserve at all possible grassland sites in the reserve. In addition, walking surveys (distance up to 1 km) using existing trails were done within forested areas adjacent to grasslands in which hispid hare were observed or their sign detected to assess hare use of forested areas. Coordinates of confirmed hare locations were measured in the field using a hand held GPS unit. All locations were combined to develop hare distribution maps (ArcMap version 9.3, ESRI Inc., Redlands, California, USA software).

### *Habitat use*

Randomly placed plots of 20 × 20 m were used before and after fire and searched for hare sign. Different plots were used before and after fire. Sign was more difficult to survey prior to the fire due to the presence of tall grasses (2-6 meters high). Habitat parameters were sampled in plots where hispid hare pellets or their nest sites had been encountered. Parameters recorded include number of pellets, ground cover, fire history, anthropogenic pressure and land features. Distance between adjacent plots was >100 m. In each corner of each plot, a 4 × 4 m subplot was sampled

for shrubs (woody plants below 3 m height), and a 1 × 1 m subplot for herbs. In total 80 plots were sampled before fire and 73 plots were sampled after the fire.

Simpson's index ( $D_s$ ) and Simpson's diversity index ( $D$ ) were used to measure plant diversity (Ravindranath et al. 1997, Begon et al. 1996, Magurran 1988) in habitat before and after the fire. These were calculated as:

$$D_s = \sum n_i (n_i - 1) / N(N-1) \quad \text{and} \quad (D) = 1 - D_s$$

(Equation 1)

Where  $D_s$  is the diversity index,  $n_i$  is the number of individuals belonging to a species  $i$  and  $i = 1$  to  $k$ ,  $k$  is the total number of species,  $N$  is the total number of individuals of all species. The value of this index ( $D$ ) ranges between 0 and 1. Larger values of ( $D$ ) denote higher vegetation diversity.

#### *Population density*

A hispid hare pellet survey was conducted after fire for estimating the population density. Pellet group counts after the fire were used for calculating population density because it was only possible to count pellets and walk through the grassland area after the burn. The survey was conducted using 4 systematically placed transect lines (5 km x 10 m wide) and 128 km of walking transects (20 wide with two persons). We also searched for hare sign in 73 sample plots placed across potential habitat. We used nine defecation rates for a hare (Yadav 2005). The aim of these transect surveys was to count all fresh pellets to calculate pellet density. We were used to estimate the density of hispid hare by applying the following formulas.

$$\text{Pellet density } (N) = \text{Total pellet groups} / \text{transect area} \times \text{transect number}$$

(Equation 2)

Population density ( $P$ ) = Observed pellet density in a specific time period / Estimated defecation rate for a single animals. *(Equation 3)*

Finally, the population density was multiplied by the total area of potential habitat of hispid hare to estimate the current hare population abundance in the SWR.

### *Diet analysis*

Pellets of hispid hare were collected for micro-histological analysis to estimate hare diet (Sparks and Malechek 1968, Shrestha et al. 2005). Hispid hare pellets were distinguished on the basis of their size and shape. Eighty samples were collected from the field before the fire (November-December 2009) and 73 samples after the fire (April-May 2010). From each sample, five pellets were subsample for preparation of microscopic slides (Sparks and Malechek 1968). Although highly digestible materials may be underestimated; such fecal analysis provides adequate data to rank forage species importance for herbivores (McInnis et al. 1983).

Samples were processed in a laboratory where each sample was washed in distilled water and kept in 2% alcohol for 24 hours. The pellets were washed again with 25% alcohol for 1 hour and shaken to separate the contents. Samples were then dried in an oven for 24 hours at 40° C before being ground using a simple clean electric grinder. The samples were then sieved used 1mm to 0.3mm sieve and washed with 5% potassium hydroxide till the black color disappeared. This was followed by three rounds of dehydration with alcohol. Thereafter, a series of alcohol-xylol treatments were carried out using a gradient of 30%, 50%, 70%, 90% and 100% ethanol and finally the samples were treated with xylene for complete dehydration.

The material from each sample was spread onto permanent slides for observation under a microscope. Specimens from 39 species of grass/shrubs and 5 species of trees were prepared as reference slides. In total 132 reference photomicrographs were prepared (example is given in

Fig. 2). Pellets fragment images were taken at a similar level of magnification (100× and 400×), brightness and color conditions to that of the reference photomicrographs (Shrestha and Wegge 2008). A total of 80 and 73 slides were prepared for the samples collected before and after the fire respectively. Twenty fragments were randomly chosen from each slide to compare with reference slides. Fragments that could not be identified to species were grouped as unidentified.

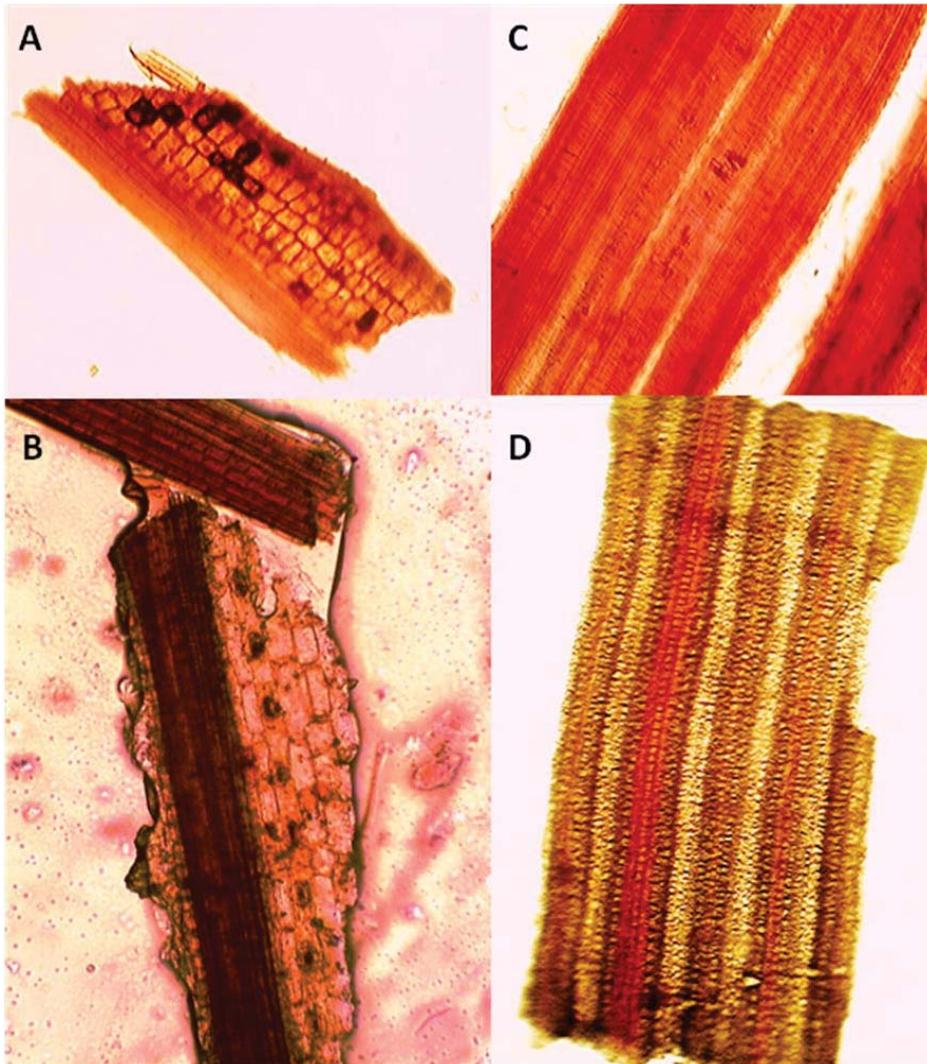


Figure 2. References photomicrographs of selected plant fragments found in hispid hare pellets: A). *Saccharum spontaneum*, B). *Narenga porphyrocoma*, C). *Desmostachya bipinata*, D). *Imperata cylindrica*, and magnification of 100x and 400x .

The Relative Frequency (*RF*) of each species was calculated to estimate the percentage that a species represented in the diet of hispid hare (Sparks and Malechek, 1968). Simpson's index ( $D_s$ ) and Simpson's index of Diversity ( $D$ ) were used to measure the diversity of plants in the diet of hispid hare before and after fire.

#### *Statistical analysis*

Spearman's rank correlation coefficients were used to assess the relationships between hare pellet numbers and distance from grassland, forest and proximity to water sources. ANOVA and Chi-squared ( $\chi^2$ ) tests were used to test for differences in the numbers of plants and other habitat parameters occurring in hare habitat before and after the fire and the differences in diversity indices. A significance level of  $\alpha = 0.05$  was used for all statistical tests.

## **Results**

#### *Distribution and habitat use*

Hispid hares were distributed across the grasslands of SWR (including Silalekh, 24 no Pillar (Nepal India boarder pillar), Barkaula area near the Army Post, Singhpur Phanta, and DhaknaGhat, Piparia, and Rani Lake areas. The Watch Tower (TINTALE MACHAN) area in the southern part of Shuklaphanta supported a higher number of hispid hares compared to others areas. Total potential areas of hispid hare habitat covered 41km<sup>2</sup> grassland area in the SWR (Fig. 1 details see [Aryal and Yadav, 2010](#)).

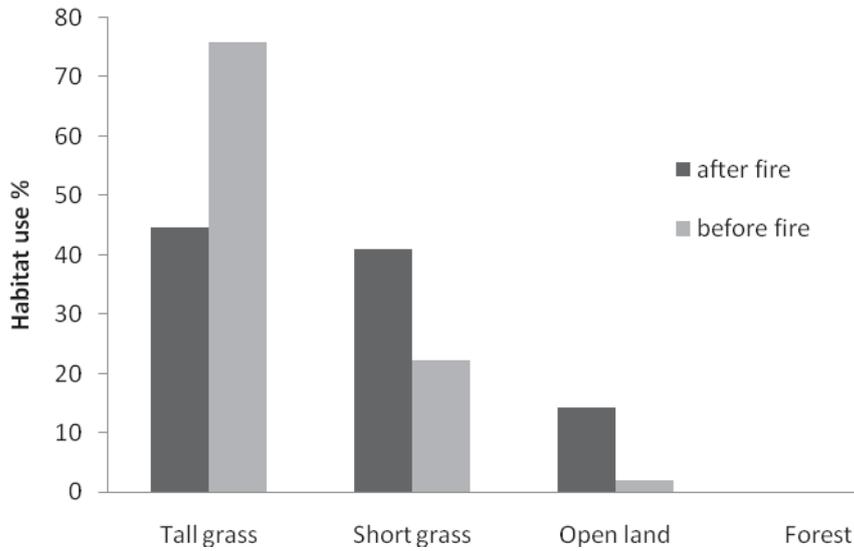


Figure 3. Habitat use by hispid hare before fire (N=80; SE=9.5) and after fire (N=73; SE=10.73).

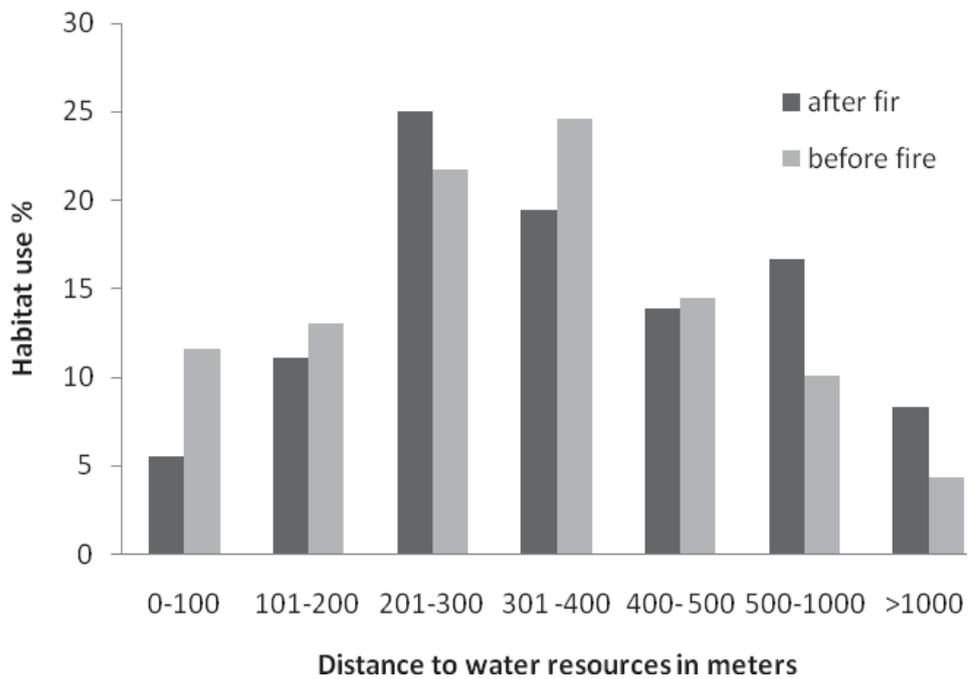
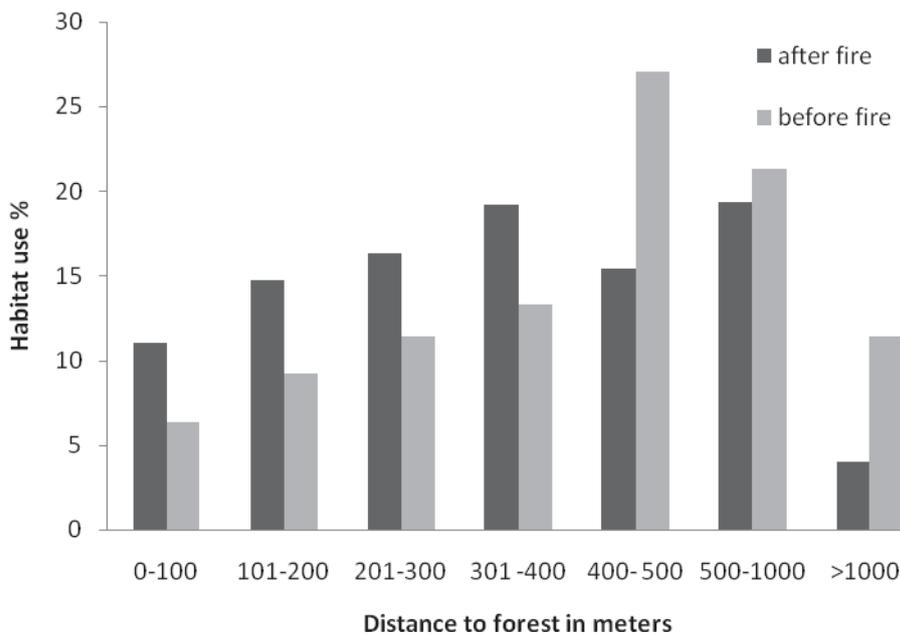


Figure 4. Hispid hare habitat use in relation to distance from water resources before fire (N=80; SE= 1.87) and after fire (N=73; SE=0.91) in grasslands.

Assuming that the presence of pellets indicates hispid hare habitat, hispid hare used mostly the tall grassland (2 - 6m); 75.9% before fire and 44.5% after fire. Pellets were also found in open land with short grass (<2 m) cover; 14.3% after the fire and 1.9% before the fire. No significant difference was found in habitat use before and after the fire ( $\chi^2 = 2$ ,  $df = 4$ ,  $P = 0.37$ ). No pellets were found in forest areas (Fig. 3). After fire, more pellets were found further from the water sources (200 to <1000m) compared to before the fire (100 to <500 m) ( $r_s = 0.75$ ,  $P = 0.05$ ; Fig. 4). More hispid hare pellets were encountered closer to forest after fire (< 400 m) compared to before fire (> 400 m) ( $r_s = 0.39$ ,  $P = 0.38$ ; Fig. 5).

A total of 41 species of plants were recorded in hispid hare habitat and the dominant plant species were *Saccharum spp*s (RF = 22%), *Narenga porphyrocoma* (RF = 18%), *Imperata cylindrica* (RF = 13%), *Themeda arundinacea* (RF = 11%), *Phragmites karka* (RF = 9%). There were no significant differences in species distribution before and after fire ( $F = 1.97$ ,  $d.f. = 40$ ,  $P = 0.18$ ). However, species diversity was slightly higher before in comparison to after fire ( $D = 0.90$  and  $D = 0.87$ , respectively).



**Figure 5.** Hispid hare habitat use in the grassland relation to distance from forest habitat before fire (N=80; SE=2.02) and after fire (N=73; SE=2.75)

*Population and pellet density*

After the fire, 152 groups of pellets were encountered in the survey (total sampled area = 2.93 km<sup>2</sup>), giving a pellet density of 51.87 pellets/km<sup>2</sup>. Hence, using equation 3 the population density of hispid hare was 5.76 ± 0.72 individuals/km<sup>2</sup> (0.0576 individual/ha). It is estimated that there were maximum of 219 ± 40 hispid hares remaining in the grassland of SWR.

*Diet composition*

Nineteen plant species were recorded in hispid hare pellets. *Saccharum spontaneum* (30.73% after fire, 25.51% before fire) and *Imperata cylindrica* (11.73% after fire and 19.9% before fire) occur most often in hare pellets followed by *S. arundinaceae*, *Misconthes nepalensis*, *S. munja*, *Desmostachya bipinata*, *Corex vesicularosa*, *Hemarthria compressa*, *Phragmites karka* etc (Table1). There was no significant difference in plants used for feeding before and after fire ( $F = 27.6$ ,  $df = 10$ ,  $P = 0.14$ ), however a slightly higher diversity of plants ( $D = 0.87$ ) was recorded in hispid hare diet after the fire than before ( $D = 0.86$ ).

Table 1: Frequency of plants in hispid hare pellets before fire (N=80; SE=3.55 ) and after fire (N=73; SE=2.87).

Scientific name	Frequency	Frequency
	After fire%	Before fire %
<i>Saccharum spontaneum</i>	30.73	25.51
<i>Imperata cylindrica</i>	11.73	19.90
<i>Misconthes nepalensis</i>	7.26	3.57
<i>Desmostachya bipinata</i>	6.15	4.08
<i>Narenga porphyrocoma</i>	5.03	3.57
<i>Saccharum munja</i>	5.03	-----

<i>Saccharum arundinaceae</i>	5.03	9.18
<i>Themeda arundinacea</i>	4.47	6.63
<i>Cyperus rotundus</i>	3.91	-----
<i>Corex vesicularosa</i>	3.91	5.10
<i>Cynodon doctylon</i>	3.91	-----
<i>Hemarthria compressa</i>	2.79	4.59
<i>Botrichola globara</i>	2.23	1.02
<i>Phragmites karka</i>	1.12	8.67
<i>Coolebrolic opposofifolia</i>	1.68	-----
<i>Ricinus commonis</i>	----	0.53
Unidentified	5.02	7.65

## Discussion

### *Distribution and Population*

Surveys for sign of hispid hare were conducted before and after the fire in SWR. However, due to the difficulty of detecting hare sign in tall grassland, transect surveys were only conducted after the fire. In addition, it was difficult to directly observe hispid hare during the day as they are primarily nocturnal (Aryal and Yadav 2010). No direct sightings were made of hare although camera traps did confirm the presence of a hispid hare (Aryal and Yadav 2010). The SWR authority and local people burn grassland each year between February and April to stimulate re-growth of grasses for livestock grazing. This period is also the main breeding period for hispid hare (Bell 1986, Bell 1987), and consequently grassland burning is likely to reduce the breeding success of hispid hare. Additionally, in the summer the grassland of SWR is submerged by flood waters from the Mahakali River. These two events are likely important limiting factors for hispid hare population in the reserve. Nonetheless, hispid hare populations persist in small numbers and the conclusion from this research is that hares are well adapted to this tropical ecosystem. We suggest that a change in the current grass burning strategy to a preferred burning period prior to December or after the hispid hare breeding season in April would reduce current impacts on

hispid hares in this area. In addition, burning should be done selectively, patch by patch, giving resident hare the opportunity to escape.

The current hispid hare population density of 0.058/ha calculated in this study was orders of magnitude lower than those from previous studies in this region i.e. and 6.10/ha (Bell 1987) and 1.01/ha (Yadav 2005). Although our population estimate might be an underestimate because our survey was conducted after fire, this apparent large decline over time highlights an urgent need for changes to conservation management of the wild population, as well as a captive breeding program to maintain viable populations of hispid hare in SWR.

Flooding during the summer inside the reserved might be another threat for hispid hare populations. Potential predators before the fire include tigers and other cat species. Likely predators after the fire are vulture, raptors and eagles. Lack of protective cover (tall grasses) for hares may make them more vulnerable to predators and avian predators in particular might be potential threats for hispid hare survival in the reserve; therefore, diet analysis of avian predators should be carried out in the hispid hare habitat.

Hispid hare in the SWR were found in isolated patches of grassland that was dominated by *Saccharum* spp. This type of grassland is found throughout the lowland areas of Nepal including Chitwan National Park, Bardia National Park and KoshiTapu Wildlife Reserve. Population surveys should be carried out in these areas to evaluate the presence and population status of this species.

#### *Diet composition*

More than 41 forage species were available in the grassland habitat but hispid hare selected a much smaller number of species to include in their diet: *Saccharum* spp and *Imperata cylindrica* contributed >55% to hispid hare diet both before and after the fire. Sites that are burnt frequently have fewer grass species, and a few species dominated the whole area (Nayak 2010). Therefore,

continued use of fire management may lead to changes in vegetation composition including distribution of the forage plants of hispid hare. The result is likely to change the distribution and abundance of the habitat and forage plants preferred by hispid hares and the potential reduction in the hispid hare population in SWR.

#### *Habitat use*

After fire hispid hare sign was more frequently found in areas distant from water sources if new growth grass existed compared to when only unburned grass was present. This suggests that hispid hare benefit from the water content of new growth grasses enabling them to expand their range away from water sources after fires.

Preferred hispid hare habitats often contained taller plant species which may increase their reproductive success by decreasing the risk of predation of their offspring and provide cover for adults. Plants species diversity was not found to differ before and after the fire within the hispid hare potential habitat. Most plants associated with small mammalian herbivores are important components of their diets (Harris and Miller 1995, Bagchi et al. 2004, Mishra et al. 2004). Since these small mammals were found to establish new colonies every 2–5 years, researchers conclude that this localized influence could broaden to larger scales over longer durations of time (Laska 2001, Bagchi et al. 2006). A similar scenario is likely to apply for hispid hare. Therefore, annual fires in grassland may have changed the soil structure leading to greater plant diversity. Fires will burn hispid hare nests and may cause death of juvenile and adult hispid hares as grass land fires can move across grassland at high speed. Indeed, such disturbances may reduce the chance of survival, expansion, and establishment of new populations and colonies of hispid hare in the grasslands of SWR. These threats should be clearly understand and appropriate management and research should be planned and implemented to maintain a viable population of hispid hare.

### *Management implications*

Hispid hare used tall grassland and more than 19 forage plant species in the high latitude grasslands of SWR. The preferred species were *S. spontaneum* and *Imperata cylindrica*. The hispid hare population in the SWR was estimated at approximately  $219 \pm 40$  individuals under our assumptions. When this value is compared to previous reports that used the same methods we conclude that the hispid hare population remaining in SWR is likely to be declining and fire is likely to be having negative impacts on the hispid hare population in this region. There were no significant changes in plant distribution before and after the fire but a slightly higher diversity of plant species was found in hispid hare diet after the fire. Population management strategies and a field-based conservation captive breeding/reintroduce program should be implemented urgently to restore and maintain a viable population of hispid hare in SWR. It is also recommended that the time of annual grass burning is changed to avoid the hare breeding season and reduce the potential negative effects of such grassland management on hispid hare populations.

### **Acknowledgements**

We thank the Department of National Park and Wildlife Conservation (DNPWC)/ Government of Nepal for providing permission to conduct this study. We thank Suklaphanta Wildlife Reserve (SWR) and National Trust for Nature Conservation- Suklaphanta Conservation Programme (NTNC-SCP) for providing field support and to Zoologische Gesellschaft für Arten- und Populationsschutz e. V. (ZGAP), Germany for their financial support to this project. This project was part-funded by the Massey University Research Fund (New Zealand).

We thank campus chief (Associate Prof. Hari Tripathi) and Associate Prof. Raj Koirala for providing laboratory facilities for diet analysis at the Institute of Forestry, Pokhara, Nepal. We thank Shambhu Paudel and Susma Giri for their support in data entry and lab work.

## References

- Aryal, A. and Yadav, H.K. 2010. First cameras trap sighting of critically endangered hispid hare (*Caprolagus hispidus*) in Shuklaphanta wildlife reserve-Nepal. World Applied Science Journal 9: 367-371.
- Bagchi, S., Mishra C. and Bhatnagar, Y.V. 2004. Conflicts between traditional pastoralism and conservation of Himalayan ibex (*Capra sibirica*) in the Trans-Himalayan Mountains. Animal Conservation 7: 121–128.
- Bagchi, S., Namgail T. and Ritchie, M.E. 2006. Small mammalian herbivores as mediators of plant community dynamics in the high-altitude arid rangelands of trans-Himalaya. Biological Conservation 127: 438-442
- Bell, D. 1986. A Study of the Hispid hare *Caprolagus hispidus* in Royal Suklaphanta Wildlife Reserve, western Nepal: A Summary Report. Dodo, Journal of the Jersey Wildlife Preservation Trust 23: 24-31.
- Bell, D.J. 1987. Study of the Biology and Conservation Problems of the Hispid Hare. Final Report. University of East Anglia, England, 38 pp.
- Bhatta, D.D and Shrestha, T.K. 1977. The Environment of Suklaphanta. Tribhuvan University Kathmandu, Nepal, 38 pp.
- Bhatta, N. 1999. Impact of Burning and Grazing on Vegetation Composition and above Ground Biomass Production in Mangalsera Grassland of RSWR, Nepal. M.Sc. Thesis, Tribhuvan University, Nepal, 69 pp.
- Brown, K.1997. Plain tales from the grasslands: Extraction, value and utilisation of biomass in Royal Bardia National Park, Nepal. Biodiversity and Conservation 6: 59-74.

- DNPWC. 2003. Royal Suklaphanta Wildlife Reserve Management Plan 2003. Department of National Parks and Conservation, pp: 1-18, Nepal.
- Harris, R.B. and Miller, D.J. 1995. Overlap in summer diets of Tibetan plateau ungulates. *Mammalia* 59: 197–212.
- IUCN. 1993. Nature Reserves of the Himalaya and the Mountains of Central Asia. Oxford University Press, World Conservation Monitoring Centre, Gland, Switzerland, 458 pp.
- IUCN. 2010. IUCN Red List of Threatened Species. Version 2010.1. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 22 April 2010.
- Laska, G. 2001. The disturbance and vegetation dynamics: A review and an alternative framework. *Plant Ecology* 157: 77–99.
- Lehmkuhl, J.F., Upreti, R.K. and Sharma, U.R. 1988. National parks and local development: grasses and people in Royal Chitwan National Park, Nepal. *Environment Conservation* 15: 143-148.
- Maheswaran, G. 2002. Status and Ecology of Endangered Hispid Hare *Caprolagus hispidus* in Jaldapara Wildlife Sanctuary. West Bengal, India. Bombay Natural History Society and Wildlife Conservation Society, New York, 47 pp.
- Main, M.B., Weckerly, F.W. and Bleich, V.C. 1996. Sexual segregation in ungulates: new directions for research. *Journal of Mammalogy* 77:449-461.
- McInnis, M.I., Vavra, M. and Krueger, X. 1983. A comparison of 4 methods used to determine the diets of large herbivores. *Journal of Range Management* 36: 302-306.

- Mishra, C., Wieren, S.E., Ketner, P., Heitkonig, I.M.A. and Prins, H.H.T. 2004. Competition between livestock and bharal (*Pseudois nayaur*) in the Indian Trans-Himalaya. *Journal of Applied Ecology* 41: 344–354.
- Nayak, R.R. 2010. Effects of Recurring Forest Fire on Ground Vegetation Composition and Soil Properties in a South Indian Tropical Forest. M.Sc. Thesis, Tata Institute of Fundamental Research, National Centre for Biological Sciences. India, 43 pp.
- Peet, N.B., Watkinson, A.R. and Bell D.J.1997. The Management of Tall Grasslands for the Conservation of Biodiversity and Sustainable Utilization. Scientific and Management Report. University of East Anglia, UK and Department of National Parks and Wildlife Conservation, Nepal, 89 pp.
- Peet, N.B., Watkinson, A.R., Bell, D.J. and Kattel, B.J. 1999. Plant diversity in the threatened sub-tropical grasslands of Nepal. *Biological Conservation* 88: 193-206.
- Saetre, D.V. 1993. People and Grasses: A Case Study from Royal Bardia National Park, Nepal. M.Sc. Thesis, Agricultural University of Norway, Norway, 87 pp.
- Shrestha, R. and Wegge, P. 2008. Wild sheep and livestock in Nepal Trans-Himalaya: Coexistence or competition?. *Environmental Conservation* 35 : 125–136
- Shrestha, R., Wegge, P. and Koirala, R. 2005. Summer diets of wild and domestic ungulates in Nepal Himalaya. *Journal of Zoology* 266: 111–119.
- Sparks, D.R. and Malechek, J.C. 1968. Estimating percentage dry weight in diets using a microscopic technique. *Journal of Range Management* 21: 264–265.

Yadav, B. 2005: Status, Distribution and Habitat Use of Hispid Hare (*Caprolagus hispidus*) in Royal Suklaphanta Wildlife Reserve, Nepal. B.Sc. Thesis, Institute of Forestry, Tribhuvan University, Nepal, 53 pp.

## Chapter Five

### Climate change impact on an ecosystem

#### Summary

This chapter reports on the status of the changed patterns of land use and the effects of climate change in the Himalayan region (Paper I below). The aim of the chapter is to evaluate the impact of recent climate change, and the potential impact of anticipated future climate change on the fauna and human inhabitants of the upper Mustang region of the Nepalese Trans-Himalaya region. The study shows that the average annual temperature in the upper Mustang region has increased by 0.13°C per year over the last 23 years. The most seriously affected villages in the upper Mustang are: Samjung village (at 4100 m altitude) and Dhey village (3800 m), where villagers have been forced to relocate to an area with better water availability. This chapter discusses changes in forest and grassland cover, and reports on tree line shifting in the region and concludes that, as a result of climate change, the grasses and shrubs are less abundant at higher elevations, increasing the dependency of blue sheep (*Pseudois nayaur*) on crops found at lower elevations. This, in turn, draws snow leopards (*Panthera uncia*) down from their higher elevation habitats to lower elevations bringing them closer to villages, increasing their interactions with livestock and humans. Such a situation results in an increased number of depredations and human-snow leopard conflict, which has adverse effects on the livelihood of local people (and snow leopards). It is observed that changing climatic conditions in the Trans-Himalayan region is inducing changes in both the ecosystem and in people's livelihood.

This chapter contains one paper as follows:

I.Aryal, A., D. Brunton and D. Raubenheimer 2013. Impacts of climate change on human society wildlife ecosystem interactions in the Trans-Himalayan region of Nepal. *Theoretical and Applied Climatology* DOI: 10 .1007/s00704-013-0902-4.

## Chapter Six

### Perspectives and conclusions

#### Human-Wildlife conflict and management strategy

##### *Snow leopard-human conflict*

Livestock predation is the main cause of human-wildlife conflicts throughout the world (Mech 1981, Oli et al. 1994, Cozza et al. 1996, Pedersen 1999, Graham et al. 2004, Namgail et al. 2007, Aryal et al. 2012a & b). No universal approach to mitigating such conflicts exists. Successful conflict management strategy is based on the level of conflict, type of animals involved, socio-economic status of the people, and the culture of the area (Oli et al. 1994, Cozza et al. 1996, Naughton-Treves 1997, Sekhar 1998, Siex and Struhsaker 1999, Butler 2001, Imam et al. 2002, Zang and Wang 2003, Mishra et al. 2003, Patterson et al. 2004, Nyhus and Tilson 2004b & a).

In this study I found there is a high possibility of such livestock depredation by snow leopards in the rangelands of the Trans-Himalayan region as these ecosystems provide common resources for both livestock and wildlife (Jackson et al. 1996, Mishra 1997, Hussain 2003). The study of human-snow leopard (*Panthera uncia*) conflict found that 2.3% of the total livestock in the upper Mustang region are killed by snow leopards each year (Chapter one; paper I). The study of local livestock and their grazing area in the region showed that the local economy is largely dependent upon the agro-pastoral system. Region-specific conflict mitigation strategies were explored and two possible solutions were developed: a) provide an alternative source of income for villagers as well as conservation education opportunities at the local level; and b) implement a livestock insurance programme. Recommendations are made to initiate the programmes in small villages such as Chhoser as a pilot project and then to extend it to other areas (Chapter one; paper I).

Traditional rotational grazing based on the season, in which livestock move to lower elevations in winter and higher elevations in summer, is a very common practice in the area. The movement of livestock influences the snow leopards and other predators in the region. Reduction in rangeland productivity due to over-grazing in the region is reported by Pokharel (2006), and an increase in number of livestock in recent years has been reported (DDC 2008). The observed livestock density (22 animals/ km<sup>2</sup>) was higher than the optimum carrying capacity of pasture land in the upper Mustang region. A further study on the carrying capacity of the rangelands is recommended to understand the maximum allowable livestock population in the area.

The health parameters of livestock within this region are also important to consider while investigating the extent and consequence of livestock depredation. The poor health status and pathogens in livestock make them weak and reduce their ability to escape from predators. It is therefore possible that there might be an overestimation of livestock predation as they may have died due to poor health or accident (Kruuk 1972, Houston 1977, Oil et al. 1994, Hewson 1990, Aryal et al. 2012b). It is therefore recommended that livestock receive regular health check-ups and medical treatment, and that the infected livestock are quarantined until they recover, reducing the chances of other livestock becoming infected.

#### *Rangelands and Society-Rangeland use conflict*

Rangelands occupy 60% of the Himalayan landscape and are considered to be critical ecosystems in the Himalayas (Yi and Sharma 2009, ICIMOD 2012). The benefits of rangeland include supporting local livelihood, providing various ecosystem services, promoting eco-tourism, and supporting biological diversity (ICIMOD 2012). Livestock ranching and medicinal plant collection in the rangelands are major means of livelihood for rural people (Miller 1997, Dong et al. 2009). The rangelands are considered to be common pools of resources (CPR) in Nepal. The excessive use and grazing of rangelands are pushing the consumption of rangeland

resources beyond the limits of sustainable yields (Blomquist and Ostrom 1985, Wade 1987). The depletion of CPR occurs either due to the lack of management institutions or conflicting claims over the resources (Adams et al. 2002). Chapter one (Paper *II*) explains the conflict over rangeland use in upper Mustang region. The conflict was raised for the use of rangeland resource based on traditional use and the provisioning of rangeland use in a revised government policy. The second paper of chapter one analyzes the conflict in rangeland use between two villages in upper Mustang which shows the significance of rangelands to local livelihood. It also concludes that unclear rangeland related policies and the remote location of rangelands are the major barriers for the proper management of rangelands.

Chapter one (Paper *II*) presents the cause of conflict over rangeland use between two communities in upper Mustang. Historical evidence and local perception indicate that conflicts over the use of rangelands became more complex due to the increased pressure on their use. In our study, two possible ways to manage the conflicts were proposed and these suggestions may also be relevant to other parts of the country. Firstly, as the conflict is related to its use during summer, the parties can share the use of seasonal rangelands in a fair manner. Particularly when the party with political rights (the Chhunup VDC who has boundary control) over the disputed area has no winter grazing lands while the party with traditional use rights (the Chhoser VDC) has such resources. Secondly, there should be an external support system in place to enhance the productivity of rangelands and the production of fodders cultivated on private and public lands. Solutions should ensure Chhunup villagers use of the rangeland does not compromise their long term sustainability. The ongoing conflict does not only degrade the CPR but it also threatens social institutions based on traditional systems. It is very important to incorporate the lessons learnt from community forestry for the sustainable management of rangelands resources.

*Involvement of local people in the management of the northern Barandabhar Forest Corridor*

The Barandabhar Forest Corridor (BFC) links the Mahabharat range to the Chitwan National Park (Dhakal et al. 2011, Bhattarai and Basnet 2004, Bhattarai 2003), allowing the movement of one-horned rhinoceros (*Rhinoceros unicornis*) and Royal Bengal tiger (*Panthera tigris tigris*) towards higher altitudes during monsoon seasons (Tiwari et al. 2007). For the management and restoration of wildlife populations across central and southern Asia, the retention and restoration of corridors is considered essential (Tiwari et al. 2007). Chapter one (Paper III) briefly outlines the background ecological information for the northern part of BFC. It is anticipated that this study will establish a baseline for future studies to help link the CNP with the Mahabharat range for the conservation of biological diversity and that this will occur through the participation of local communities in the Chitwan valley.

This study highlights the importance of the northern BFC as a wildlife corridor between the CNP and the Mahabharat range. It forms an example of the approach required for biodiversity conservation; movement away from the existing protected area system to a more integrated and sustainable model that ensures the participation of local communities. This approach is necessary to achieve the conservation goals of sustaining wildlife habitats and populations while engaging local communities in conservation efforts and supporting their livelihoods. Participatory forest management still requires more studies to optimize its effectiveness at addressing conservation goals, and the BFC may provide an example in this direction. Though further detailed study is needed, the current study provides basic information for future research. The management and conservation of this corridor, as proposed by the present study, is expected to be an important step in ensuring the preservation of landscape connectivity in Nepal for the movement of wildlife including rhinos and tigers. The conservation of areas beyond the national parks will be feasible in the long-term by ensuring the participation of local communities in

habitat management. This study recommends implementing the participatory BCF management model by involving all stakeholders that belong to the BCF.

### **Predators: brown bear ecology and conservation strategy**

Three different bear species (Asiatic black bears, sloth bears, and brown bears) are found in Nepal. Brown bears (*Ursus arctos*) occur in small isolated populations in remote mountain regions of Eurasia and North America (Servheen 1990, Servheen et al. 1999). Due to lack of the knowledge about its ecology and distribution in remote Himalayan regions of the country, very little information is available on the brown bear in the Nepal (Gurung 2004, Aryal et al. 2010a-Chapter two, paper *I*). Therefore, the brown bear was investigated in Manasalu Conservation Area and its presence as well as human-brown bear interactions was confirmed (Chapter two; Paper *I*). The ecological study carried out in Annapurna Conservation Area revealed that the Himalayan marmot is the major prey base for the brown bear in the region (Chapter two, Paper *II*). Based on my research on the brown bear, a brown bear conservation strategy for Nepal was designed (Chapter two, Paper *III*). This study (Chapter two, Papers *I* and *II*) recommends further research along the boarder of Nepal and China to confirm its existence. The study recommends initiating regional brown bear research to estimate occupancy and movements using genetic hair-snare sampling and GPS data.

Chapter two (Paper *II*) investigates the connectivity of brown bear habitat, and predicted an area of  $\sim 4000 \text{ km}^2$  as a suitable habitat for brown bear population. Of this suitable habitat, 48% lies outside protected areas. The conservation of areas outside the protected area and the corridor which links the SPNP and the ACA should be the focus of brown bear research. Due to the absence of fuel wood and tree species in the Himalayan region, the uprooting of shrubs and the collection of dung are very common (Uniyal et al. 2009) which is creating more pressure on the ecosystem of the area. Chapter two (Paper *III*) describes the existing habitat of brown bears in

the study site. It concludes the necessity of controlling the existing practice of the collection of wild plants for fuel, the provisioning of alternative fuel sources, the promotion of private and community plantations, and an increase in the use of solar energy. Finally, the study (Chapter two, Paper II) suggests preparing a draft for the brown bear conservation action plan for Nepal, and recommends the implementation of a three-stage conservation program in Nepal as below;

- a. detail the status of the brown bear both in and outside the protected areas;
- b. raise conservation awareness and improve local livelihood
- c. finalise and implement a participatory brown bear conservation action plan in Nepal.

### **The conservation and ecology of snow leopards and its main prey species, the blue sheep**

The blue sheep (*Pseudois nayaur*) has formed a major prey base for the endangered snow leopard (*Panthera uncia*) population in the Himalayan region of Nepal (Rogers 1991, Oli et al. 1993, Lovari et al. 2009, Aryal et al. 2010b), although accurate estimates of population size and studies of predator/prey dynamics have yet to be carried out (Schaller 1977, Oli et al. 1993, Dagleish et al. 2007, Harris 2008, Aryal et al. 2010b). Studies suggest that the snow leopards have re-populated the Sagarmatha National Park (Ale 2007, Lovari et al. 2009) and that livestock depredation has begun. However, the Himalayan tahr was the main prey species of snow leopards in the region (SNP). The present study (Chapter three, Paper I) found that the blue sheep population density was lowest in upper Mustang (0.86 blue sheep/km<sup>2</sup>) which was associated with a lower plant diversity than in other areas. The study also estimates the blue sheep population biomass, approximately 38,925 kg, which could support approximately 19 snow leopards (1.6 snow leopards/100 km<sup>2</sup>) in the upper Mustang region. The study has estimated an initial carrying capacity of the region for snow leopards, but further investigation is needed to understand the role of other predators in modifying this estimate and a prescribed management option should be implemented to maintain their habitat.

My study (Chapter three, Paper II) also concluded that a non-invasive, genetically based population survey method (using scat) is the most appropriate method for estimating the snow leopard population and its movements. Chapter III (Paper II) shows that the estimated home range is 89.4 km<sup>2</sup> for males and 59.3 km<sup>2</sup> for females based on their seasonal scat patterns and on the genetic study. This home range was more than previous record through the radio collar study in Nepal (Jackson 1996, Oli 1997). The study also concludes that livestock makes up 18% of the snow leopard diet and that blue sheep contributed (63%) to the snow leopard diet. Further genetic-based studies should be conducted to examine the connectivity and population density of snow leopard in the Himalayan region of Nepal.

Chapter three (Paper II) concludes that the Sagarmatha (Mt. Everest) National Park (SNP) habitat is similar to the Kanchanjunga Conservation Area and suggests that blue sheep be translocated to SNP from KCA. This will then reduce the human-snow leopard conflict in the SNP where blue sheep are absent.

### **Small mammals and their distribution and ecology**

#### *Marmot ecology, distribution, and diet*

The Himalayan marmot (*Marmota himalayana*) is a small burrowing herbivore and an ecosystem engineer which helps to maintain the ecosystem (Jones et al. 1994, Jones et al. 1997, Brown and Heske 1990, Nikol'skii and Ulak 2005, Bagchi 2005, Nikol'skii and Ulak 2006), and makes up a significant proportion of the diet of snow leopards (*Paranthera uncia*) and brown bears (*Ursus arctos*) in the Himalayas (Oli et al. 1994, Aryal et al. 2010b, Aryal et al. 2012b). However, despite its importance the marmot is one of the least studied species in the region (Gromov et al. 1965, Zimina 1978, Bibikov 1989, Heptner and Naumov 1992, Elli et al. 1999, Gombobaatar et al. 2001, Nikol'skii and Ulak 2005, Nikol'skii and Ulak 2006). Therefore this study (Chapter four; Paper I) contributes to ecological studies exploring diet, nutrients, and

habitat of marmots. I confirmed its distribution throughout the upper Mustang region; close to water resources, warm valleys; and ranging from 3000 and 5500m elevation. Local people claimed that the population of marmot has been declining, and yet there is apparently no illegal marmot harvesting and they also don't have negative attitude towards the species. However, the marmot population has been in decline in other parts of its distribution range (like China and Mongolia) because of illegal trade, over-harvesting, and lethal control as pests (Smith and Foggin 1999, Batbold 2002, Xu et al. 2006, Bagchi et al. 2006, Murdoch et. al. 2009). In this study, I found that marmot promotes soil formation process by digging and maintains the soil nutrients which likely contributes to higher plant diversity in the region. Furthermore, studies on the interaction of marmot with livestock, plant diversity, its role in grassland ecosystems and the impact of climate change should be undertaken in the near future.

#### *Hispid hare diet and distribution*

The hispid hare (*Caprolagus hispidus*) is an endangered small mammal distributed throughout the lowland grasslands of Nepal and India (Aryal and Yadav 2010, IUCN 2010). These grasslands also support a range of other endangered animal species, including tigers (*Panthera tigris*), rhinos (*Rhinoceros unicornis*), and the Bengal florican (*Eupodotis bengalensis*) (IUCN 1993, IUCN 2010). Grassland habitats are universally one of the most threatened ecosystems (Bhatta 1999). The first confirmation of the presence of the hispid hare in this region was accomplished using camera traps (Aryal and Yadav 2010). The study (Chapter four; Paper II) confirmed that the species is distributed within a 41km<sup>2</sup> grassland area of the Suklaphanta Wildlife Reserve of Nepal. In general, grassland fires during the hispid hare breeding period were one of the main threats faced by the species (Bell 1986, Bell 1987). Another threat is the submergence of the SWR grassland due to flooding of the Mahakali River. Therefore, I recommend a change in the existing grass burning strategy, particularly in timing, either prior to December or after the

hispid hare breeding season in April. Furthermore, a patch- -by-patch burning technique should be employed, giving residential hare the opportunity to escape.

A current hispid hare population density of 0.058/ha was calculated in this study. However, more detailed camera trap studies should be conducted annually to monitor its population in the area. Additionally, a captive breeding program should be initiated to maintain viable populations of the hispid hare in SWR and other regions. Hispid hares in the SWR were found in isolated patches of grassland that were dominated by *Saccharum* spp. This type of grassland is found throughout the lowland areas of Nepal including Chitwan National Park, Bardia National Park, and KoshiTapu Wildlife Reserve. Population surveys should be carried out in these areas to evaluate the presence and population status of this species.

#### *Climate change impacts on Ecosystems*

The United Nations Intergovernmental Panel on Climate Change (IPCC) reported an increase in global mean temperatures of between 1.4 and 5.8° C by the year 2100 (Locky and Mackey 2009; IPCC 2001). High altitude cold deserts, such as the trans-Himalayan region, are among the most vulnerable of all ecosystems to these climatic changes (Christensen and Heilmann-Clausen 2009, Xu et al. 2009, Dong et al. 2009, Sharma and Tsering 2009, Aryal et al. 2012a, b & c). Furthermore, the high altitude, harsh climatic conditions, and low productivity of these regions make the human inhabitants vulnerable to changes. Such changes reduce the effectiveness of the cultural adaptations that have enabled human inhabitants to persist in these marginal habitats. However, while there are many studies of climate change that focus on community and individual perceptions (Bagchi et al. 2004, Berkes 1999, Cruikshak 2001, Nuttal 2001, Riedlinger and Berkes 2001, Fox 2002), there is a lack of information specifically related to these high altitude ecosystems and their human inhabitants.

This study (Chapter five, Paper I) reports that increases in the temperature and snow melting directly impacts the livelihood of local people, ecosystems, prey-predator relationships, and wildlife-livestock interactions in the Himalayas. Therefore, further climate change adaptation strategic activities and awareness should be implemented in the region. In conclusion, the current level of climate change appears to be altering the Trans-Himalayan region ecosystems, wildlife, plants, and local livelihood. A strategy adapted to mitigate climate change should be implemented at the local level. Such a strategy could include: plantations on private land and in local areas; the use of solar energy for cooking and heating; the spread of native grass seeding around the area; the development of water holes in the areas where long distances need to be covered; the storage of rainfall water for agriculture; the construction of reservoirs for winter and times of water shortage; control of poaching; continued monitoring of the distribution and shift of trees; the encouragement of social, cultural and religious beliefs; and the involvement of local people in the implementation of any kind of programme related to the study, adaptation, mitigation, and measurement of climate change. A national participatory community based climate change program should be prepared and implemented at the local level. Some initiatives started at a local level might influence the global mission to reduce the effect of climate change on the environment and local livelihoods. The government should take these issues seriously, and the subsequent studies and measures for adaptation and mitigation should then be implemented at a national level.

## **References**

Adams, W.M., D. Brockington, J. Dyson and B. Vira. 2002. Analytical Framework For Dialogue On Common Pool Resource Management. Department of Geography, University of Cambridge, Cambridge.

- Ale, S.B. 2007. Ecology of the snow leopard and the Himalayan tahr in Sagarmatha (Mt. Everest) National Park, Nepal. PhD Thesis, University of Illinois at Chicago, Chicago, Illinois, USA.
- Aryal A., D. Raubenheimer, S. Sathyakumar, B.S. Poudel, W. Ji, K.J. Kunwar, J. Kok , S. Kohshima and D. Brunton. 2012a. Conservation strategy for brown bear and its habitat in Nepal. *Diversity* 4(3): 301-317.
- Aryal A., S. Sathyakumar and C. C. Schwartz. 2010a. Current status of the brown bear in Manasalu Conservation Area Nepal. *Ursus* 21:109–114.
- Aryal, A. and H.K. Yadav. 2010. First cameras trap sighting of critically endangered hispid hare (*Caprolagus hispidus*) in Shuklaphanta wildlife reserve-Nepal. *World Applied Science Journal* 9: 367-371.
- Aryal, A., J. Hopkins, W. Ji, D. Raubenheimer and D. Brunton. 2012b. Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (2): *In-press*.
- Aryal, A., S. Gastaur, S. Menzel, T.B. Chhetri. and J. Hopkins. 2010b. Estimation of blue sheep population parameters in the Dhorpatan Hunting Reserve, Nepal. *International Journal of Biodiversity and Conservation* 2(3): 051-056.
- Bagchi S., T. Namgail and M.E. Ritchie .2006. Small mammalian herbivores as mediators of plant community dynamics in the high-altitude arid rangelands of Trans-Himalaya. *Biological Conservation* 127: 438 –442.
- Bagchi, S., C. Mishra and Y. V. Bhatnagar. 2004. Conflicts between traditional pastoralism and conservation of Himalayan ibex (*Capra sibirica*) in the Trans-Himalayan mountains. *Animal conservation* 7: 121-128.

- Bell, D. 1986. A Study of the Hispid hare *Caprolagus hispidus* in Royal Suklaphanta Wildlife Reserve, western Nepal: A Summary Report. *The Dodo: Journal of the Jersey Wildlife Preservation Trust* 23: 24-31.
- Bell, D.J. 1987. Study of the Biology and Conservation Problems of the Hispid Hare. Final Report. University of East Anglia, England, 38 pp.
- Berkes, F. 1999. Indigenous knowledge systems and resource management systems in the Canadian Subarctic. In: Berkes, F., and Folke, C., eds. Linking social and ecological systems. Cambridge: Cambridge University Press. pp. 98–128.
- Bhatta, N. 1999. Impact of Burning and Grazing on Vegetation Composition and above Ground Biomass Production in Mangalsera Grassland of RSWR, Nepal. M.Sc. Thesis, Tribhuvan University, Nepal, 69 pp.
- Bhattarai, B.P. 2003. Conservation threats to wild ungulates in Barandabhar Corridor Forest, Chitwan, Nepal. MSc Thesis. Central Department of Zoology-Ecology Program, Tribhuvan University, Nepal.
- Bhattarai, B.P., and K. Basnet. 2004. Assessment of crop damage by wild ungulates in the eastern side of Barandabhar Corridor Forest, Chitwan. *Proceedings of IV National Conference on Science and Technology* March 23-26, 2004.
- Blomquist, W and E. Ostrom. 1985. Institutional capacity and the resolution of a commons dilemma. *Policy Studies Review* 5(2): 383-393.
- Blumstein, D.T. 2009. Social Effects on Emergence from Hibernation in Yellow Bellied Marmots. *Journal of Mammalogy* 90: 1184-1187.

- Blumstein, D.T., S Im, A. Nicodemus and C. Zugmeyer.2004. Yellow-bellied marmots (*Marmota flaviventris*) hibernate socially. *Journal of Mammalogy* 85: 25–29.
- Brown J.H and E.J. Heske.1990. Control of desert–grassland transition by a keystone rodent guild. *Science* 250: 1705–1707.
- Butler, JRA. 2001. The economic costs of wildlife predation on livestock in Gokwe communal land, Zimbabwe. *African Journal of Ecology* 38 (1): 23-30.
- Christensen, M and J. Heilmann-Clausen. 2009. Forest biodiversity gradients and the human impact in Annapurna Conservation Area, Nepal. *Biodiversity and Conservation* 18(8): 2205-2221.
- Cozza K, R. Fico, L. Battistini and E Rogers. 1996. The damage- conservation interface illustrated by predation on domestic livestock in central Italy. *Biological Conservation* 78 (3): 329-337.
- Cruikshank, J. 2001. Glaciers and climate change: Perspectives from oral tradition. *Arctic*. 54(4): 377–393.
- DDC.2008. The Mustang District Profile. District Development Committee (DDC), Mustang district office, Government of Nepal.
- Dhakal, R.R., G. Kafle and J.N. Yadav. 2011. Comparative assessment of floristic diversity in a buffer zone community forest and a community forest of Barandabhar corridor, Chitwan, Nepal. *Journal of Horticulture and Forestry* 3(8): 244–250.
- Dong, S., J. Lassoie, K.K. Shrestha, Z. Yan, K. Sharma and D. Pariya. 2009. Institutional development for sustainable rangeland resource and ecosystem management in mountainous areas of northern Nepal. *Journal of Environmental Management* 90: 994–1003.

- Elli S.D.H., P. Tsengeg, P. Whitlock and M.H. Ellis. 1999. Predators as prey at a golden eagle *Aquila chrysaetos eyrie* in Mongolia. *Ibis* 141: 139–158.
- Fox, S. 2002. These are things that are really happening: Inuit perspectives on the evidence and impacts of climate change in Nunavut. In: Krupnik, I., and Jolly, D., eds. The earth is faster now: Indigenous observations of Arctic environmental change. Fairbanks, Alaska: Arctic Research Consortium of the United States. pp.12– 53.
- Gombobaatar, S., D. Sumiya, O. Shagdarsuren, E. Potapov and N. Fox. 2001. Diet studies of saker falcon (*Falco cherrug*) in Mongolia. In Proceedings of the 2nd International Conference on the Saker Falcon and Houbara Bustard (eds E. Potapov, S. Banzragch, N. Fox & N. Barton), pp. 116–127. Middle East Falcon Research Group, Ulaanbaatar, Mongolia.
- Graham, K., A. P. Beckerman and S. Thirgood. 2005. Human–predator–prey conflicts: ecological correlates, prey losses and patterns of management. *Biological Conservation* 122: 159-171.
- Gurung, M. 2004. Brown bear observation in the Damodar Kunda Valley, Mustang District, Nepal. *International Bear News* 13:12–14.
- Harris, R.B. 2008. *Pseudois nayaur*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 19 March 2011.
- Hewson, R. 1990. Victim of myth: Predation upon lambs by foxes in the absence of control. League Against Cruel Sports. Department of Zoology, University of Aberdeen.
- Houston, D. 1977. The effect of hooded crow on hill sheep farming in Argyll, Scotland. *Journal of Applied Ecology* 14: 1-15.
- Hussain, S. 2003. The status of snow leopard in Pakistan and its conflict with local farmer livelihoods. *Oryx* 37:26–33

- ICIMOD. 2012. Rangeland. ICIMOD, Kathmandu, Nepal. Access 7 March 2012  
<http://www.icimod.org/?q=1277>.
- Imam E., H. Yahya and I. Malik. 2002. A successful mass translocation of commensal rhesus monkeys *Macaca mulatta* in Vrindaban, India. *Oryx* 36 (1): 87-93.
- Inouye, D. W., B. Barr, K. B. Armitage and B. D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. *Proceedings of the National Academy of Sciences* 97: 1630–1633.
- IPCC. 2001. Climate Change 2001: Synthesis Report. Cambridge, UK: Cambridge University Press. 2001, pp 1-396.
- IUCN. 1993. Nature Reserves of the Himalaya and the Mountains of Central Asia. Oxford University Press, World Conservation Monitoring Centre, Gland, Switzerland, 458 pp.
- IUCN. 2010. IUCN Red List of Threatened Species. Version 2010.1. <[www.iucnredlist.org](http://www.iucnredlist.org)>. Downloaded on 22 April 2010.
- Jackson, R. M., G. Ahlborn, M. Gurung and S. Ale. 1996. Reducing livestock depredation losses in the Nepalese Himalaya. In R. M. Timm, A. C. Crabb (eds), Proceedings of the 17th Vertebrate Pest Conference. University of California, Davis, CA, pp 241–47.
- Jones C. G., J. H. Lawton and M. Shachak. 1997. Positive and negative effects of organisms as physical ecosystem engineers. *Ecology* 78: 1946-1957.
- Jones C. G., J. H. Lawton and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* 69: 373-386.
- Kruuk, H. 1972. *The spotted hyena: A study of predation and social behaviour*. University of Chicago Press, Chicago, Illinois, USA.

- Locky, H and B. Mackey. 2009. The Nature of Climate Change: Reunite International Climate Change Mitigation Efforts with Biodiversity Conservation and Wilderness Protection. *International Journal of Wilderness* 2(15): 7-14.
- Lovari, S., R. Boesi, I. Minder, N. Mucci, E. Randi, A. Dematteis and S. B. Ale. 2009. Restoring a keystone predator may endanger a prey species in a human altered ecosystem: the return of the snow leopard to Sagarmatha National Park. *Animal Conservation* 12: 559-570.
- Mech, L. D. 1981. *The Wolf: The Ecology and Behaviour of an Endangered Species*. Doubleday, New York.
- Miller, D. 1997. Conservation biodiversity in the HKH rangelands. *ICIMOD Newsletter* 27 (Spring), 8–11.
- Mishra, C. 1997. Livestock depredation by large carnivores in the Indian Trans-Himalaya: conflict perceptions and conservation prospects. *Environmental Conservation* 24:338–343.
- Mishra, C., P. Allen, T. McCarthy, M. Madhusudan, A. Bayarjargal and H. Prins. 2003. The role of incentive programs in conserving the Snow Leopard. *Conservation Biology* 17 (6): 1512-1520.
- Molur, S., C. Srinivasulu, B. Srinivasulu, S. Walker, P.O. Nameer and L. Ravikumar 2005. Status of non-volant small mammals: Conservation Assessment and Management *Plan (C.A.M.P) workshop report*. Zoo Outreach Organisation / CBSG-South Asia, Comibatore, India.
- Namgail, T., J. L Fox and Y. V. Bhatnagar. 2007. Carnivore-Caused Livestock Mortality in Trans-Himalaya. *Environment Management* 39:490-496.
- Naughton-Treves L. 1997. Farming the forest edge: Vulnerable places and people around Kibale National Park, Uganda. *Geographical Review* 87 (1): 27-46.

- Nikol'skii A.A and A. Ulak. 2005. The Range of the Himalayan Marmot (*Marmota himalayana*, Rodentia, Sciuridae) in Nepal, at the Southern Limit of Genus Marmota Distribution, *Zoologicheskyy Zhurnal* 84:282–284.
- Nikol'skii A.A and A. Ulak. 2006. Key Factors Determining the Ecological Niche of the Himalayan Marmot, *Marmota himalayana* Hodgson (1841). *Russian Journal of Ecology* 37: 46–52.
- Nuttall, M. 2001. Indigenous peoples and climate change research in the Arctic. *Indigenous Affairs* 4: 26–34.
- Nyhus, P.J and R. Tilson. 2004. Characterizing human-tiger conflict in Sumatra, Indonesia: implications for conservation. *Oryx* 38 (1): 68-74.
- Oli, M. K., I.R. Taylor and M. E. Rogers. 1994. Snow leopard *Panthera uncia* predation of livestock: an assessment of local perceptions in the Annapurna Conservation Area, Nepal. *Biological Conservation* 68:63–68.
- Oli, M.K., I.R. Taylor and M.E. Rogers.1993. Diet of the snow leopard (*Panthera uncia*) in the Annapurna Conservation Area, Nepal. *Journal of Zoology* (London) 231: 365-370.
- Oli MK.1997. Home range of Snow leopards in Nepal.*Mammalia* 61, 355–60.
- Patterson, B. D., S. M. Kasiki, E. Selempo and R.W. Kays. 2004. Livestock predation by lions (*Panthera leo*) and other carnivores on ranches neighboring Tsavo National ParkS, Kenya. *Biological Conservation* 119 (4): 507-516.
- Pedersen, V., J. D. C. Linnell, R. Andersen, H. Andren, M. Linden and P. Segerstrom.1999. Winter Lynx *Lynx lynx* predation on semidomestic reindeer *Rangifer tarandus* in northern Sweden. *Wildlife Biology* 5 (4): 203–211.

- Pokharel, A., M. Chhetri and C. Upadhyaya. 2006. Effects of grazing on plant species diversity and above ground biomass in a Trans- Himalayan Rangeland. *Banko Janakari* 17(1): 25-31.
- Riedlinger, D and F. Berkes. 2001. Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar Record* 37:315-328.
- Roberts, T.J. 1977. *The Mammals of Pakistan*. Ernest Benn, London, UK.
- Schaller, G. B. 1977. Mountain monarchs: Wild sheep and goats of the Himalaya. University of Chicago Press, Chicago, 425 pp.
- Sekhar N.U. 1998. Crop and livestock depredation caused by wild animals in protected areas: the case of Sariska Tiger Reserve, Rajasthan, India. *Environmental Conservation* 25 (2): 160-171.
- Servheen, C. 1990. The status and conservation of the bears of the world. International Conference for Bear Research and Management, Monograph Series No.2.
- Servheen, C., S. Herrero and B. Peyton. 1999. Bears. Status survey and conservation action plan. Bears. IUCN/SSC Bear and Polar Bear Specialist Groups. IUCN, Gland, Switzerland and Cambridge, U.K.
- Sharma, E and K. Tsering. 2009. Climate change in the Himalayas: The vulnerability of biodiversity. *Sustainable Mountain Development* 55: 10-12.
- Siex, K. S and T. T. Struhsaker. 1999. Colobus monkeys and coconuts: a study of perceived human-wildlife conflicts. *Journal of Applied Ecology* 36 (6): 1009-1020.
- Smith A.T and J. M. Foggin. 1999. The Plateau Pika (*Ochotona curzoniae*) is a keystone species for biodiversity on the Tibetan plateau. *Animal Conservation* 2:235-240.

- Smith, A and Y. Xie. 2008. *The Mammals of China*. Princeton University Press, Princeton, New Jersey.
- Tiwari, S., R. Regmi and M. Green. 2007. Tiger-rhino conservation project: landscape-scale conservation of the endangered tiger and rhino population in and around Chitwan National Park. Report of the final evaluation mission. United Nations Development Programme.
- Uniyal, S.K., A. Awasthi and G. S. Rawat. 2009. Biomass availability and forage quality of *Eurotia ceratoides* Mey in the rangelands of Changthang eastern Ladakh. *Current Sciences* 89 (1):201-205.
- Van Staalduin, M.A and M.J.A. Werger. 2007. Marmot disturbances in Mongolian steppe vegetation. *Journal of Arid Environments* 69: 344–351.
- Wade, R. 1987. The management of Common property resources: Collective action as an alternative to privatization or state regulation. *Cambridge journal of Economics* 11: 95-106.
- Xu, J., R. Grumbine, A. Shrestha, M. Eriksson, X. Yang, Y. Wang and A. Wilkes. 2009. The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods. *Conservation Biology* 23(3): 520–530.
- Yi, S and E. Sharma. 2009. Climate change and the Hindu Kush-Himalayan rangelands. Information Sheet # 8/09, ICIMOD, Kathmandu, Nepal. Available at [http://books.icimod.org/uploads/tmp/icimod-climate\\_change\\_and\\_the\\_hindu\\_kush-himalayan\\_rangelands.pdf](http://books.icimod.org/uploads/tmp/icimod-climate_change_and_the_hindu_kush-himalayan_rangelands.pdf), accessed on 7 March 2012.

Zahler, P., B. Lkhagvasuren, R.P. Reading, J. Wingard, S. Amgalanbaatar, S. Gombobaatar, N.

W. H. Barton and Y. Onon. 2004. Illegal and unsustainable wildlife hunting and trade in Mongolia. *Mongolian Journal of Biological Sciences* 2:23–31.

Zhang L and N. Wang. 2003. An initial study on habitat conservation of Asian elephant (*Elephas maximus*), with a focus on human elephant conflict in Simao, China. *Biological Conservation* 112 (3): 453-459.



**MASSEY UNIVERSITY**  
GRADUATE RESEARCH SCHOOL

**STATEMENT OF CONTRIBUTION  
TO DOCTORAL THESIS CONTAINING PUBLICATIONS**

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

**Name of Candidate:** Achyut Aryal

**Name/Title of Principal Supervisor:** Prof. Dianne Brunton

**Name of Published Research Output and full reference:**

1. Aryal, A., D. Raubenheimer, R. Pandit, R. Rai, U. B. Shrestha, N. Lama, D. Brunton. (In press). Rangelands and Society: status, rights, conflicts and indigenous conflict management strategies in rangeland of Nepal. *Mountain Research and Development* 33 (1): XX-XX: <http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00055.1>
2. Aryal, A., D. Brunton, T K Shrestha, R. K. Koirala, J. Lord, Y. B. Thapa, B. Adhikari, W. Ji, D. Raubenheimer. 2012. Biological diversity and management regimes of the northern Barandabhar Forest Corridor: an essential habitat for ecological connectivity in Nepal. *Tropical Conservation Sciences* 5 (1):38-49.
3. Aryal, A., S. Sathyakumar, & C.C. Schwartz. 2010. Current status of the brown bear in Manasalu Conservation Area Nepal. *Ursus* 21(1):109-114. doi: 10.2192/09GR029.1
4. Aryal, A., J. Hopkins, W. Ji, D. Raubenheimer and D. Brunton. 2012. Distribution and diet of brown bear in Annapurna Conservation Area, Nepal. *Ursus* 23 (2): 231-236
5. Aryal A., D. Raubenheimer, S. Sathyakumar, B.S. Poudel, W. Ji, K.J. Kunwar, J. Kok, S. Kohshima and D. Brunton. 2012. Conservation strategy for brown bear and its habitat in Nepal. *Diversity* 4(3): 301-317.

**In which Chapter is the Published Work:** Chapters one and two

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:  
data collection, analysis, manuscript writing

Candidate's Signature

21/01/2013

Date

Principal Supervisor's signature

21/01/2013

Date



**MASSEY UNIVERSITY**  
**GRADUATE RESEARCH SCHOOL**

**STATEMENT OF CONTRIBUTION  
TO DOCTORAL THESIS CONTAINING PUBLICATIONS**

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

**Name of Candidate:** Achyut Aryal

**Name/Title of Principal Supervisor:** Prof. Dianne Brunton

**Name of Published Research Output and full reference:**

1. Aryal, A., D. Raubenheimer, W. Ji and D. Brunton. 2013. Blue sheep in the Annapurna Conservation Area, Nepal: habitat use, population biomass and their contribution to the carrying capacity of snow leopards. *Integrative Zoology*. In press (DOI: 10.1111/1749-4877.12004).
2. Aryal, A., D. Brunton and D. Raubenheimer. 2013. Habitat assessment to translocating blue sheep to maintain a viable snow leopard population in the Mt Everest Region, Nepal. *Zoology and Ecology (formally Acta Zoologica Li.)* 32(1): In press: DOI:10.1080/21658005.2013.765634
3. Aryal, A., D. Brunton, W. Ji, H. Yadav, B. Adhikari, D. Raubenheimer. 2012. Diet and habitat use of hispid hare *Caprolagus hispidus* in Shuklaphanta Wildlife Reserve Nepal. *Mammal Study* 37 (2): 147-154. (Hispid hare photo on cover page of the journal).

**In which Chapter is the Published Work:** Chapters three and four

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:  
data collection, analysis, manuscript writing

Candidate's Signature

21/01/2013

Date

Principal Supervisor's signature

21/01/2013

Date



**MASSEY UNIVERSITY**  
**GRADUATE RESEARCH SCHOOL**

**STATEMENT OF CONTRIBUTION  
TO DOCTORAL THESIS CONTAINING PUBLICATIONS**

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

**Name of Candidate:** Achyut Aryal

**Name/Title of Principal Supervisor:** Prof. Dianne Brunton

**Name of Published Research Output and full reference:**

Aryal A, D Brunton and D Raubenheimer. 2103. Impacts of climate change on human-wildlife- ecosystem interactions in the Trans-Himalayan region of Nepal. Theoretical and Applied Climatology DOI: 10 .1007/s00704-013-0902-4. Online first

**In which Chapter is the Published Work:** Chapter five

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:  
and / or
- Describe the contribution that the candidate has made to the Published Work:  
Data Collection, Analysis, and Manuscript writing

**Achyut Aryal**  
Digitally signed by Achyut Aryal  
DN: cn=Achyut Aryal, o=Massey University,  
ou=Institute of Natural and Mathematical  
Sciences, email=a.aryal@massey.ac.nz, c=NZ  
Date: 2013.06.24 10:34:20 +12'00'

---

Candidate's Signature

**24 June 2013**  
Date

**Dianne Brunton**  
Digitally signed by Dianne Brunton  
DN: cn=Dianne Brunton, o=Massey  
University, ou=INS,  
email=d.h.brunton@massey.ac.nz, c=NZ  
Date: 2013.06.24 14:37:35 Z

---

Principal Supervisor's signature

**24 June 2013**  
Date