STATUS, DISTRIBUTION AND FORAGING ECOLOGY OF WOLF IN THE NORTH-WESTERN HIMALAYAN LANDSCAPE, INDIA

Thesis submitted to the

Saurashtra University, Rajkot, Gujarat

For the award of the degree of

Doctor of Philosophy in Wildlife Science

by

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I, Shivam Shrotriya, declare that the thesis entitled has been prepared by me "**Status, Distribution and Foraging Ecology of Wolf in the North-western Himalayan Landscape, India**" under the supervision of **Dr. Bilal Habib**, Scientist-E, Wildlife Institute of India and co-supervision of **Dr. Yadvendradev V. Jhala**, Scientist-G, Wildlife Institute of India**.** No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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Mr. Shivam Shrotriya has put more than six terms of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted for any degree to any other University or Institution.

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EXECUTIVE SUMMARY

Despite the grey wolf *Canis lupus* being the most studied mammalian species worldwide, wolves of the Himalayas remain in shadow with no information available on their ecology. The Himalayan wolf lineage is known to have genetic uniqueness, as it might be the oldest diverging population of the wolf-dog clad worldwide. This research commenced with the objectives of 1) understanding nature and pattern of livestock predation by the Himalayan wolf and the attitude of local communities towards them, 2) studying food habits of the Himalayan wolf at the landscape level and its diet niche overlap with sympatric carnivore species, and 3) comprehending the status, distribution pattern and factors determining the distribution of the Himalayan wolf and its prey. The study was conducted in an area of 1,41,391 km^2 encompassing Leh and Kargil districts of Ladakh region and Lahaul & Spiti and Kinnaur districts of Himachal Pradesh. There are six high-altitude protected areas in the districts of Leh and Lahaul & Spiti. The fieldwork for this study was conducted from 2014 to 2018.

Questionnaire-based interviews were conducted to study the pattern of livestock depredation by carnivore species and public perception towards the carnivores. A total of 1865 interviews in 133 villages of Leh and Kargil districts were conducted. Public perception towards carnivore species was recorded on a 5-point Likert scale for three attributes of the perception, i.e., attitude towards the species, knowledge about the species and effect on the livelihood of the responded. Data on compensation for carnivore caused livestock depredation were also collected from the Department of Wildlife Protection. It was found that snow leopard *Panthera uncia* attack cases (82.33%) contributed the most in the data reported to

the department for compensation. Wolf depredation cases were either not reported or possibly claimed as snow leopard attacks. Livestock depredation pattern from the data collected through interview surveys was dissimilar to the compensation data. Interestingly, feral dogs were the top predators of the livestock (n=270, 44.70%), followed by the Himalayan wolf (n=207, 34.27%) and snow leopard (n=76, 12.58%). Public attitude towards wolves and snow leopard was overall positive and similar across the landscape. However, people were averse to feral dogs compared to wolves in the areas of dog presence (Wilcoxon paired test, V= 161, $p < 0.001$). Pastoralism as an occupation ($p < 0.001$) and records of wolf attacks in the region ($p = 0.064$) were linked with a negative public attitude towards wolves.

Wild ungulate population estimation in the Himalayan region and other mountainous areas is a challenge due to difficult access to most of the areas and low densities of the wildlife. In the mountain regions, it is nearly impossible to meet the assumptions of traditional line transect method to estimate ungulate populations. Therefore, a new approach of the simultaneous point-count method was adapted to the field conditions and habitat characteristics of the Trans-Himalayas. A total of 35,000 km^2 area in Changthang wildlife sanctuary (WLS) and Nubra-Shyok WLS was surveyed by a large team of field staff and volunteers. Altogether 63 point-count locations were observed with temporal repeats. Kiang *Equus kiang* was the most sighted species with 425 observations, while Tibetan antelope *Pantholops hodgsonii* and wild yak *Bos mutus* were sighted only twice. Population densities of kiang (1.003 ±0.42), blue sheep *Pseudois nayaur* (0.23 ±0.18 in Changthang WLS and 0.25 ±0.14 in Nubra WLS), Tibetan argali *Ovis ammon hodgsonii* (0.02 ±0.03), Tibetan gazelle *Procapra picticaudata* (2.43

±0.90), Asiatic ibex *Capra ibex sibirica* (0.46 ±0.26) and Ladakh urial *Ovis vignei vignei* (0.17 ±0.09) were estimated. The novel method of simultaneous point-count allowed the population estimations of major ungulate species within reasonable limits over the vast landscape in a shorter time. Distribution of the prey species was also modelled over the entire study area. Since many observations of Kiang were recorded, its distribution was modelled by Maxent method. For four other ungulates, Boolean logic models were used to delineate their distribution range. Kiang habitat was estimated to be 5,738 sq km in Changthang WLS. Blue sheep (57,057 sq km), Tibetan argali (14,605 sq km), Asiatic ibex (59,100 sq km) and Ladakh urial (18,280 sq km) were distributed in a larger area within the landscape.

The Himalayan wolf occurs along with snow leopard as a major carnivore in the Trans-Himalayan landscape. Red fox *Vulpes vulpes* is another widespread carnivore of the landscape. In this research, diet patterns, niche overlap and the competition were studied by conducting scat analysis. A total of 1600 scats were collected from the field, and information on another 573 snow leopard scats was generated from literature. Analyses were performed on a total of 2173 scats (wolf-542, snow leopard- 604, red fox- 1027). Prey items in the scats were recorded as relative frequency of occurrence during the laboratory analysis. Livestock was a major contributor to the wolf diet (56.46%). Small prey items such as pika (13.54%) and marmot (6.99%) were quite frequently represented in the wolf diet. Snow leopard predated majorly on blue sheep (30.79%), and red fox had a diverse diet of small prey (18.85%), scavenging on livestock carcass (16.49%), fruits and wild seeds (15.05%) and other human-derived materials including poultry (11.89%). The dietary niche of the carnivore species varied in the wild species consumption. However, large contributions from livestock in the diets caused a considerable overlap (Pianka's mean observed index= 0.503, randomized simulated mean index= 0.491, p= 0.15). RLQ based ordination analysis was performed to understand the effect of prey and predator traits on their dietary relationships. Predator morphology and habitat preferences significantly affected their prey choices ($p < 0.05$). Site-specific prey selection by the wolf was observed, but there were no significant preferences at the landscape level (log-likelihood test ratio: G2 = 6.79, df = 12, p = 0.871).

Information on the distribution of a rare species is the basic information required to formulate the conservation strategy. Wolf, however, is a challenging species in modelling its habitat suitability, as models fail to account for their adaptability. Modern machine learning methods have offered a possible solution in modelling distribution of such species. In this Maxent algorithm was applied to model the distribution of the wolves in the Trans-Himalayan landscape of the north-western Himalayas, India. A total of 2,249 wolf presence locations were generated from scats collection (n=542), direct sightings (n=20) and radio-collaring fixes (n=1687). After rarefication of the location to resemble a similar sampling effort, 93 locations were used to train and test the models. Information on many as 31 environmental predictor variables was collected, and 15 layers were used in the modelling process after removing the correlated variables. Selection criteria based on AICc, omission rates and AUC values were used to evaluate and select the best performing models in both approaches. A total of 47,176 km^2 area in the north-western Trans-Himalayan landscape was found as suitable wolf habitat. The mean temperature of the coldest quarter, isothermality, human population density and mean diurnal temperature range were the main contributing factors in the wolf distribution model.

This thesis generates crucial information on the ecology of rare Himalayan wolf lineage. Taxonomic status of the Himalayan wolf is yet to be resolved, and the ecological information from this thesis provides a comparison to other wolf lineages worldwide. This research identifies best suitable habitat for the wolves in a large landscape and recommends wolf-specific planning outside of the protected area network as well. Based on the suitable habitat and home ranges of the wolves in the Himalayas, It was estimated that about 126 wolf-packs (378 to 630 adult individuals) could survive in the Trans-Himalayan landscape of Ladakh and Spiti, India. Threats of climate change and hybridization exist for the wolves in the Himalayas. However, the primary threat to them comes from the local pastoralists. The Himalayan wolves heavily depend on livestock for subsistence and get persecuted in the retaliatory killing. Therefore, modification of public perception is essential for planning long-term conservation of the wolves in the Himalayas. Wildlife management practices to promote the recovery of wild prey densities are promising since the wolves have shown the tendency to switch away from the livestock where wild prey is available.

Chapter 1

INTRODUCTION

1.1 Background

The grey wolf *Canis lupus* is one of the most widely distributed terrestrial mammals on the globe, and it serves as the top predator in much of its range (Mech and Boitani 2003). Therefore, it has been studied so extensively that probably more studies are conducted on it than any other carnivore (Mech and Boitani 2003; Musiani et al. 2010). However, there has been a considerable geographic bias with most of the studies focusing on the North American and European wolves (Pilot et al. 2014). Wolf populations of Asia have not garnered much attention from the scientific community, despite showing a diverging evolutionary history compared to other wolves (Matsumura et al. 2014). Wolf is included in the Red List of the IUCN under the category Least Concerned (LC) (Boitani et al. 2018). CITES lists the wolf in Appendix II, which consists potentially endangered species. The populations from India, Pakistan, Nepal and Bhutan are included in Appendix I of CITES, as these populations are in danger of extinction. The wolf in India is included in Schedule I of the Wildlife Protection Act, 1972.

Despite a continuous historical distribution of the grey wolf throughout Europe, Asia and North America, considerable morphological differentiation among the wolves has led to an argument over splitting species and delimiting the number of subspecies (Nowak 2003; Sillero-Zubiri and Macdonald 2004; Wozencraft 2005; Pilot et al. 2014). Species recognition and systematics of canids have always been a subject of much debate among the experts. Canid Action Plan, published by IUCN/SSC Canid Specialist Group, mentions that the scientists propose the existence of 34 to 38 canid species (Macdonald and Sillero-Zubiri 2004). Several new species and subspecies of wolves have been identified and reported from different parts of the world. Approximately 13 subspecies of the grey wolf *Canis lupus* are recognised, which may not be related so closely (Jhala and Sharma 2004).

Until recently it was considered that there were two subspecies of wolves in India- 1) Indian wolf or peninsular wolf *Canis lupus pallipes*, and 2) Himalayan or Tibetan wolf *Canis lupus chanco*. The Indian wolf dwells in a few disconnected patches of central and southern India, while the Himalayan wolf is reported from the Trans-Himalayan landscape of India. Hodgson (1847) was the first one to report the presence of wolves in the Himalayas. Morphology based classification of the wolves in the Himalayas kept their taxonomic status shuffling since the first description (Hodgson 1847; Blandford 1888; Pocock 1941). However, investigation based on mtDNA revealed that the Himalayan wolf is not only distinct but also the oldest of the other grey wolf lineages worldwide (Aggarwal et al. 2003, 2007; Sharma et al. 2004). While other wolf and dog lineages are closely related to each other and diverging about 0.15 million years ago (Vilà et al. 1997), Himalayan wolf lineage diverged about 0.8 million years ago (Sharma et al. 2004). Interestingly, the time of this divergence closely matches with the uplift of Tibetan plateau and rapid habitat modification in the region (Sun and Liu 2000; Sharma et al. 2004). Hence, the genetic distinctiveness of the Himalayan wolf may have been an outcome of ecological and behavioural adaptations during this evolutionary timeline.

A scientific review of the debate around the taxonomic status of the Himalayan wolf was published during the beginning of this PhD research (Shrotriya et al. 2012). Since then, newer studies on the genetics of the wolf populations from the Himalayas have revealed more into their evolutionary history and relatedness with surrounding wolf populations (Subba 2012; Matsumura et al. 2014; Chetri et al. 2016; Werhahn et al. 2016, 2018; Joshi et al. 2020; Wang et al. 2020). Notwithstanding, the latest meeting of the canid specialist group in Portugal could not resolve the taxonomic issues related to the Himalayan wolf nomenclature (Alvares et al. 2019). Apart from genetic studies, investigations on other aspects of ecology and biology of these wolves were scanty. The dissertation was proposed to study the status, distribution and foraging ecology of the wolf in the north-western Himalayan landscape.

1.2 Hypotheses and Objectives

One of the most ancient lineages of the wolf has persisted in the Trans-Himalayan landscape even though the low primary productivity of these areas allows only sparse ungulate populations (Lovari and Mishra 2016). The last and only available study about the population size of the Himalayan wolf estimated their abundance as low as about 350 individuals over the area of 50,000 km^2 in Ladakh and Spiti valley of the Indian Trans-Himalayas (Fox and Chundawat 1995). Further, livestock grazing in these areas has a long history of over three millennia (Schaller 1998). Most of the grazers are nomadic by nature and keep migrating with thousands of small-livestock such as goats and sheep. The movement pattern of the livestock grazers has remained the same for about a few millennia, and the traditional practices and routes have not changed much (Handa 1994). Wolves, therefore, are well exposed to the presence of livestock and grazing pattern over a long period. The wolves, eventually, might have adapted to harvest the best out of the livestock grazing practices. Presence of easy prey should attract wolves, which was evident by their larger share (~60%) in livestock predation compared to other sympatric carnivores (Namgail et al. 2007). The pastoralist communities, in response, have developed ways to cope with livestock predation by the wolf. Hence, occasional retaliatory killing is reported in a few studies from these areas (Mishra 1997; Jackson and Wangchuk 2000).

Since the wolf has persisted despite their low density and human persecution, while the pastoralists have developed mechanisms to minimise the livestock loss to carnivore predation, both of them are expected to have adapted for co-existence. Differences in the pastoral practices across the landscape were expected to influence the feeding habits and prey selectivity of the wolf. In the view of optimal foraging theory and prey switching theory, **the wolf was expected to shift the diet to easily procurable and abundant livestock while successfully minimising the risk of being persecuted.** The literature on wolf distribution suggests a positive influence by prey density and negative influence by human pressure and road density (Mladenoff et al. 1995, 2009; Belongie 2008; Llaneza et al. 2012). However, positive association of the wolves with human presence is reported from arid landscape in Israel due to availability of food subsidy (Barocas et al. 2018). **Human presence, a major cause of disturbance and persecution, is associated with the presence of livestock. Thus a threshold level was expected to balance off both the effects**.

The present study was conducted to test the abovementioned two hypotheses with the following objectives.

1. To evaluate the nature and pattern of livestock predation by the wolf and the attitude of local communities towards the wolf.

2. To study food habits of the wolf at the landscape level and what is the diet niche overlap and segregation of sympatric carnivore species.
3. To study status, distribution and factors determining distribution pattern of wolf and its prey.

1.3 Study Area

The Trans-Himalayan landscape is the northernmost area of India, spanning over 1,86,000 km^2 area along the Indo-China border (33-35° N, 76-79° E). It is a high elevation, dry land of rugged mountains and open plains north of the Himalayas. Five northern states share the Trans-Himalayan landscape in India. It includes Leh and Kargil districts (Ladakh), Spiti valley and parts of Kinnaur district (Himachal Pradesh), parts of Uttarkashi, Chamoli and Pithoragarh districts (Uttarakhand), Tso-Lhamo region of North Sikkim district (Sikkim) and Tawang district (Arunachal Pradesh). Reports of the wolf presence have appeared throughout the landscape including Nepal, Bhutan and Tibetan plateau (Hodgson 1847; Pocock 1941; Fox et al. 1986; Chundawat 1992; Fox and Chundawat 1995; Bhattacharya and Sathyakumar 2010; Maheshwari and Sharma 2010; Chanchani et al. 2011; Matsumura et al. 2014; Chetri et al. 2016; Werhahn et al. 2019b).

Elevation of the Trans-Himalayan landscape varies from 2,800 m to 7,000 m high Himalayan peaks. The Indian Trans-Himalayan region is one of the least populated areas with a human density of 4.9 individuals/km^2 (Chandramouli 2013). The entire area falls in rain-shadow of the Himalayas, and annual precipitation ranges from 500-1000 mm in valleys just north of the high Himalayan ranges to approximately 100 mm in the central Trans-Himalayan valleys (Hartmann 1983). Most of the people are agro-pastoralist; and nomadic, semi-nomadic and settled

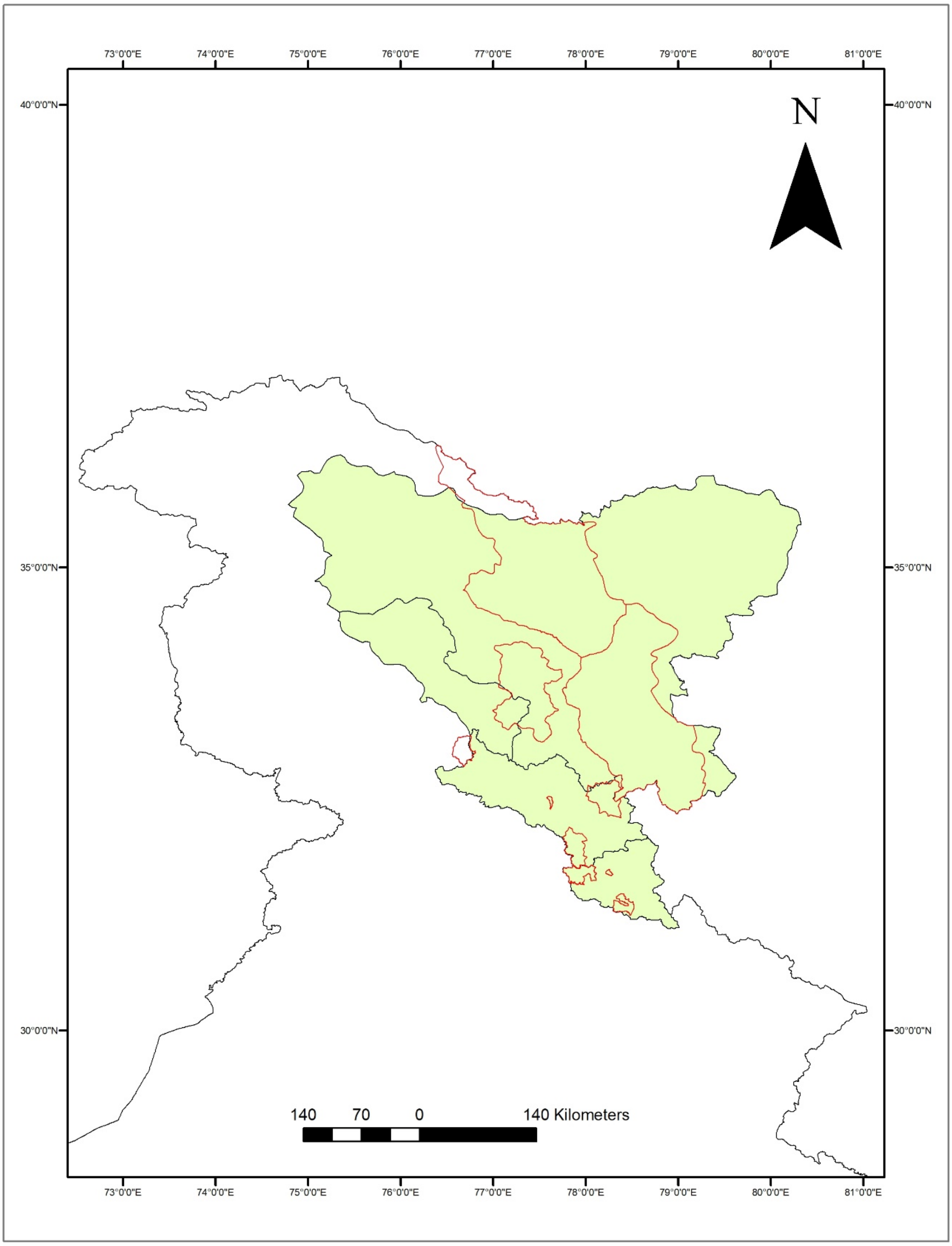

Figure 1.1 *Selected study area (in green) in the Trans-Himalayan landscape of India. Leh and Kargil districts within Indian control are included along with Lahaul & Spiti and Kinnaur districts of Himachal Pradesh. Protected areas are shown in the red boundary.*

villagers inhabit these areas. Livestock grazing and associated use of rangelands is widespread across the Trans-Himalayan landscape and has played an important role in the ecological history of the region (Mishra et al. 2001; Bagchi et al. 2004).

Compared to the other terrestrial ecosystems of India, where most of the wildlife populations survive inside protected areas, the Himalayan and the Trans-Himalayan landscapes are unique in that wildlife populations here occur across the landscape beyond protected area network (Mishra et al. 2010). Eight species of wild ungulates are present in the Trans-Himalayan landscape of the north-western Himalayas and provide the main source of wild prey. Blue sheep *Pseudois nayaur* and Asiatic Ibex *Capra ibex sibirica* are the most common wild ungulates, while small populations of Ladakh urial *Ovis vignei vignei*, Tibetan argali *Ovis ammon hodgsonii*, kiang *Equus kiang*, Tibetan gazelle *Procapra picticaudata*, Tibetan antelope *Pantholops hodgsonii* and wild yak *Bos mutus* are also present (Fox et al. 1991; Chundawat and Qureshi 1999). Two species of marmot *Marmota himalayana* and *M. caudata*, woolly hare *Lepus oiostolus*, five species of pika or mouse hare *Ochotona spp.*, snowcock *Tetraogallus himalayensis* and *T. tibetanus* and chukar *Alectoris chukar* can also form a part of wild prey for carnivores. Apart from the wolf, sympatric carnivores in the Trans-Himalaya include snow leopard *Panthera uncia*, lynx *Lynx lynx isabellinus*, wild dog *Cuon alpinus laniger* and brown bear *Ursus arctos* (Fox and Chundawat 1995).

The Trans-Himalayan landscape in two districts of Ladakh region in Indian control (Kargil and Leh) and two districts of Himachal Pradesh (Lahaul & Spiti and Kinnaur) was selected for this study (Figure 1.1). The study area encompasses a total of 1,41,391 km^2 area of the Indian Trans-Himalayas. Leh district holds three high-altitude protected areas- Hemis national park (NP), Changthang wildlife sanctuary (WLS) and Karakoram (Nubra-Shyok) WLS. Kibber WLS, Chandratal WLS and Pin NP are other three high-altitude protected areas of the landscape, falling in Spiti valley, Himachal Pradesh. The protected areas in Kinnaur district, Himachal Pradesh are Lippa-Asrang WLS, Rupi-Bhabha WLS and Raksham-Chitkul WLS, where the protected areas include only a portion of the Trans-Himalayan landscape. Ladakh region has been politically separated from the erstwhile Jammu & Kashmir state on 5th August 2019. Most of this research was carried out before the separation. Therefore, the references to local departments and locations are mentioned with reference to their earlier position with the state of Jammu & Kashmir.

CHAPTER 2.

PATTERN OF LIVESTOCK DEPREDATION AND PUBLIC PERCEPTION TOWARDS CARNIVORES IN LADAKH, INDIA

2.1 Introduction

Human-wildlife conflict, defined as any action by humans or wildlife that negatively impacts the other, is a worldwide conservation concern (Treves et al. 2006; Woodroffe et al. 2007). Livestock depredation by the carnivores causes substantial loss to pastoral communities, making it a major challenge for conservation practitioners (Miller 2015). The conflict arises due to compromised interests of local farmer/herder community and conservation goals (Suryawanshi et al. 2013). The human dimensions, such as public perceptions of the value of wildlife, management of wildlife species, and the impact of wildlife on local people, influence wildlife management decisions (Decker et al. 2001). Therefore, examining people's attitudes is crucial for policy-making, management planning and public awareness (Gillingham and Lee 1999).

Although several large and small carnivore species occur in the Trans-Himalayan landscape of India, public perception towards the carnivores is majorly shaped by the Himalayan wolf and snow leopard- the most widespread and top two carnivores of this landscape. Brown bear is another conflict species; however, its presence is limited in the northern Kargil district (Maheshwari et al. 2012). The pastoralists often have a strong negative attitude towards the carnivore species (Mishra 1997; Treves et al. 2004, 2017; Bagchi and Mishra 2006; Behdarvand et al. 2014). Large carnivores have been facing resentment with herders even without causing severe problems due to an "innate fear and deep-seated cultural hostility from past experiences” (Berg 2001), and the wolf may be blamed for far more predation than they commit (Kellert et al. 1996). The wolves are known for killing multiple livestock in one attack or surplus killing (Mech and Boitani 2003; Bruskotter et al. 2007; Van Duyne et al. 2009), whereas snow leopard usually takes one or two livestock (Linnell et al. 1999) except in a few occasion and incidences (Mijiddorj 2011). Surplus killing is a severe financial hardship to stock owners and often the cause of hostile attitude towards wildlife (Oli et al. 1994; Jackson and Wangchuk 2000). Large carnivores in the Himalayan region have persisted in low abundances of wild-prey, and a high level of livestock predation exists, resulting into retaliatory killing (Fox et al. 1986; Chundawat 1992; Jackson et al. 1996; Mishra 1997; Chundawat and Qureshi 1999; Jaypal 2000; Sathyakumar and Qureshi 2003; Namgail et al. 2007). This study, therefore, focused on two aspects of the human-wildlife conflict in the Ladakh region of the north-western Himalayan landscape: 1) The pattern of livestock depredation by carnivore species, and 2) the pattern and causes of public perception towards the carnivores.

2.2 Methods

2.2.1 Data collection

Conducting questionnaire surveys is one of the commonly used methods to collect data on wildlife from the public (Pretty 1995; White et al. 2005). A total of 1,865 public interviews were conducted asking questions on the livestock predation and public perception in between the year 2014 to 2018 (Table 2.1). Information from previous interview-based studies in this landscape were used to delineate the target study area where wolf and snow leopard presence is known (Namgail et al. 2007; Habib et al. 2013). All 133 villages within and surrounding three major protected areas, *viz.*, Changthang wildlife sanctuary (WLS), Nubra-Shyok WLS

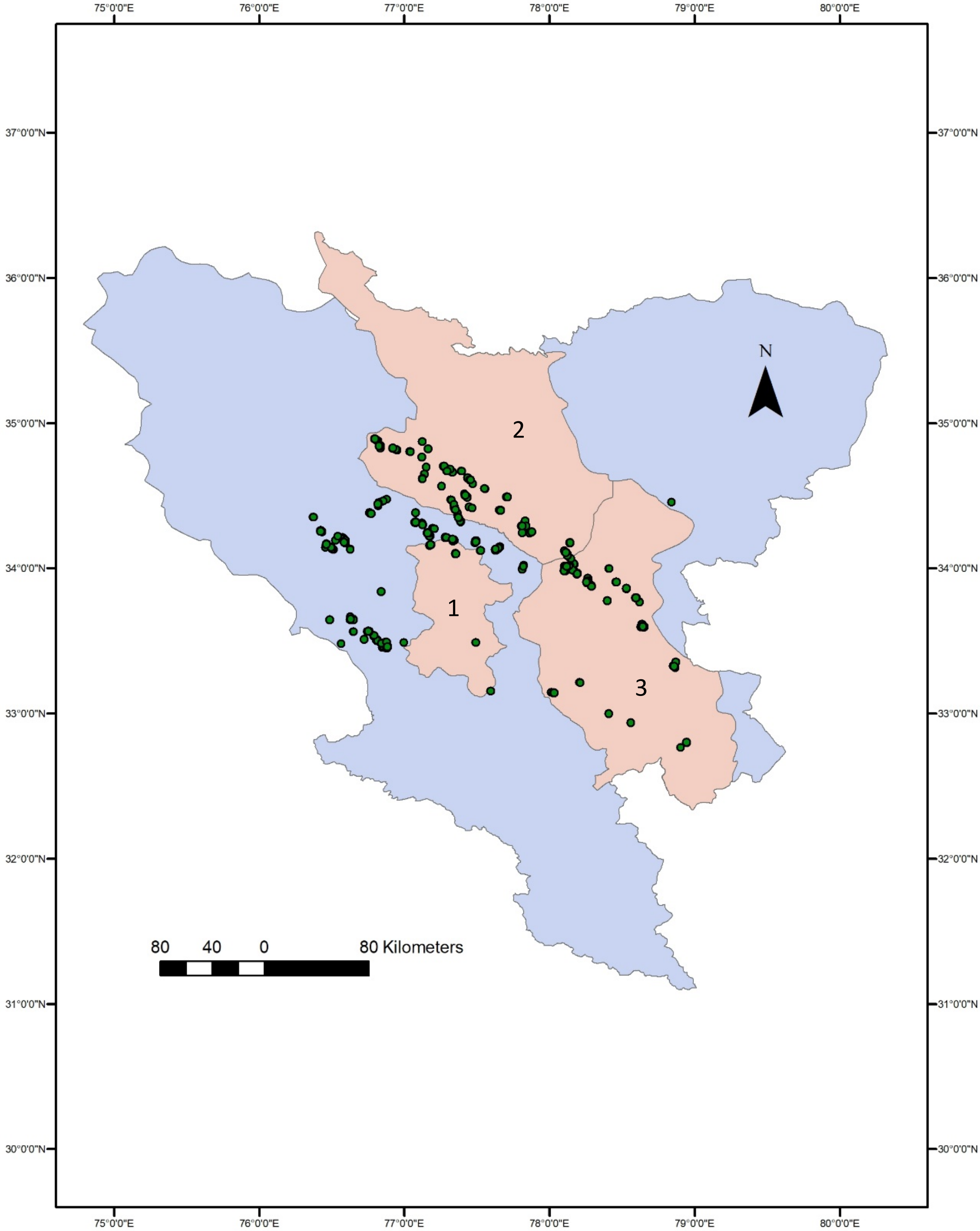

Figure 2.1 *Coverage of the survey effort and geographic spread of interview locations in the north-western Trans-Himalayan landscape. Protected areas: 1- Hemis National Park, 2- Nubra-Shyok WLS, 3- Changthang WLS.*

and Hemis national park, of Leh and Kargil districts of Ladakh were covered under this study (Figure 2.1). A list of the surveyed villages along with the GPS locations is provided in Appendix-1. Northern Kargil was not included in this study due to low reporting of wolf and snow leopard presence and no protected area (Maheshwari et al. 2012). On average, 20% of the households were targeted per villages, and a single interview was conducted per household. A structured questionnaire with open-ended and closed-ended questions was prepared (Appendix-2). Problems of collecting authentic data on people's attitude are highlighted by Heberlein (2012), and efforts were made to minimise the errors. The questions were conducted in the local language with the help of a translator. Since the species number is limited and most species have a distinguished local name, the chances of misidentifying the wildlife species were low. Colour photographs of the carnivore and ungulate species were presented to the interviewee to ascertain their wild animal identification skills. Public perception towards carnivore species was recorded on a 5-point Likert scale and three attributes of the perception, i.e., attitude towards the species, knowledge about the species and effect on the livelihood of the responded, were measured. Attitude towards co-existence with the carnivore was scaled 1 for "strongly agree" and 5 for "strongly disagree". The respondents were asked to describe the carnivore attack along with the information on time, location and attacking species. Any record with ambiguity in identifying the carnivore or description of the event was not included in the data. If a depredation case was older than one year before the interview, it was removed from the analyses. Secondary data on livestock predation and compensation was obtained from the Department of Wildlife Protection, Leh, Jammu and Kashmir. Between the years

2013 to 2017, a total of 533 cases of livestock depredation by carnivores were reported to the Department of Wildlife Protection, Leh, Jammu and Kashmir.

2.2.2 Statistical Analyses

Summary graphs on respondent profile, livestock depredation cases and responses were prepared using Microsoft's Excel version 2016. All the statistical analyses were performed in R version 3.6.3 (R Core Team 2020). Ordinal regression was performed to analyse the effect of various factors on the public attitude towards carnivores. The following variables were tested for their effect: 1) location of the village inside or outside the protected area, 2) religion of the respondent- Buddhist/ Muslim, 3) gender- male/ female, 4) occupation- farmer, nomadic (including pastoralists and farm labourers) and non-pastoralists including in-service, job, business and tourism, 5) age, 6) latitude and longitude, and 7) if the respondent has also reported a case of livestock depredation by the corresponding carnivore species. Since 85.71% nomadic respondents were also pastoralists, the variable on nomadism was removed from ordinal regression. Out of 880 respondents that provided information on education, 56.83% joined school below 10^{th} grade (high-school), and 36.35% qualified 10^{th} grade but did not go for higher studies. Among the informants on education, only 5.29% respondents were from pastoralist class. Since there was low reporting on education and it correlated with the occupation, education was also removed as a variable from the analyses. Cumulative link mixed random modelling, with the "clm" function in the "ordinal" package of R (Christensen 2018), was used to construct models predicting Likert scale ordinal responses from a series of generalised linear mixed models (GLMMs). R package "effects" was used to visualise the effect sizes for predictors of attitude (Fox et al. 2019). Akaike's Information Criterion (AIC) was used to rank the models and select the final model (Burnham and Anderson 2002). The attitude of people towards wolves and feral dogs were compared using the Wilcoxon signed-rank test. All the analyses codes are attached in Appendix-3.

2.3 Results

2.3.1 Respondent profile

Many of the respondents did not provide information for all the profiling characteristic and attitude related questions. Therefore, the sum of respondent numbers for any profile-class in Table 2.1 could be less than 1,865. Respondents were predominantly male (59.55 %) and within age classes of 35 to 65 (65.98%). Farming (56.66%) and nomadic pastoralism (19.37%) were the most common occupations (Table 2.1). Although schooling appears to be a dominant class in education, many respondents did not provide any information, and the majority of non-informing respondents could not have received formal school education. However, religious education and the ability to read is quite common in this region. Therefore, the respondents should not be considered illiterate for not going to school.

2.3.2 Livestock depredation

Data on 532 livestock compensation cases from the Department of Wildlife Protection, Leh revealed that most of the cases reported to the department were the attacks of snow leopard (82.33%) (Figure 2.2). Livestock depredation pattern from the data collected through interview surveys was contrary to the compensation data. A total of 604 livestock depredation cases were recorded during this study from 2014 to 2018. Most of the cases reported in this study were, interestingly, linked to stray dogs (n=270, 44.70%) and the Himalayan wolf (n=207, 34.27%) (Figure 2.3). Cases of brown bear attacks (n=46) were reported only from

Table 2.1 *Respondent characteristics of the three protected areas in Leh and Kargil districts, Ladakh, India.*

Total no. of respondents	1865		
Gender			
Male	1095	Female	744
Age class			
15-25	79	25-35	216
35-45	335	45-55	378
55-65	348	65-75	227
>75	104		
Occupation			
Security services	128	Business	66
Farmer	1047	Govt. services	102
Homemaker	74	Labourer	19
Nomadic pastoralist	358	Student	32
Tourism	23		
Education			
No schooling	13	>10th	495
10th pass	227	12th pass	89
Graduate	49	Post-graduate	6
Location of the respondents			
Changthang WLS	201	Nubra-Shyok WLS	498
Hemis National Park	25	Outside PA	1141

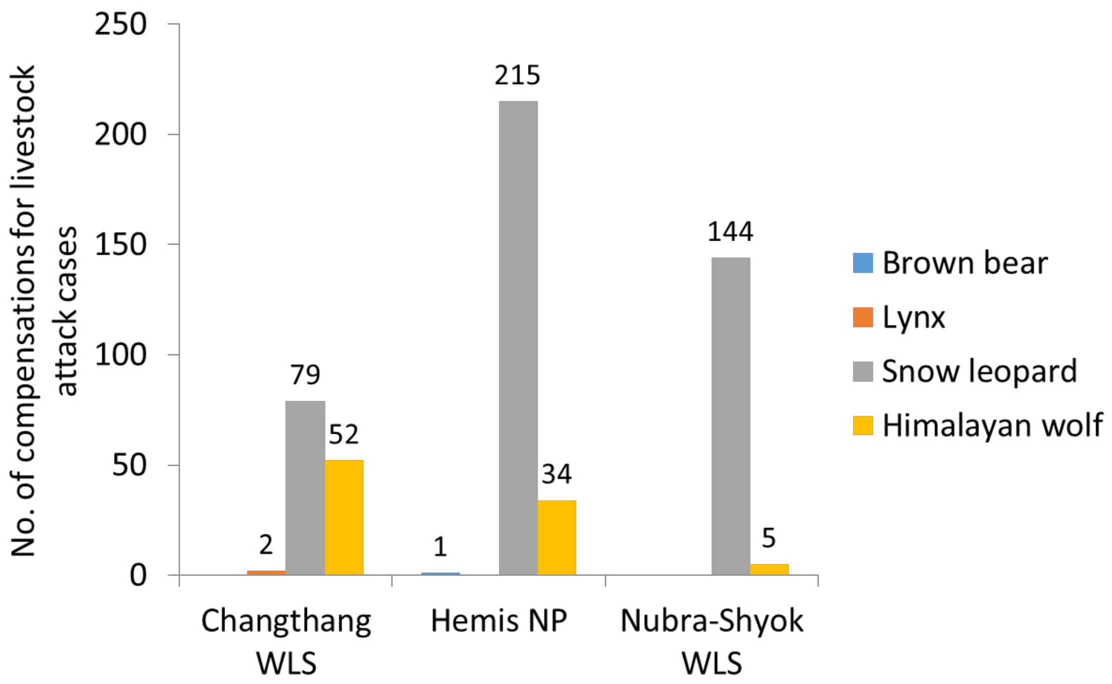

Figure 2.2 *Livestock compensation cases paid by the Department of Wildlife Protection, Leh during 2013 - 2017 (n=532).*

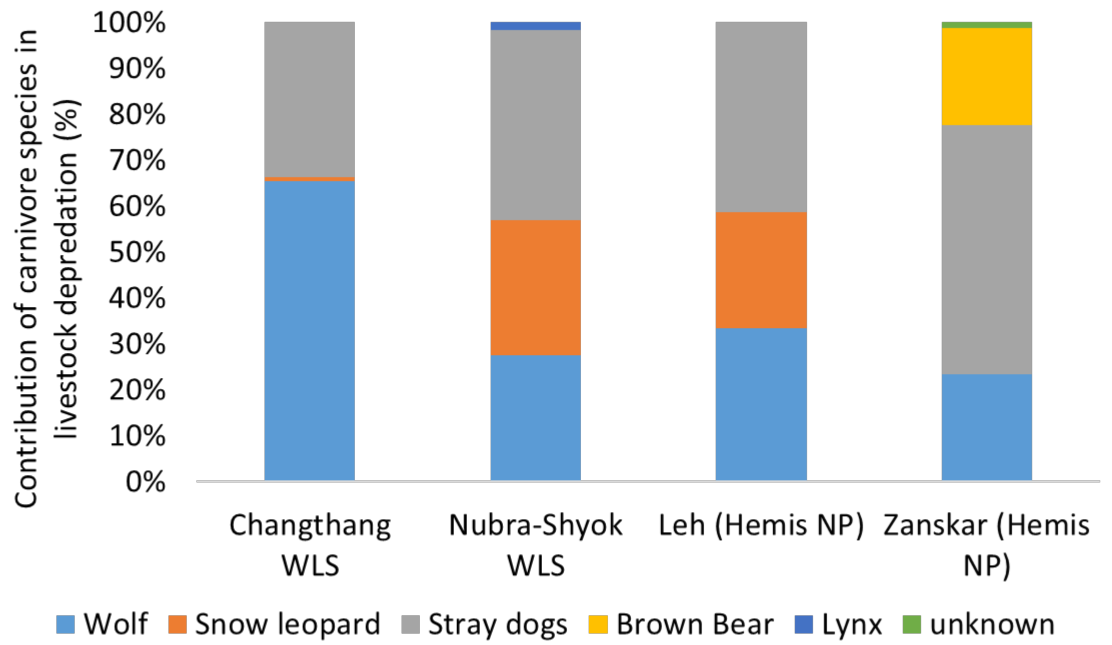

Figure 2.3 *Livestock depredation cases as reported by the respondents during the questionnaire survey in Ladakh during 2014 - 2018, India (n=604).*

Zanskar region of Kargil district, and only two cases of lynx attack were reported from Nubra-Shyok WLS. Almost all of the snow leopard cases (n=75), except one case from Chanthang WLS, were reported from either Nubra-Shyok WLS or villages around Leh town which is close to Hemis national park. In Changthang WLS, most of the depredation cases were linked to the Himalayan wolf (65.42%).

2.3.3 Knowledge and perceptions

The interviewees were scored on their views about the importance of wolf presence for the overall landscape. Most of the people thought that the wolf was an important species for Ladakh (44.06% of 1784 responses) (Figure 2.4). On the question of the effect of the wolf on their livelihood, most of the persons responded with “no effect” (75.35% of 1785 responses), followed by “strongly affected” (9.64%) (Figure 2.5).

The respondents were scored for their agreeability on the co-existence with the carnivore species such as wolf and snow leopard. Public attitude towards the Himalayan wolf and snow leopard highly co-varied, with most of the respondents agreeing for the co-existence with the wolf (35.16%) and snow leopard (47.25%) (Figure 2.6). Since the feral dogs were the top predator of the livestock in the Changthang region, questions regarding public attitude towards the dogs were added in selected questionnaire surveys in Changthang WLS (n= 110). The presence of feral dogs was considered more harmful than the presence of wolf by most of the respondents (Wilcoxon paired test, $V= 161$, $p < 0.001$) (Figure 2.7).

Further exploration of the public attitude towards the wolf revealed that most of the negative responses were associated with occupation and region. While pastoralist and labourers mostly responded with “disagree” and “strongly disagree”, students and persons engaged in tourism had the most positive

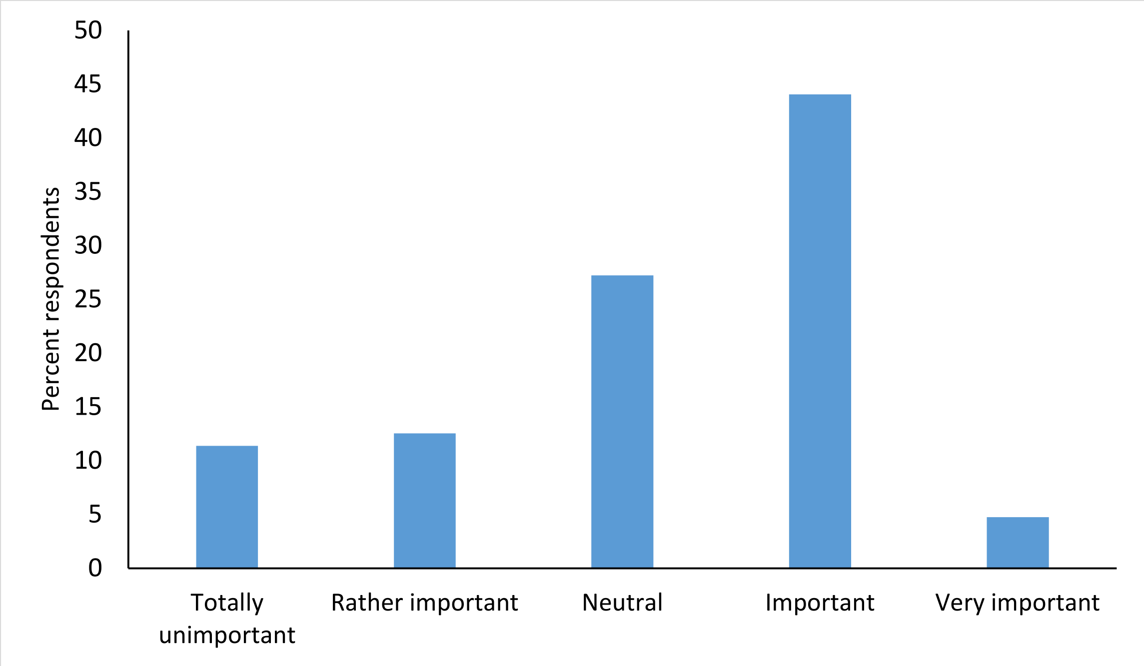

Figure 2.4 *Responses of interviewed people from Ladakh, India on how important is the presence of the wolf in their landscape (n= 1784).*

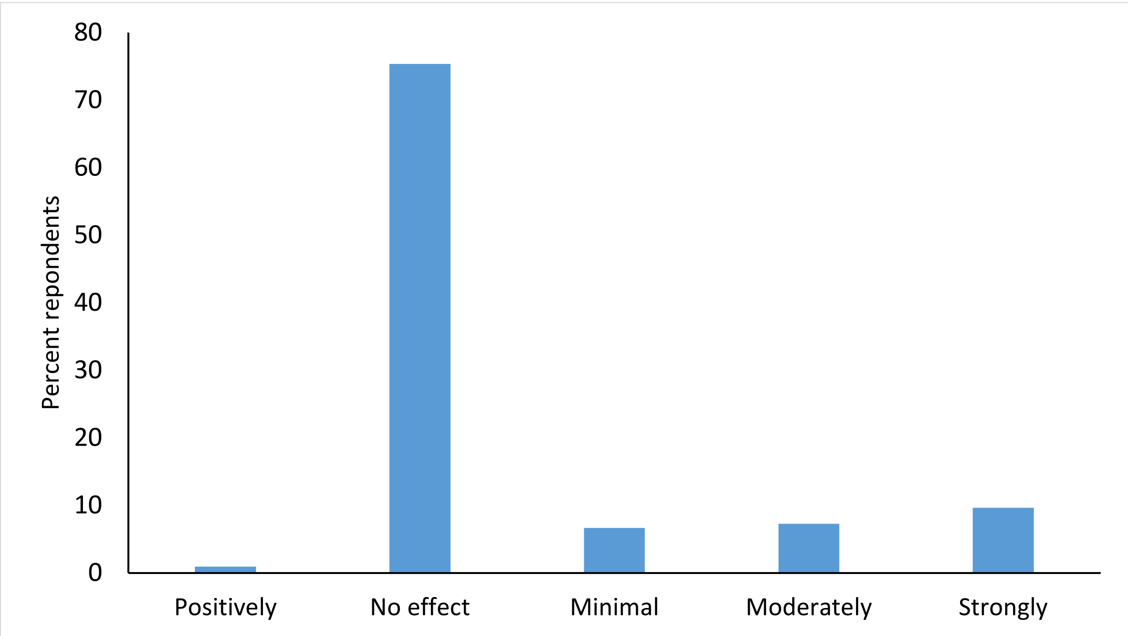

Figure 2.5 *Responses of interviewed people from Ladakh India on how negatively the wolf affects their livelihood (n=1785).*

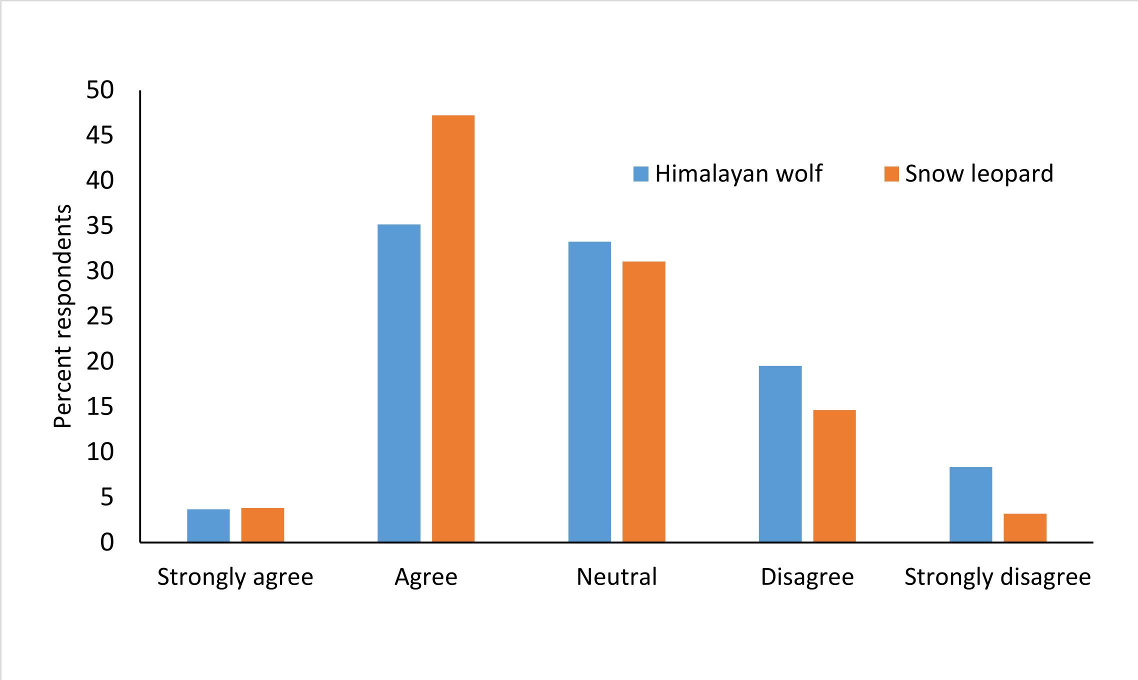

Figure 2.6 *Difference in public responses on the co-existence with the Himalayan wolf and snow leopard in Ladakh, India (n=1786).*

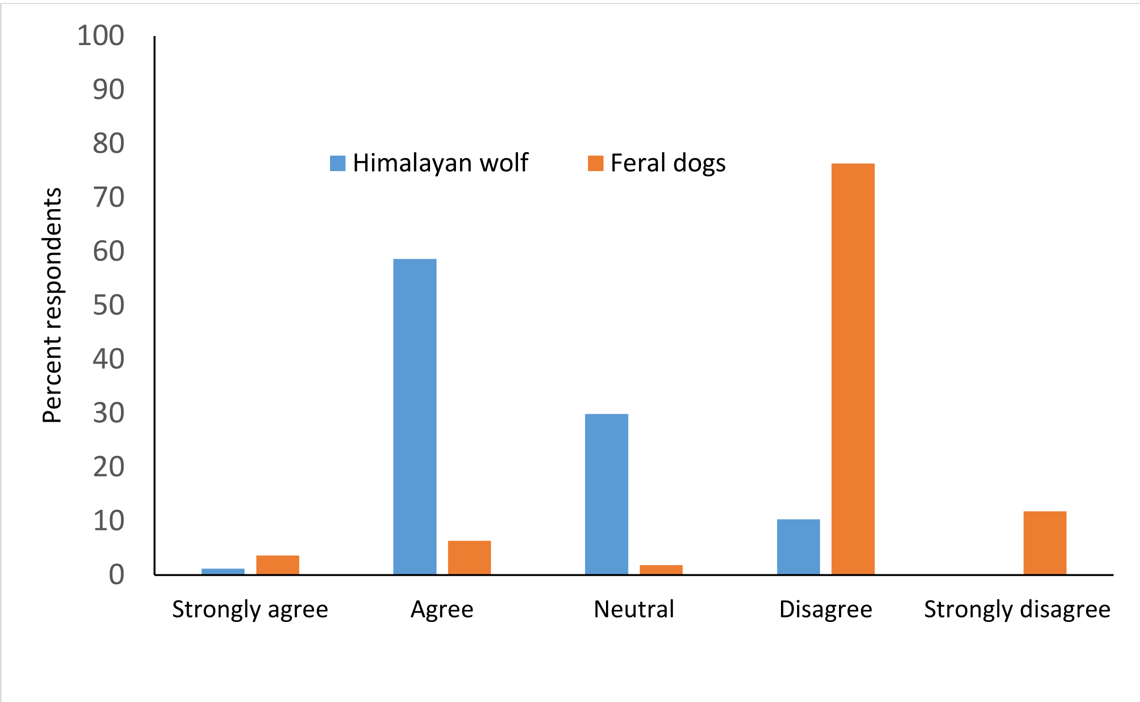

Figure 2.7 *Difference in public responses on the co-existence with the Himalayan wolf and feral dogs in Changthang WLS, Ladakh, India (n=110).*

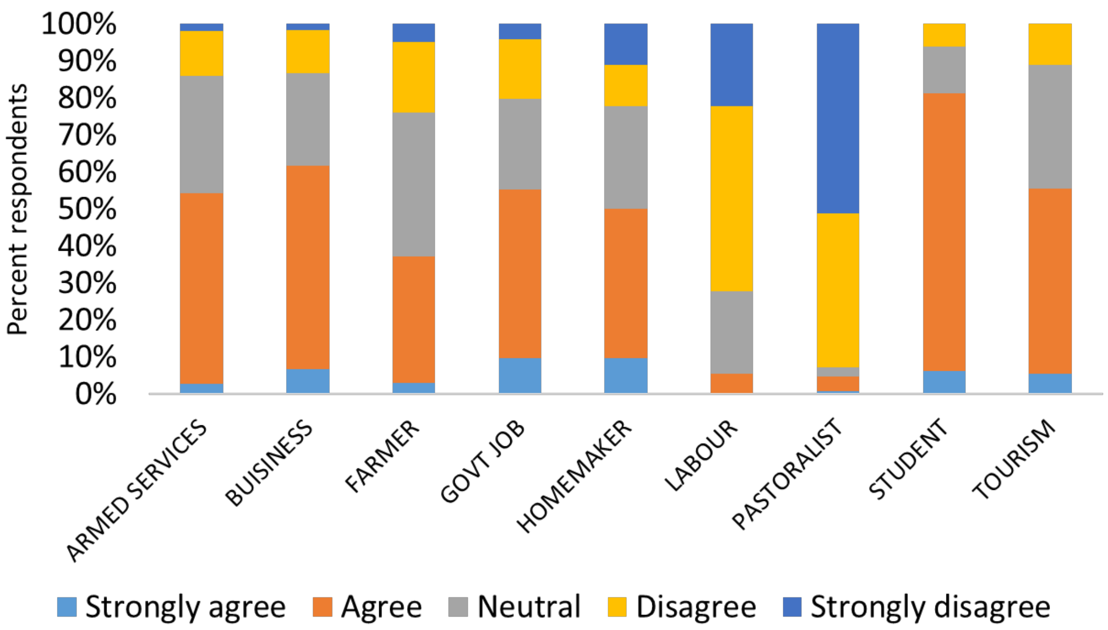

Figure 2.8 *Variation in public attitude (agreement on co-existence) towards the Himalayan wolf among various occupation classes in Ladakh, India (n= 1786).*

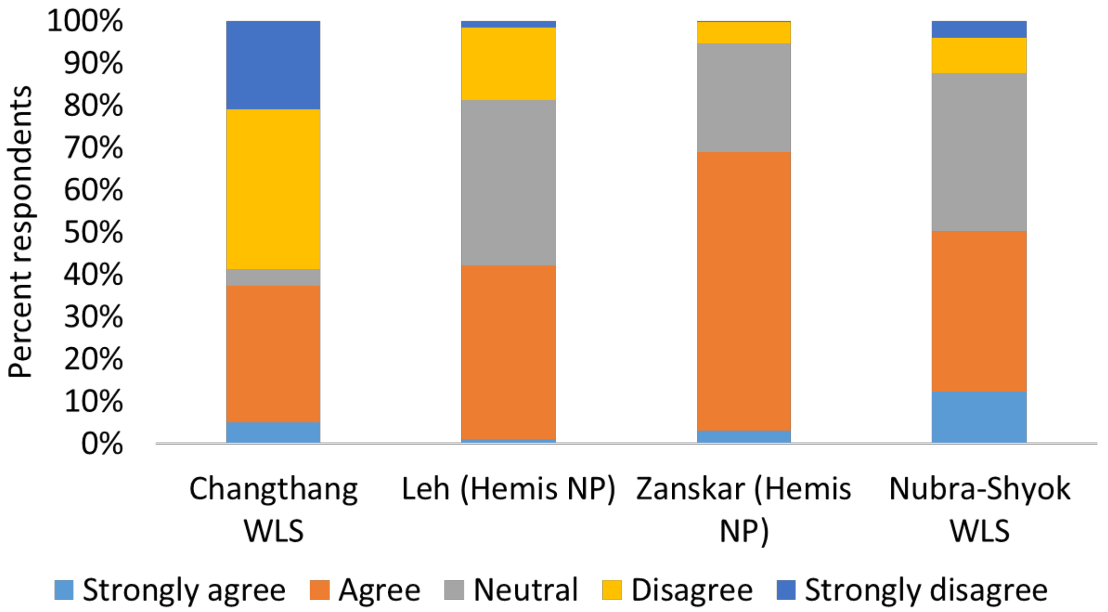

Figure 2.9 *Variation in public attitude (agreement on co-existence) towards the Himalayan wolf in different protected areas of Ladakh, India (n= 1786).*

responses (Figure 2.8). Strong disagreement for the co-existence with the wolves came from Changthang WLS while the respondents from Zanskar region in Kargil responded positively towards it (Figure 2.9).

2.3.4 Factors affecting attitude

The best models explaining the effect of factors on public attitude towards wolf and snow leopard were selected using the AIC criterion (Table 2.2). In both cases, the presence of protected area, religion, gender, occupation and livestock depredation were the influential factors. Influence of the factors is illustrated in Table 2.3 and Figure 2.10. Probability of positive attitude score increased inside the protected areas compared to outside. Men were more positive towards co-existence compared to women, and Muslims responded more positively compared to Buddhists. Reporting of livestock depredation cases negatively reflected in the attitude of the people. Pastoralism was the most influential factor resulting in negative attitudes towards both the carnivore species.

Table 2.2 *AIC based selection of top three models for ordinal regression of the public attitude towards wolf and snow leopard.*

Model name	Model AIC value	
	Himalayan wolf	Snow leopard
~ PA+religion+gender+occupation+livestock depredation	**3840.79**	**3805.863**
~ PA+religion+gender+occupation	3842.211	3810.441
~PA+religion+gender+occupation+livestock depredation+age+latitude+longitude	3846.401	3810.393

Table 2.3 *GLMM of ordinal attitude response toward (a) Himalayan wolf and (b) snow leopard in Ladakh, India.*

a) Himalayan wolf				
Model coefficients				
	Estimate	Std. Error	Z value	Pr(>|z|)
PA_presence	-0.4467	0.1019	-4.385	1.16E-05
Religion_muslim	-0.9673	0.1647	-5.874	4.25E-09
Gender_male	-0.7696	0.0961	-8.006	1.18E-15
Occupation_non-pastoralist	-0.2357	0.1245	-1.893	0.0584
Occupation_pastoralist	2.306	0.2578	8.944	<2.00E-16
Depredation_wolf	0.2669	0.1439	1.855	0.0637
b) Snow leopard				
Model coefficients				
	Estimate	Std. Error	Z value	Pr(>|z|)
PA_presence	-0.4736	0.1019	-4.65	3.32E-06
Religion_muslim	-1.0385	0.1621	-6.405	1.50E-10
Gender_male	-0.5938	0.0965	-6.155	7.49E-10
Occupation_non-pastoralist	0.1624	0.122	1.331	0.18305
Occupation_pastoralist	2.191	0.2582	8.486	<2.00E-16
Depredation_snow_leopard	0.5618	0.2175	2.583	0.00979

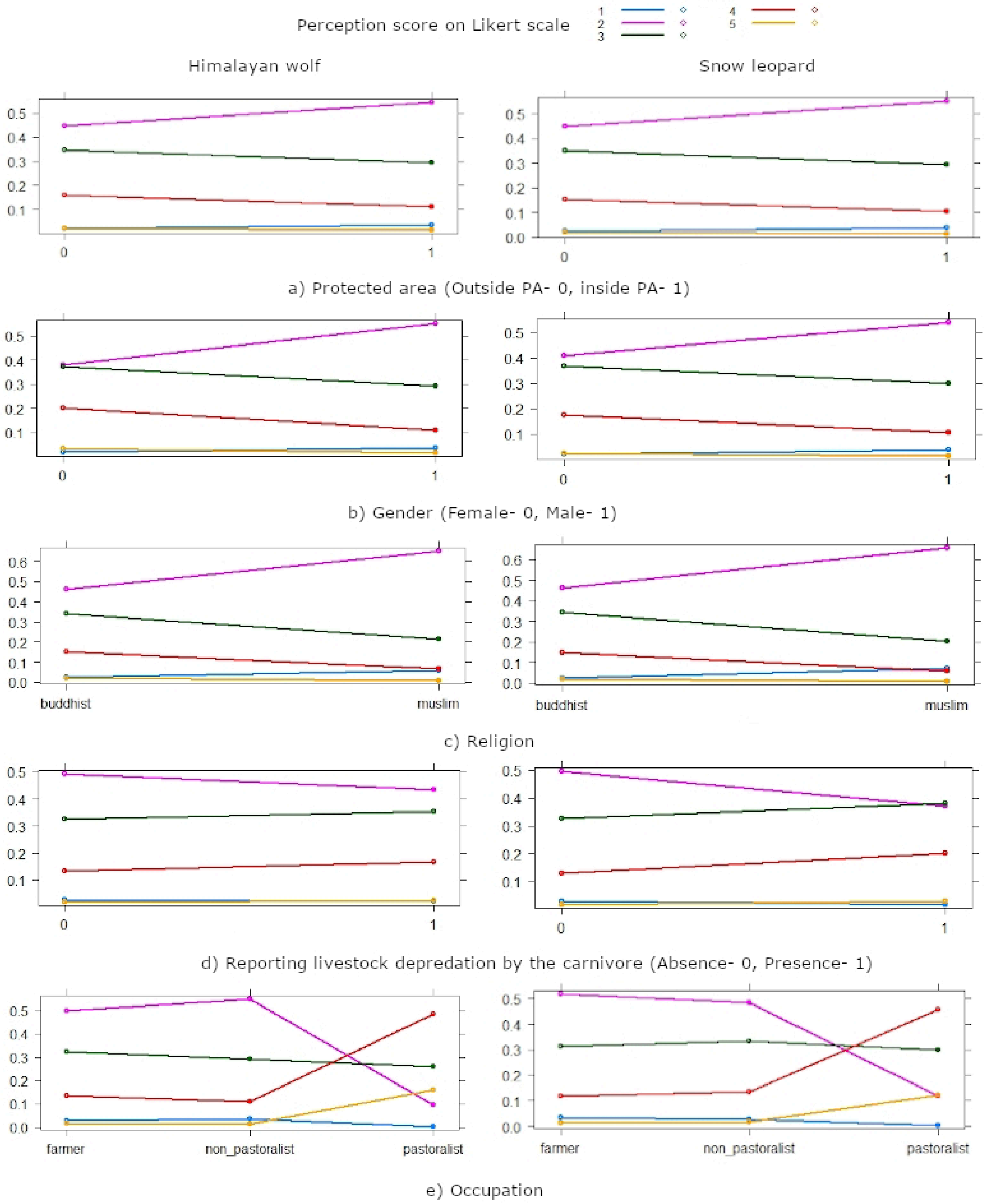

***Figure 2.10** Effect plots illustrating the influence of predictors on attitudes toward co-existence with the wolves and snow leopards. Likert scale: 1- Strongly agree, 2- Agree, 3- Neutral, 4- Disagree, 5- Strongly disagree.*

2.4 Discussion

Wolf depredations of livestock are a ubiquitous source of conflict in every country where wolves and livestock overlap (Fritts et al. 2003). The snow leopard is also reported to subsist on livestock and come in conflict with the humans (Lyngdoh et al. 2014; Bocci et al. 2017; Suryawanshi et al. 2017). Wolves are known for hunting on livestock, and there are cases of even child-lifting and killing humans from almost every part of their distribution range (Jhala and Sharma 1997; Rajpurohit 1999; Linnell et al. 2002). Livestock makes a substantial part of their diet worldwide. A high level of livestock-predation is reported from the areas where availability of wild prey is low, such as Portugal, central Italy and Mongolia (Meriggi and Lovari 1996; Ciucci and Boitani 1998; Vos 2000; Zhang et al. 2009; Imbert et al. 2016). Livestock predation by Indian wolf is reported to be high to medium according to the abundances of wild prey, e.g., wolf predated less on livestock due to an abundance of Blackbuck in Gujrat (Shahi 1982; Jhala 1993; Kumar and Rahmani 2000; Jethva and Jhala 2004). In a study in the Trans-Himalayas of India, wolf and snow leopard accounted for an average of 18% of livestock depredation, the equivalent of about half the annual income of the herder (Mishra 1997). Snow leopard in Nepal was responsible for 63% of all livestock mortality (Jackson et al. 1996). Wolf was the top predator of livestock in Ladakh region with a share of about 60% predation cases (Namgail et al. 2007; Habib et al. 2013). However, the exaggeration of the actual conflict is possible in public-survey based studies (Lindsey et al. 2005; Mijiddorj 2011). Grazing practices also determine the level of conflict, and the chances of predation by carnivores increase in the case of unsupervised grazing, where livestock is left unattended (Jackson et al. 1996).

Depredation pattern in this study revealed the uprising of a third top-predator of livestock in the Trans-Himalayan landscape. Feral dogs have become a menace in several parts of the landscape, killing livestock and harassing wildlife (Home et al. 2017; Mahar 2017). While wolf was the top predator of livestock in previous studies from Ladakh (Namgail et al. 2007; Habib et al. 2013) accounting for about 60% cases, in this study their contribution was only 34.07%. Feral dogs, which accounted for only 18.84% cases during 2011 survey (Habib et al. 2013), have replaced the wolf by contributing 44.70% cases in the present study. This rings an alarm for conservation of local wildlife and changing ecological dynamics.

A negative public attitude towards the wolves and retaliatory killing are reported from the Trans-Himalayan landscape in India. Traditional hunting pits still exist, and occasional illegal killing cases were recorded during the field work of this study. It was found in this study that public attitude towards the co-existence with the wolves was closely linked with the presence of livestock attack. People largely disagreed with living along the wolves in the villages of Changthang WLS, while the people in Nubra-Shyok WLS generally preferred the presence of wolves (Figure 2.9). A considerable number of respondents (12.35% of 243) expressed a strong agreement to the presence of wolves in Zanskar valley, which falls on the south-western border of the Hemis National Park in Kargil district. Zanskar is geographically isolated to other places in Leh district. Such pattern of the perception becomes obvious when we ponder at the distribution of livestock depredation cases. Most of the wolf attacks on the livestock (n= 70) have been reported from Changthang WLS while Nubra-Shyok WLS has the least number of wolf attacks (n= 32) (Figure 2.3).

Positive attitude towards wolves and snow leopard close to Hemis National Park, Leh valley and Nubra-Shyok WLS could also be caused by historical reasons. These areas have received development and modernization faster than Changthang region. The livelihood practices in these areas have changed from livestock grazing to other options such as government and other salaried jobs (Chandola 2012). Further, the monetary benefits to the people and facility development due to the boom in tourism industry in past one and half decades have been largely concentrated around Leh and Nubra (Dada and Ahsan-ul-Haq 2018). On the other hand, nomadic pastoralism and livestock-based livelihood continue to dominate the narrative in Changthang. Hence, the cases of livestock predation by the wolf, and stronger negative perception of the people towards wolves have more occurrence in the villages of Changthang WLS. It is a common understanding that the pastoral communities in south Asia and QTP China have positive attitude towards wildlife by virtue of adherence to the basic tenets of Buddhism that include love, respect, and compassion for all life forms (Karmapa and Dorje 2011). Contrariwise, in this study Muslims showed more positive attitude towards wolf and snow leopard. It is to be noted that Muslim communities in Ladakh (mostly present in the western Ladakh) are settled villagers and comparatively better educated than the tribal Buddhists of Changthang WLS.

Compensation schemes have been lopsided in the favour of snow leopards, which might affect the reporting and attitude of the people. Kusi et al. (2019) have reported a similar pattern for public attitude towards the wolves and snow leopard in Humla, Nepal, where the presence of compensation scheme positively affected their responses towards the species. Although the overall pattern of public attitude towards wolves and snow leopard did not vary much, reporting of the cases to the

Department of Wildlife Protection shows a clear variation in the responses (Figure 2.2). There are two possible reasons for such patterns- 1) compensation for wolf attacks is not promoted on a par with that of snow leopard, and 2) there is practical difficulty in reporting wolf cases due to loss of evidence. Wolves usually hunt in packs and do not leave the killed livestock behind. Lack of knowledge about the importance of large carnivores can result in negative attitudes towards them (Mijiddorj 2011). However, this doesn't apply to the data presented in this study. People are fairly aware of the importance of the wolf and other carnivores. The negative attitude arises mostly due to direct impact on the livelihood, which is region and occupation specific. Ratio of carnivore-caused livestock loss to livestock holding could also influence the attitude of the respondents where livestock holding sizes vary considerably (Mijiddorj 2011). Computation of livestock loss in monetary terms is an important information for compensation schemes and conservation measures (Jethva and Jhala 2004). Exclusion of the data on livestock holding of the respondents, livestock loss in monetary terms and contribution of carnivore-caused depredation in overall mortality of the livestock could be a limitation of the current study. The data were obtained during the field surveys and could be further analysed to inform on such patterns.

Snow leopard is a flagship species for conservation and decades long awareness programs, development of snow leopard focused tourism and existing religious symbolism for snow leopard has garnered positive public attitude towards it. A common narrative that wolves and humans mostly have a negative interaction is widespread throughout the globe. It was expected that a similar pattern would exist in any prominent wolf landscape, including the Trans-Himalayas of India. The data and analyses in this chapter exhibit that the narrative in Ladakh is neither straightforward negative towards wolves, nor one that would require huge efforts to change. Pastoralists of the eastern Changthang face most of the wolf-caused damage of livestock. However, the feral dogs are on the top of their worries compared to the wolves. Herders in Changthang form a key community where conservation inputs could yield the most efficient results. Compensation schemes, via either direct subsidy or insurance policies, are the most effective mechanism in changing public attitudes (Ogra and Badola 2008). Providing compensation for the wolf attacks similar to snow leopard and promoting the awareness about the scheme among livestock holders is crucial. In the latest efforts by local conservation organizations, religious outfits and governmental bodies have come forward together and campaigned to change the public perception towards wolves. Riding the non-violence sentiment of the people and highlighting evolutionary importance of the Himalayan wolves in Ladakh, several old wolf hunting pits have been converted to wolf-stupas promoting their conservation (Ghoshal et al. 2018). Wildlife tourism in Ladakh has been mostly built around snow leopard so far, which has helped in alleviating negative public attitudes towards it. Expanding the scope of tourism to wolves and other wildlife of the landscape would not only gain public support for wolves but also generate additional income for people. While pastoral practices are on a decline (Dollfus 2012), increasing school education could reduce harsh viewpoint of the people. Awareness and application of better methods of livestock guarding (such as fenced coral pans) would also bring down the number of conflict cases. Persistence of the wolves in the Himalayas could be ensured via a combination of such conservation efforts.

Chapter 3

DIVERSITY, DENSITY AND DISTRIBUTION OF MAJOR UNGULATE SPECIES IN THE TRANS-HIMALAYAN LANDSCAPE OF INDIA

3.1 Introduction

Ungulate species are a major component of terrestrial ecosystems, and their availability is a key determinant of large carnivore density (Karanth et al. 2004). Monitoring the populations of wild animals is one of the main tasks in wildlife management practices. A well-structured census for monitoring wildlife can inform the status of wildlife populations and identify the priority areas for management interventions (Shrotriya et al. 2014). However, wild ungulate population estimation in the Himalayan region and other mountainous areas has remained a challenge so far. The reason behind such failures is that most of the area is difficult to access, and wildlife populations in mountain regions occur at low densities (Barnes 2002; Singh and Milner-Gulland 2011). Even with the statistical advances of the techniques, the logistical problem of surveying remote areas with constrained resources has not been well-addressed (Ransom et al. 2012). Several techniques developed for monitoring carnivore and ungulate populations (Eberhardt 1978; Burnham et al. 1980; Buckland et al. 1993, 2004; Laing et al. 2003; Sulkawa and Liukko 2007) have performed differently under different field conditions (Suryawanshi et al. 2012). In the Trans-Himalayan region of India, Suryawanshi et al. (2012) experimented with a double-observer transect walk method. The method provides rigorous estimates; however, it is unsuitable for large landscapes due to a high requirement of human, time and money resources. Ransom et al. (2012) successfully applied a simultaneous point count method to estimate ungulate populations in a low-density landscape of Mongolia. The method of Ransom et al. (2012) had novelty in field application, as the authors engaged a large number of trained volunteers to complete the survey over a short time period.

Ladakh is unique in its ungulate diversity as a few of the species are present only in this landscape in India. There are a total of eight ungulate species found in Ladakh landscape, *viz.*, blue sheep *Pseudois nayaur*, Asiatic Ibex *Capra ibex sibirica*, Ladakh urial *Ovis vignei vignei*, Tibetan argali *Ovis ammon hodgsonii*, kiang *Equus kiang*, Tibetan gazelle *Procapra picticaudata*, Tibetan antelope *Pantholops hodgsonii* and wild yak *Bos mutus* (Fox et al. 1991; Chundawat and Qureshi 1999). The landscape features of Ladakh resemble the Mongolian landscape. Therefore, this study approached the wild ungulate population estimation adapting Ransom et al. (2012). Objectives of this study were to estimate the distribution and densities of the major ungulate species of Ladakh, India.

3.2 Methods

3.2.1 Field Methods

Due to the logistic and environmental constraints, the field surveys were split into three rounds. The first round of the survey was conducted in Changthang wildlife sanctuary (WLS) in September 2014. The initial survey was a learning experience in adapting the field method. Near-Threatened Tibetan gazelle was missed entirely in the first round of the survey due to the unsuitability of large survey-grids for locally occurring rare species. An exclusive survey to estimate the population of Tibetan gazelle was carried out in February 2015 in the second round. In the third round, Nubra-Shyok WLS was surveyed the following year in February-March 2016. Although Ladakh urial is mainly found along the Indus river in the Kargil region, any survey in the Kargil area could not be carried out due to lack of logistic support. Small populations of Tibetan antelope and wild yak are known to temporarily visit Daulat Beg Oldie and Chang Chen Mo regions of Ladakh. Field excursions into the range of Tibetan antelope and wild yak during the peak season of their presence were disrupted due to security permissions and lack of logistic support.

Field sampling protocol followed in this study was developed based on simultaneous point count method as described by Kissling and Garton (2006) and Ransom et al. (2012). The protocol, adapted for habitat and landscape of Ladakh, was published separately as a report (Shrotriya et al. 2014). In the first survey, a total area of about 23,000 km^2 was surveyed in Changthang WLS. In the third survey, a total area of about 12,000 km^2 was surveyed in Nubra-Shyok WLS. The second survey for Tibetan gazelle was conducted in Kalak-Tartar valley within Changthang WLS, which spans only about 50 km^2. The area in large-scale surveys was gridded into 15x15 km sq grids, and alternate grids were selected to cover the entire landscape (Figure 3.1). Kalak-Tartar valley was gridded into 2x2 km sq grids for the second round of the survey. Four random points were generated in each grid cell, out of which only one was selected based on accessibility and logistics. A total of 33 observation points in Changthang WLS and 17 observation points in Nubra-Shyok WLS were surveyed in large scale surveys. In Kalak-Tartar, there were 13 observation points. Field staff from the Department of Wildlife Protection, Leh and volunteers were trained in identification of the ungulate species and carrying out the survey protocol prior to the survey. Twelve teams of two observers per observation point were deployed in Changthang WLS. Similarly, eight teams of two observers were deployed in both the surveys in Kalak-Tartar and Nubra-Shyok WLS. Each team surveyed two to three nearby observation points. The survey teams were transported by vehicles to relocate them at the next observation points.

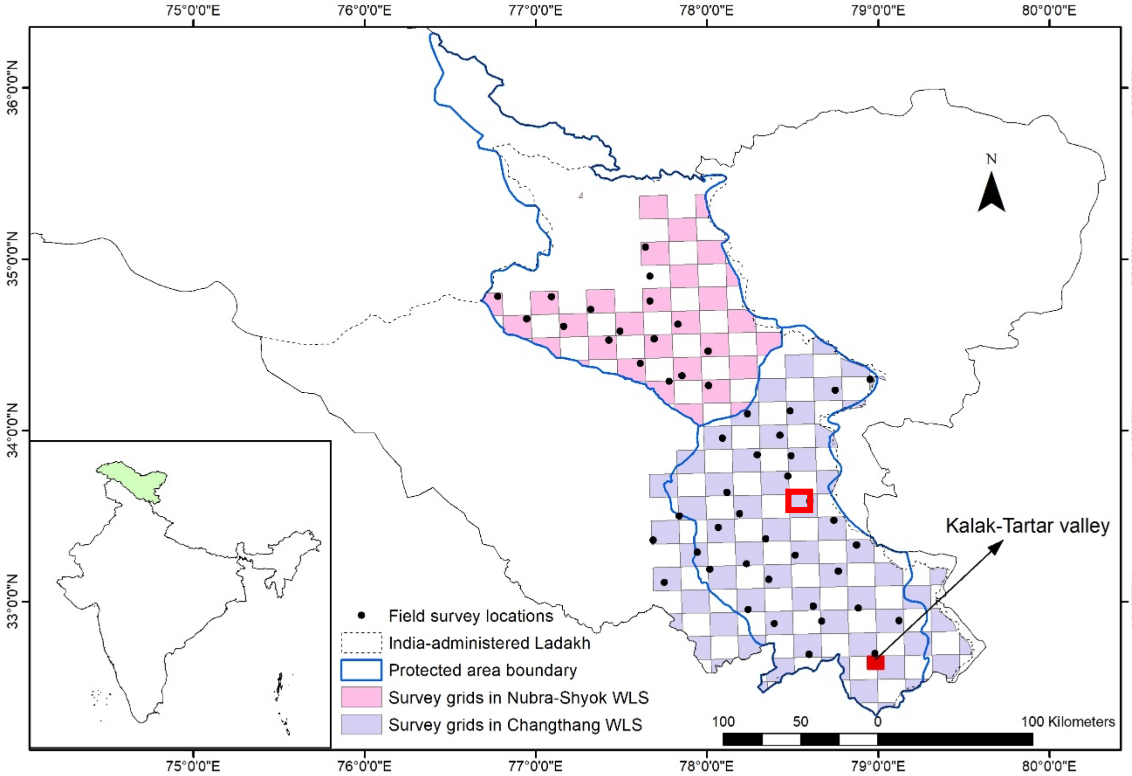

Figure 3.*1 Sampling locations and distribution of survey effort during simultaneous point-count surveys to estimate ungulate population densities in high-altitude Changthang and Nubra-Shyok wildlife sanctuaries (WLS), Ladakh, India.*

Since the animals in this landscape can be observed from up to 5 kilometer range, the traditional method of using rangefinders to estimate the distances of animals from the observers required adjustments. Regular rangefinders can estimate the distances up to 400 meter and long-range equipment are pricy. Ransom (2011) calibrated binoculars to estimate the distances for their study in Mongolia. We instead used Google Earth imageries and habitat features to estimate the distances. The maps of the landscape with predefined distance classes were prepared for each survey (example, Figure 3.2). Each team was provided with a GPS, binoculars, compass and manual maps of the area to find the distance to the animal from the point in already defined distance categories (0-200 m, 200-500 m, 500-1000 m, 1000-1500 m, 1500-2000 m, 2000-3000 m and 3000-5000 m). Each observer at each point was instructed to collect data independently, with the first observer conducting a complete 360° survey and then passing the equipment to the second observer who subsequently conducted another complete 360° survey. Observers were instructed not to share datasheets or communicate between observations. Surveys in Changthang WLS were conducted simultaneously at 18:00 hr and next day again at 06:00, 08:00, 10:00, 12:00, 14:00 and 16:00 hr for a total of seven complete surveys at each point. Out of possible 231 surveys (33 x 7), 218 surveys could be conducted. The time interval for the second and third surveys was reduced to one hr. A total of 13 repeated surveys were conducted at Kalak-Tartar from morning 06:00 hr to evening 18:00 hr. During the survey at Nubra-Shyok WLS, only eight repeats per points could be conducted from 08:00 hr to 15:00 hr due to weather and logistic conditions.

3.2.2 The distribution range of ungulate species

A total of 425 kiang locations were generated during the survey in Changthang WLS. Distribution of kiang within the study area was modelled by a maximum entropy model using software MaxEnt (ver. 3.3.3k) (Elith et al. 2006; Phillips et al. 2006). Since bio-climatic variables did not perform well in the initial models, five uncorrelated variables, *viz.*, ruggedness, slope, elevation, distance to water (USGS 2004) and normalised difference vegetation index (NDVI), were used

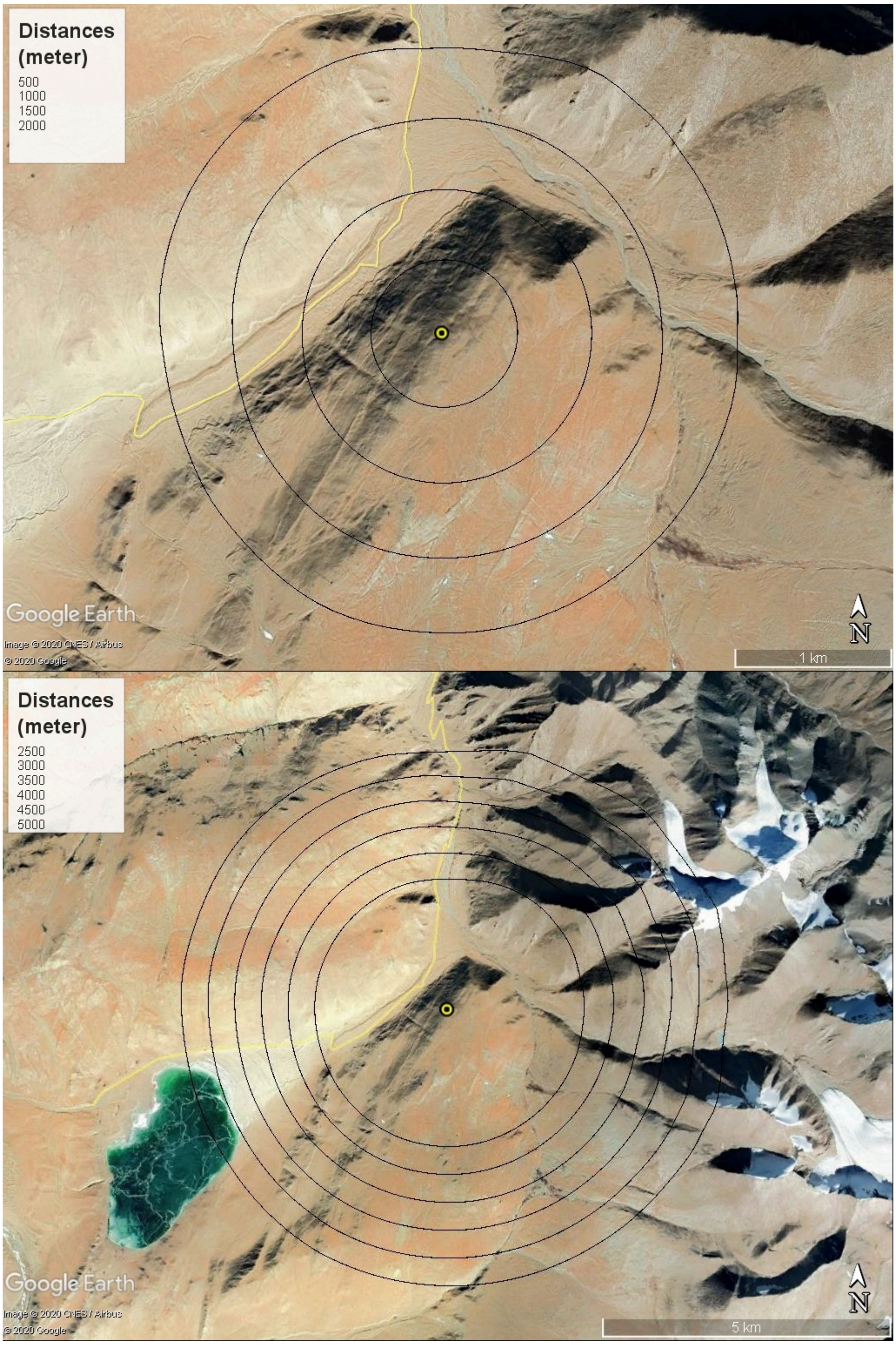

Figure 3.2 *Two pre-defined distance-class maps were provided to the observers to measure the distance of sighted animals from the observation points based on the topographical features. The example map is centered at 33° 7' 51.06"N and 78° 21' 34.58"E (an observation points in Changthang WLS).*

as predictors in the final model (Knight and Lunetta 2006). A total of 425 kiang locations were generated during this survey. Out of which, 75% of the locations were used to train the model, and the remaining 25% locations were used to test the accuracy level. Jackknife test was used to evaluate the importance of each predictor in MaxEnt model. Contribution and permutation importance of each predictor was also calculated (Phillips et al. 2006).

The number of sightings for other ungulate species was comparatively low and clumped. Therefore, Boolean logic range models were developed for Ladakh urial, Asiatic ibex, blue sheep and Tibetan argali based on Chundawat and Qureshi (1999). Landuse classes such as build-up areas, water-bodies and permanent snow-cover were masked out at the initial step. Boolean logic models were developed using the existing literature on ungulate distribution in Ladakh region and known areas of a species absence were masked out (Fox et al. 1991; Chundawat and Qureshi 1999; Namgail 2001). Blue sheep habitat was masked in the elevation range of 4000-5500 m and slope range of 15-50 degrees. Tibetan argali habitat was masked in the elevation range of 4000-5500 m and slope range of 10-30 degrees. Asiatic ibex habitat was masked for the elevation of >4000 m and slope of >25 degrees. Ladakh urial habitat was masked in the elevation range of 3000-5000 m and slope range of 5-30 degrees.

3.2.3 Statistical analyses for density estimation

All the data were analysed in Program Distance version 7.3 (Thomas et al. 2010) using the conventional distance sampling method. Data for all the repeats were pooled for a single survey. There was no systematic variation in detection function by the time of day. It was found at several observer points that both the observers systematically separated sighting area within the visible range.

Therefore, any observer bias was not calculated and data for each of the two observers were pooled together in such cases. A global detection function was modelled for blue sheep, Asiatic ibex and Ladakh urial in Nubra-Shyok WLS and then post-stratified, as the number of sightings was low for these similar body size species. Survey efforts were adjusted for visible areas in the survey at Nubra-Shyok WLS and for blue sheep in Changthang WLS, calculated by viewshed analysis of the Spatial Analyst extension in ArcGIS 9.3 (Environmental Systems Research Institute, Redlands, California, USA). Visible area adjustment was not incorporated for kiang, Tibetan argali and Tibetan gazelle; because it affected available survey area in the distant categories and the obstructions were primarily steep mountainous terrain where kiang and argali were unlikely to be present (Buckland et al. 1993; Ransom et al. 2012). Data were right truncated at 5000 m, and distance bins close to observation points were merged to 0- 1000 m to remove the effect of systematic displacement of animals. A left truncation was not performed due to animals mostly shifting to the second bin only and inflating numbers there. The best model was selected using the lowest AIC and a larger p-value of the goodness of fit (GOF) test criteria (Table 3.1). Survey points falling outside of the distribution range of a species were excluded from the species-specific analysis.

3.3 Results

Despite the open landscape at many of the observation points, the total visible area available for observation was only 15.25%. The remaining area within observation radius, assumed to be 7 km with the aid of binoculars, was obstructed by mountains, valleys and gorges. Most commonly sighted species in Changthang WLS was kiang with a total of 425 groups recorded (Figure 3.3). Maximum group size for kiang was 116. A total of eight groups of blue sheep, six groups of Tibetan argali and two groups each for Tibetan antelope and wild yak were recorded in Changthang WLS. A total of 103 observations of the Tibetan gazelle were made during the second round of the field survey. In Nubra-Shyok WLS, a total of 42 sightings were recorded in the third round of field survey (blue sheep- 12, Asiatic ibex- 22 and Ladakh urial- 8) (Figure 3.4). Analyses were performed for six commonly sighted ungulate species during the study. Information on Tibetan antelope and wild yak was not enough to perform any analyses.

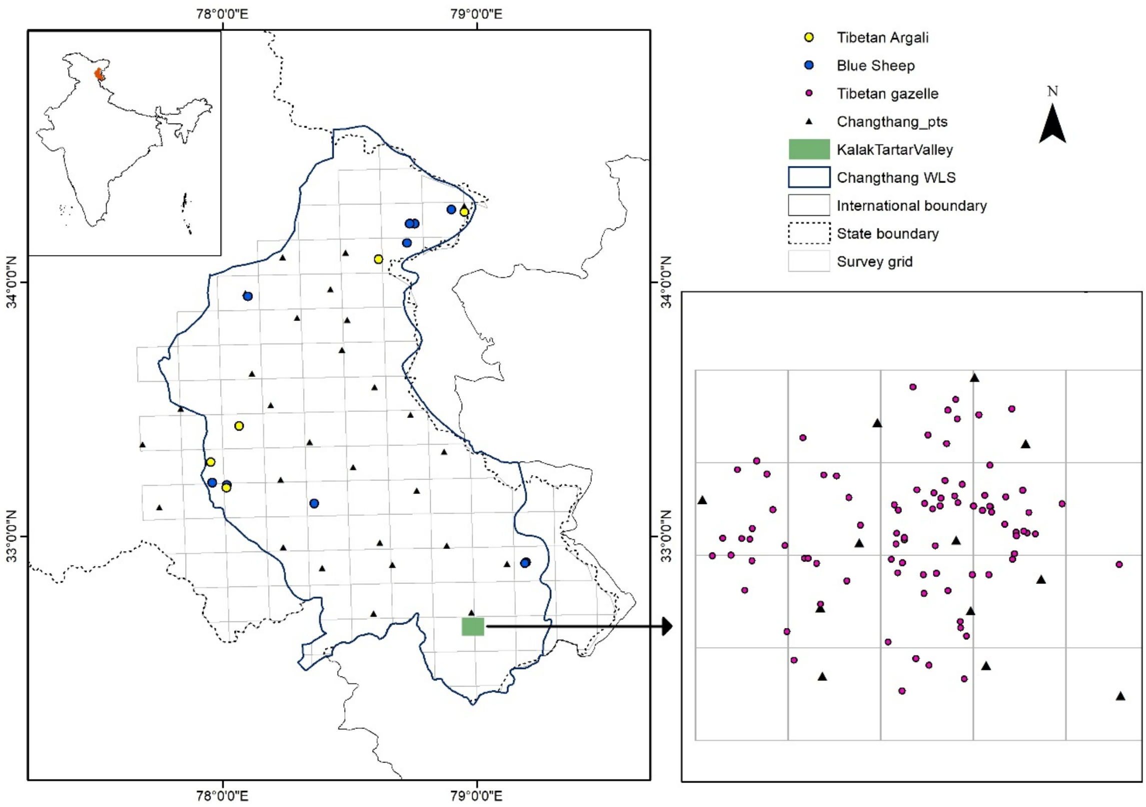

Figure 3.3 *Sighting locations of blue sheep (Pseudois nayaur), Tibetan argali (Ovis ammon hodgsonii) and Tibetan gazelle (Procapra picticaudata) in Changthang WLS. Tibetan gazelle was distributed only within Kalak-Tartar valley.*

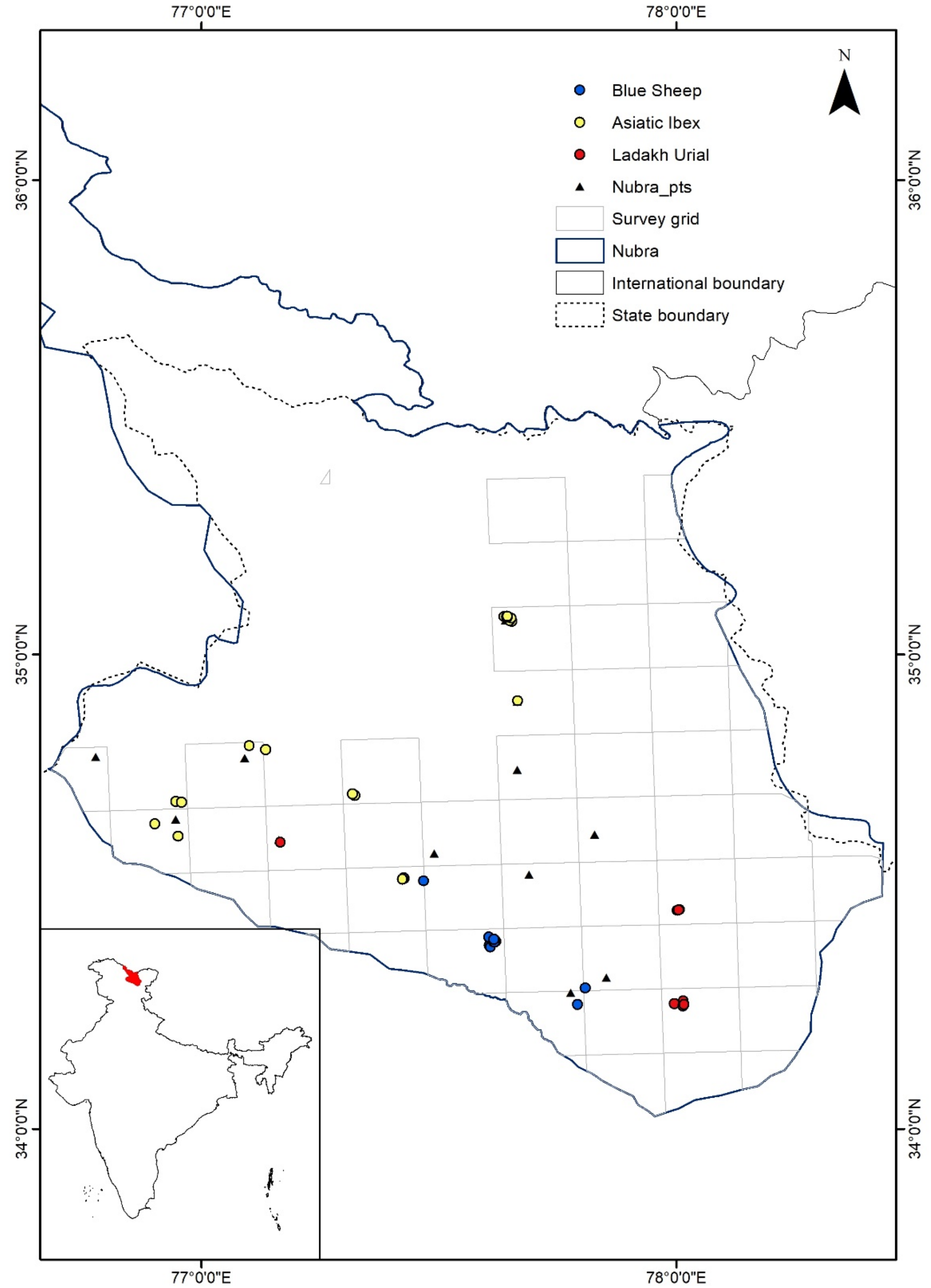

Figure 3.4 *Sighting locations of blue sheep (Pseudois nayaur), Asiatic ibex (Capra ibex sibirica) and Ladakh urial (Ovis vignei vignei) in Nubra-Shyok WLS.*

3.3.1 Kiang *Equus kiang*

Changthang is the only region in Ladakh where kiang is found, and there is a negligible presence of kiang outside the survey area. MaxEnt model used for kiang distribution was reliable as statistical estimation of accuracy shows 91.5% area under the curve (AUC) for sensitivity vs specificity. MaxEnt probability distribution of kiang is presented in Figure 3.5, categorising area into low, medium and high probabilities. Among the five variables used to predict the distribution, slope and elevation were the most important factors with the highest percent contribution (Figure 3.6 & 3.7). NDVI did not contribute to the prediction, possibly due to little variation in NDVI values during September that falls in the most productive season in Ladakh. Distance to water and ruggedness were also of little importance due to low variability of these factors in flat and low lying valleys (Figure 3.8). A 10th percentile logistic threshold identified a total of 5,738 km^2 area as suitable kiang habitat.

Out of 425 sightings of kiang, 394 sightings were within 5000 m limit set for right-truncation. Although close AICs were obtained for the competing models, the adequate fit was found for hazard rate key function with cosine adjustment (Table 3.1, Figure 3.9). Total CV was 42.37 % with the highest contribution from variance in cluster size (ranging from 1 to 116). Mean density calculated by this model was 1.003 ±0.42 per km^2, which translates to the total population of 5,755.21 ±2409.96 individuals in 5,738.28 km^2 area (Table 3.2).

3.3.2 Blue sheep *Pseudois nayaur*

Boolean logic model for blue sheep habitat estimated 57,057 km^2 area (Figure 3.10). Out of which, 9,169 km^2 area falls within Changthang WLS and 8,177 km^2 area falls within Nubra-Shyok WLS. Hazard rate key function without any

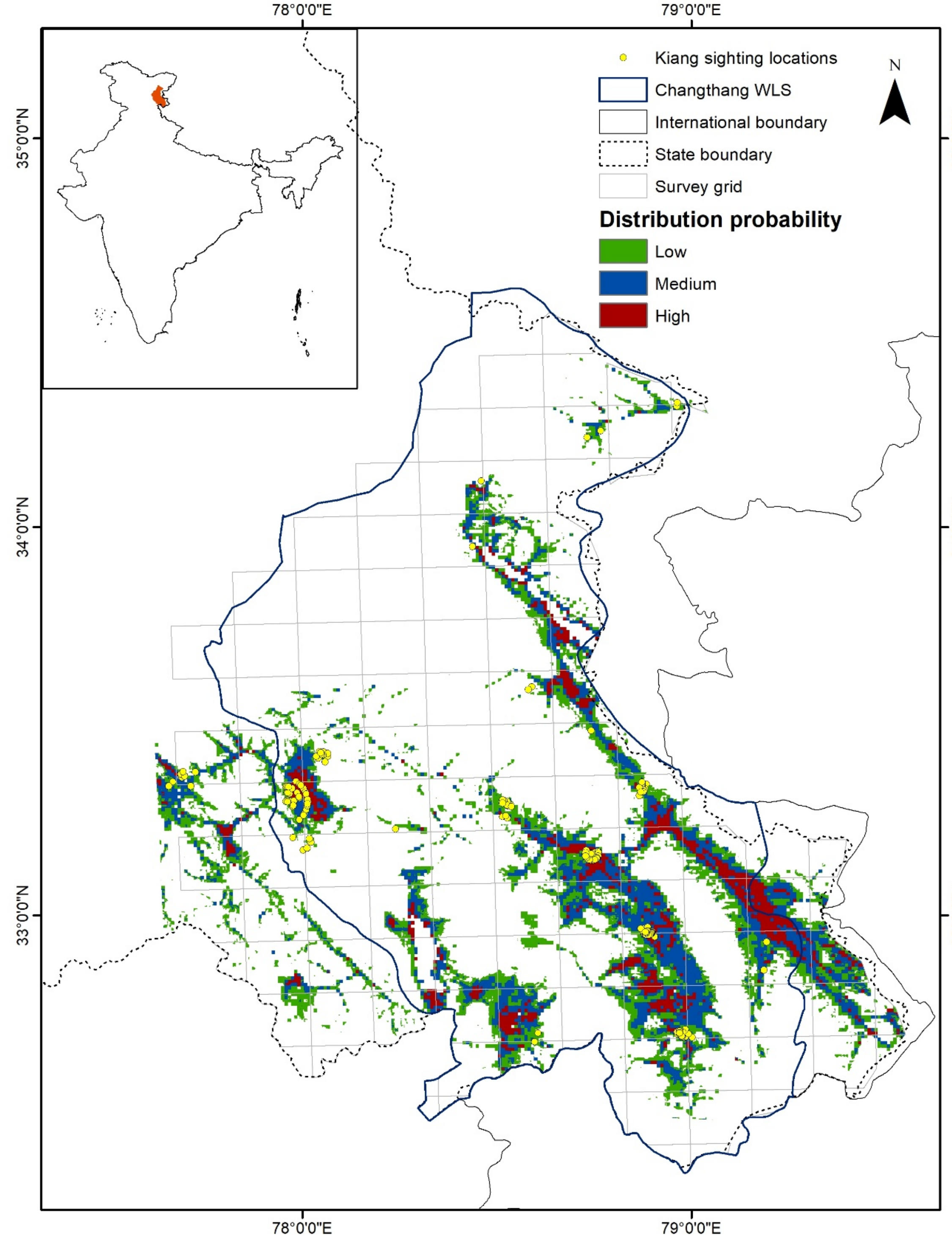

***Figure 3.5** MaxEnt probability distribution of kiang. Distribution was classified into low (<0.3), medium (0.3-0.55) and high (>0.55) probability categories for representational purpose.*

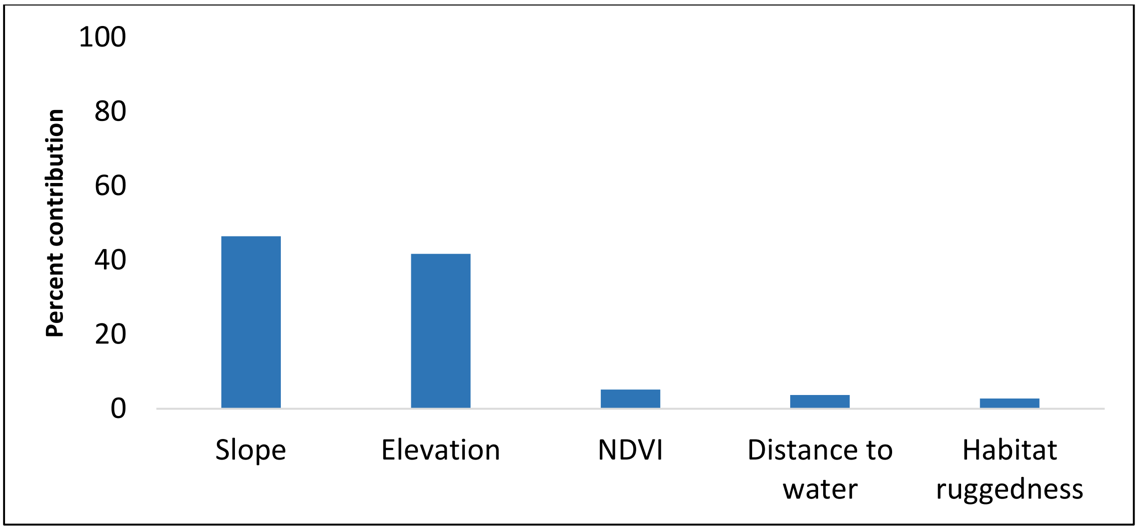

Figure 3.6 *Percent contribution of the variables in MaxEnt distribution of kiang.*

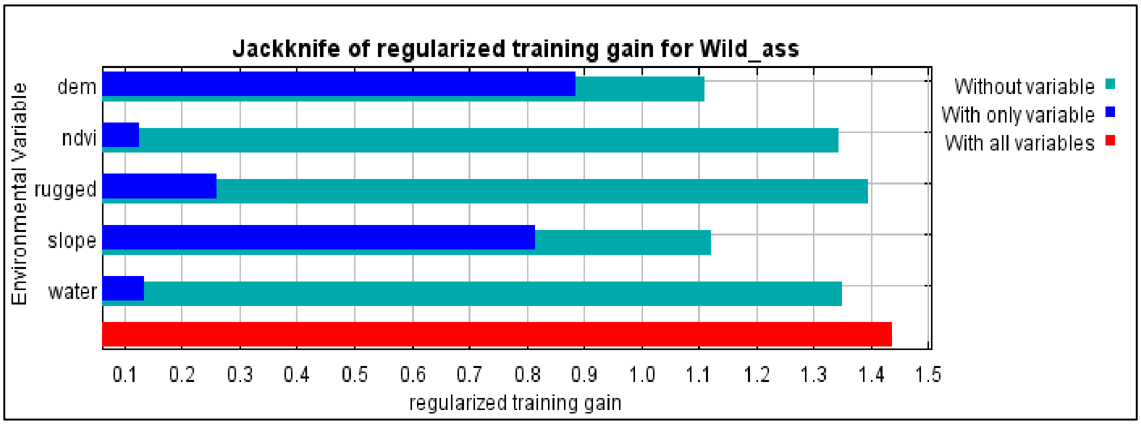

Figure 3.7 *Individual training gain of the variables used in kiang MaxEnt distribution.*

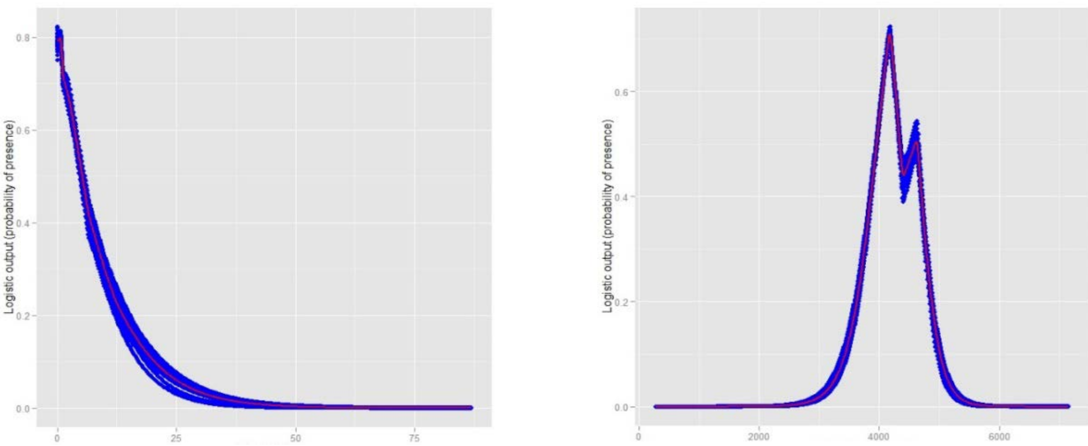

Figure 3.8 *Response curves of the most influential predictor variables for the MaxEnt distribution prediction of kiang- (a) slope, and (b) elevation.*

Table 3.1 *Description of the top models selected for fitting detection function of the ungulate species in Ladakh, India.*

Species	Detection function model	AIC	EDR (m)	CV (%)	GOF p
Kiang	Hazard rate, cosine adjustment	1114.61	1472.48	42.37%	0.56
Blue sheep (Changthang)	Hazard rate, no adjustment	17.71	1619.60	76.94	0.85
Tibetan argali	Hazard rate, no adjustment	16.39	2562.60	149.94	0.57
Tibetan gazelle	Half normal, cosine adjustment	353.59	989.39	37.22	0.77
Blue Sheep, Asiatic Ibex and Ladakh urial (Nubra-Shyok WLS)	Hazard rate, cosine adjustment	137.63	1185.3	58.29	0.26

adjustment was the best fit model for distance data from Changthang WLS, while the global model fit with hazard rate and cosine adjustment was used in Nubra-Shyok WLS (Table 3.1, Figure 3.9). Mean density in Changthang WLS was estimated to be 0.234 ±0.18 animals per km^2., resulting in a population estimate of 2145.49 ±1650.38 individuals (Table 3.2). Mean density in Nubra-Shyok WLS was estimated to be 0.254 ±0.14 animals per km^2, resulting in a population estimate of 2076.94 ±1144.77 individual (Table 3.3).

3.3.3 Tibetan argali *Ovis ammon hodgsonii*

Similar to blue sheep, Boolean logic model following the literature (Chundawat and Qureshi 1999; Namgail 2001) was developed, and a total of 14,605 km^2 area was calculated as suitable habitat (Figure 3.10). Out of this area, 9,567 km^2 falls within the survey area of Changthang WLS, where the field study for density estimation was conducted. Hazard rate key function without any adjustment was the best fit model for distance data (Table 3.1, Figure 3.9). Total density was estimated to be 0.02 ±0.03 animals per km^2, resulting in a population estimate of 191.35 ±287.02 individuals (Table 3.2).

3.3.4 Tibetan gazelle *Procapra picticaudata*

The only population of Tibetan gazelle is found in a small 50 km^2 Kalak-Tartar valley in Changthang WLS (Figure 3.1). No sightings were made beyond 4000 m distance. A systematic displacement of animals close to the observation points was evident as no sightings were made within 500 m distance. However, left-truncation was not applied because the animal displacement happened only towards the second distance bin (Figure 3.9). Based on the lowest AIC value and high chi-p value, an adequate fit was found for half-normal key function with cosine adjustment (Table 3.1, Figure 3.9). Total CV on density estimation was 37.22% with the highest contribution from variance in encounter rate. Mean density calculated by this model was 2.43 ±0.90 per km^2, which translates to the total population of 121.50 ±45.00 individuals (Table 3.2).

3.3.5 Asiatic ibex (*Capra ibex sibirica*)

Habitat of the Asiatic ibex in Ladakh was calculated to be about 59,100 km^2 using Boolean logic model (Figure 3.10). Out of which, 11,416 km^2 falls

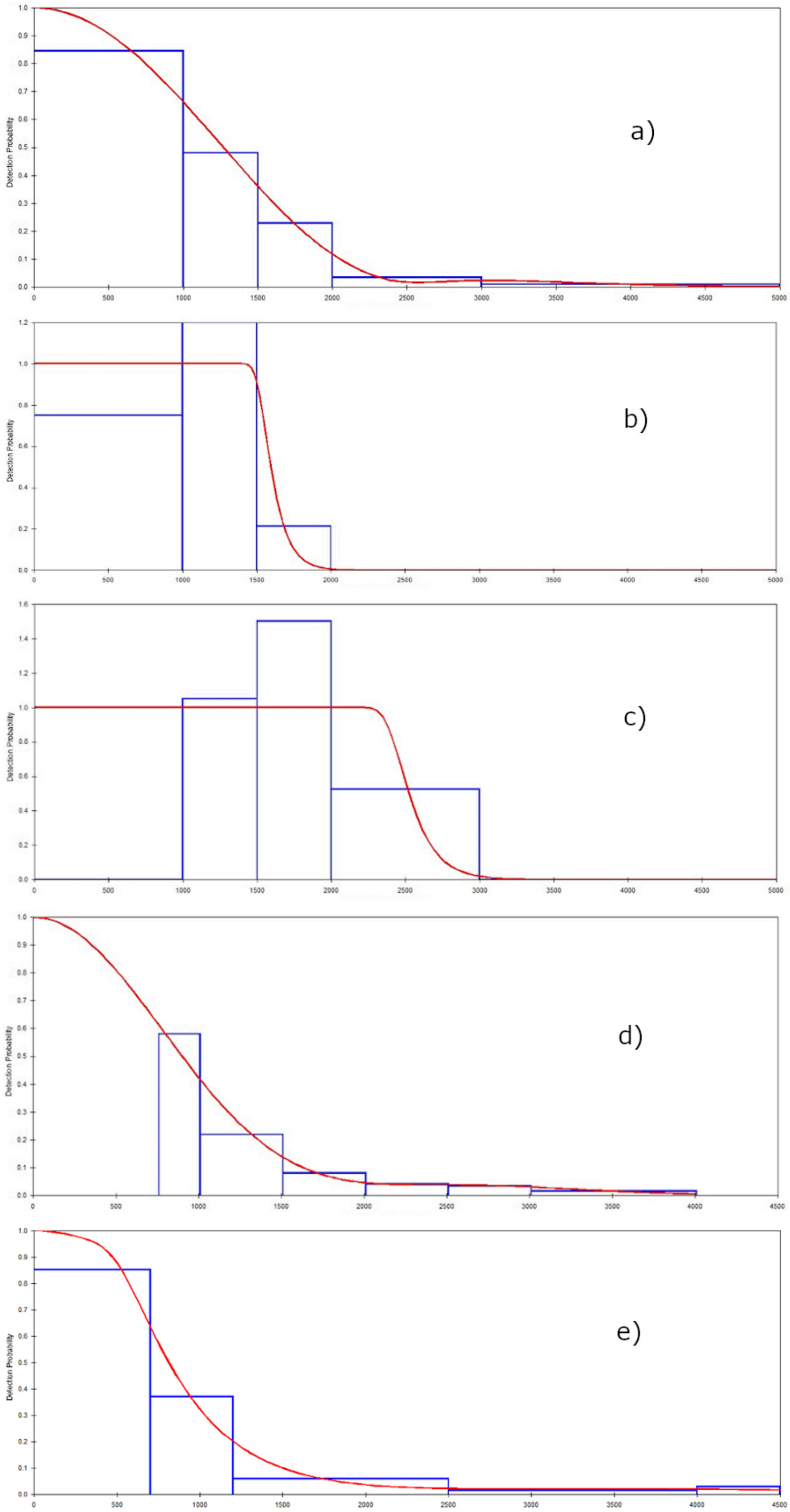

Figure 3.9 *Detection function fit for different ungulate species surveyed by point-count distance method- a) kiang, b) blue sheep in Changthang WLS, c) Tibetan argali, d) Tibetan gazelle, e) global function for blue sheep, Asiatic ibex and Ladakh urial in Nubra-Shyok WLS. Distance classes are pre-defined at 500 m interval.*

within the survey area of Nubra-Shyok WLS, where population density could be estimated from this study. Global model fit with hazard rate and cosine adjustment was used in Nubra-Shyok WLS (Table 3.1, Figure 3.9). The total density of ibex was estimated to be 0.4639 ±0.26 animals per sq. km., resulting in a population estimate of 5285.73 ±2968.23 individuals within Nubra-Shyok WLS (Table 3.3).

3.3.6 Ladakh urial *Ovis vignei vignei*

Ladakh urial range in the Trans-Himalayan landscape of Ladakh is mostly towards the western part, which is Nubra valley and Kargil. A total of 18,280 km^2 area was estimated as urial habitat by Boolean logic model (Figure 3.10). Only 2,708 km^2 area falls within the survey area of Nubra-Shyok WLS, where population density could be estimated. Global model fit with hazard rate and cosine adjustment was used in Nubra-Shyok WLS (Table 3.1, Figure 3.9). The total density of urial was estimated to be 0.168 ±0.09 animals per km^2, resulting in a population estimate of 454.89 ±243.69 individuals within Nubra-Shyok WLS (Table 3.3).

Table 3.2 *Summary statistics and estimates of density and population of blue sheep, Tibetan argali, kiang and Tibetan gazelle in Changthang WLS.*

Parameters	Blue sheep	Tibetan argali	Kiang	Tibetan gazelle
Detection probability	0.105	0.26	0.086	0.10
Density (SE)	0.234 (0.18)	0.02 (0.03)	1.003 (0.42)	2.43 (0.9)
Habitat size (km^2)	9168.76	9567.45	5738.28	50
Population (SE)	2145.49 (1650.38)	191.35 (287.02)	5,755.21 (2,409.96)	121.5 (45)

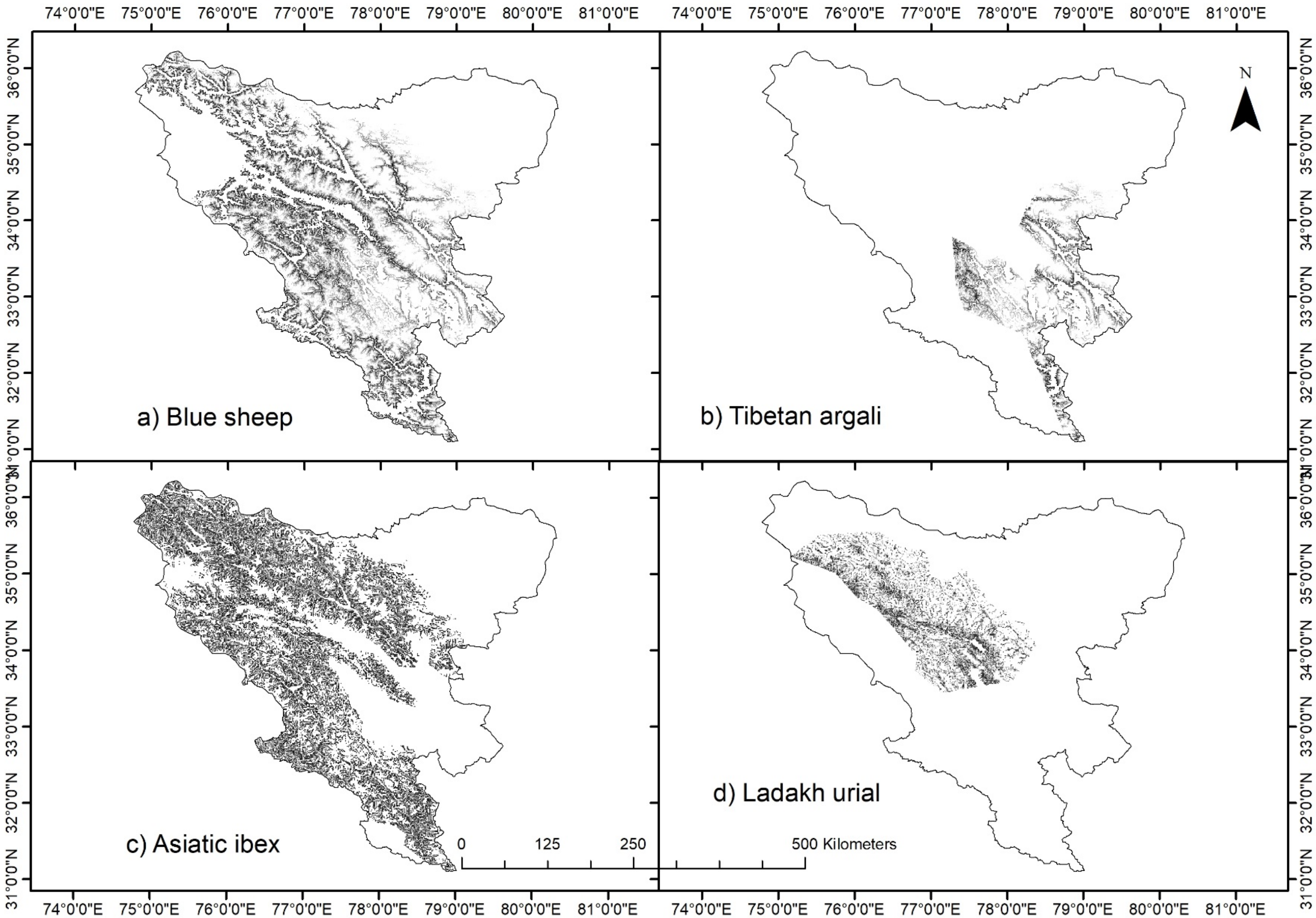

Figure 3.10 *Boolean logic distribution ranges of four ungulate species of Ladakh. The models are developed using existing literature and current study (Fox et al. 1991; Chundawat and Qureshi 1999; Namgail 2001).*

Table 3.3 *Summary statistics and estimates of density and population of blue sheep, Ladakh urial and Asiatic ibex in Nubra-Shyok WLS.*

Parameters	Blue sheep	Ladakh urial	Asiatic ibex
Detection probability		0.069	
Density (SE)	0.254 (0.14)	0.168 (0.09)	0.463 (0.26)
Habitat size (km^2)	8176.92	2707.67	11416.26
Population (SE)	2076.94 (1144.77)	454.89 (243.69)	5285.73 (2968.23)

3.4 Discussion

This study was an attempt to estimate the population estimates of major ungulate species of the Trans-Himalayas at the landscape level. Kiang habitat estimated by the MaxEnt was comparatively smaller compared to the Boolean model applied by Chundawat and Qureshi (1999). Their study predicted a total of about 7,400 km^2 area as kiang habitat. The results of this study have stricter range boundaries with a quite similar spread of distribution compared to the results of Chundawat and Qureshi (1999). Older records of kiang population state it to be somewhere 1,,500 to 2000 individuals (Fox et al. 1991; Bhatnagar et al. 2006b; Shah et al. 2008; Namgail 2009a). All of these studies have depended on total count method and extrapolated the information. Therefore, an underestimation without consideration of detection probability is suspected. To illustrate the effect of detection probability, the density of kiang was calculated on the data from the survey in Changthang WLS following a total count method. Without incorporating detection bias, the density of kiang was calculated to be 0.31 individuals per km^2. The results were comparable to the density of 0.24 individuals per km^2 estimated by Bhatnagar et al. (2006b).

Boolean logic model of distribution range suggested by Chundawat and Qureshi (1999) reported blue sheep distribution in Ladakh over 19,500 km^2, having almost half of the area in the eastern Ladakh. The estimation in this study is larger due to the incorporation of information on blue sheep presence in additional areas. Blue sheep distribution in the Nubra valley and the western Ladakh was not incorporated in the older studies. Chundawat and Qureshi (1999) have reported a general density between 0.9 to 2.7 animals/ km^2, which may reach up to 20 animals/ km^2 during congregations. Densities in this study are around 0.2 to 0.3 animals/ km^2, which is lower than the old estimates. However, the blue sheep populations in the eastern Ladakh, where this study was conducted, are sparse compared to the central Ladakh (Namgail 2009b).

Tibetan argali is known to be present in small populations distributed in the eastern Ladakh landscape (Namgail et al. 2009). The main population is found near Tsokar lake in Changthang WLS. During the course of this study, a few individuals were sighted north of Pangong Tso lake, in Kalak-Tartar valley and on the Rumbak-Markha trek in Hemis national park. Their population was reported to be 300-360 individuals by Namgail et al. (2009). However, such small populations could fluctuate sharply. Therefore, any strong inference could not be made from the difference in population estimates of this study with the previous one. Tibetan gazelle population in Ladakh region is consolidated at only Kalak-Tartar plains, which is also the largest of the only two populations found in India (another one is present in Sikkim) (Chanchani et al. 2011). The species was historically found throughout the Changthang region; however, it is now extirpated from most of its former range (Namgail et al. 2008). The current population uses a wider area during the summer season, but the individuals are congregated into the Kalak-Tartar plains during the winters. The survey in this study was conducted in the month of February during the peak winters. A population of 50 individuals was reported by Bhatnagar et al. (2006a), but local organisations have informally reported their numbers to be around 100 individuals.

Asiatic ibex is known to inhabit cliff habitat; therefore, their range is restricted to the western Ladakh in the Zanskar and Karakoram mountain ranges. A range of 28,000 km^2 ibex habitat in Ladakh was estimated by Chundawat and Qureshi (1999). The range in present study is much larger due to the incorporation of a larger area in the study. Asiatic ibex has higher encounter chances in Nubra valley in particular. Their densities are reported to be in between 0.4 to 1.5 ibex/ km^2 throughout Ladakh range, which is comparable to the density estimates in this study (Schaller 1977; Chundawat and Qureshi 1999). Distribution of Ladakh urial is restricted to the north-western part of Ladakh in Nubra valley and Kargil (Chundawat and Qureshi 1999). Chundawat and Qureshi (1999) calculated only 2,724 km^2 area as urial habitat; however, additional populations exist in the eastern Nubra valley and the total habitat could be much larger. The urial population size of approximately 1,300-1,400 individuals for entire Ladakh was estimated by Chundawat and Qureshi (1999). The current numbers could be higher, either due to an increase or discovery of new populations. A population of about 450 individuals within the survey area of Nubra valley is within realistic estimates.

Total count and double-observer transect walk surveys have been previously used to estimate the ungulate populations in the north-western Trans-

Himalayan landscape of India (Fox et al. 1991; Bhatnagar et al. 2006b; a; Namgail et al. 2009; Suryawanshi et al. 2012). The total count method does not correct for detection biases; hence results in underestimation. Moreover, the methods are quite resource consuming, and only small valley areas can be surveyed at a time. Double-observer transect walk method has a statistical superiority in incorporating improper detection and results in low standard errors. However, the logistic issues and difficulty in adoption for a landscape-level approach persist. Simultaneous point-count survey method solves most of the logistic constraint issues and can be applied to large landscapes over a short time period. However, the density estimates for some of the species have quite high error rates. The statistical analyses were limited by 1) a low number of sightings, and 2) predefined distance bins that could not be adjusted during the analyses. Both the problems can be overcome by increasing the repeats to increase the number of encounters and use of better equipment or adjusted methods to allow correct distance measures. Although the method could be applied to multi-species systems in a single survey, this study also found that habitat and species-specific adaptations could improve the estimates. Tibetan gazelle was missed entirely in an approach with 15x15 sq km grid size. However, a grid size of 2x2 sq km and species targeted survey led to realistic population estimation. The method holds the scope for improvement and achieving statistical robustness. Additionally, volunteer-based participation from local stakeholders has far-reaching implication in training and developing the skills of the participants. Awareness generation and public involvement in scientific research initiatives have wider utilities in the conservation of the species and habitat.

Chapter 4

DIET OF THE WOLF AND OTHER SYMPATRIC CARNIVORES IN THE NORTH-WESTERN HIMALAYAS, INDIA

4.1 Introduction

Food resources are the fundamental driving factor for the occurrence and distribution of any species. Diet choices of the large carnivores are often a result of their habits and availability of the prey species (Wolf and Ripple 2016). When multiple large carnivore species occur in a landscape, dietary competition among those shapes the community and ecology of the region (Caro and Stoner 2003; Andheria et al. 2007).

In the north-western Trans-Himalayan landscape of India, two carnivore species are the most widespread- the Himalayan wolf *Canis lupus chanco* and snow leopard *Panthera uncia*. Wolves are one of the most widely distributed species; therefore, a wide range of prey species make into the diet of wolves worldwide (Mech 1981; Mech and Boitani 2003; Newsome et al. 2016). As many as 39 different prey species were recorded from the diet studies on wolves from the central and south-east Asia (Lyngdoh et al. 2020). Studying foraging ecology of the wolf has helped to understand the nature and pattern of a trophic cascade in several terrestrial ecosystems (Hairston et al. 1960; Terborgh et al. 1999; Schmitz et al. 2000; Ripple and Beschta 2005; Beschta and Ripple 2009). The snow leopard is distributed in the high mountain region of central and south-east Asia. Snow leopard diet consists of 29 prey species, with significant variation in the species composition in different parts of its distribution range (Lyngdoh et al. 2014). Apart from two large carnivores, red fox *Vulpes vulpes* is a commonly occurring small carnivore in the entire Trans-Himalayan landscape. In a region of low prey availability, red fox diet includes large species carrion as well and overlaps with large carnivore diets in the Trans-Himalayan region (Reshamwala et al. 2018). The present study aims to understand the diet pattern and preferences of the Himalayan wolf in comparison to snow leopard and red fox.

4.2 Methods

4.2.1 Data collection

The landscape of the north-western Trans-Himalayas in India, including Ladakh and high altitude regions of Himachal Pradesh, was part of this research on the diet of large carnivores. Various field excursions, including the survey for wild ungulate population estimation described in chapter 3, were made to collect the scat samples of the targeted species from 2014 to 2018. A total of 1,600 scats of the three carnivore species were collected from Ladakh and Spiti regions of the north-western Trans-Himalayan landscape in India (Himalayan wolf= 542, Snow leopard= 31 and Red fox= 1027) (Figure 4.1). Scats were searched and picked on naturally occurring trails and other conspicuous sites such as den and rendezvous sites. The trails were not repeated in order to maximise the effort. If more than one scat was present at the site, a single fresh scat was collected from the site. Scats of the carnivores were identified and distinguished in the field based on shape, size, odour and quantity typical to that of the relative species, following a standard protocol (Vanak and Mukherjee 2008; Reshamwala et al. 2018). Dog scats were discarded for collection and analyses, and identified in the field based on the content originating from garbage dumps, presence of dogs in the area and proximity to human settlements. A conservative, multi-criteria approach to differentiate wolf scats from those of other canids was used by Ciucci et al. (1996).

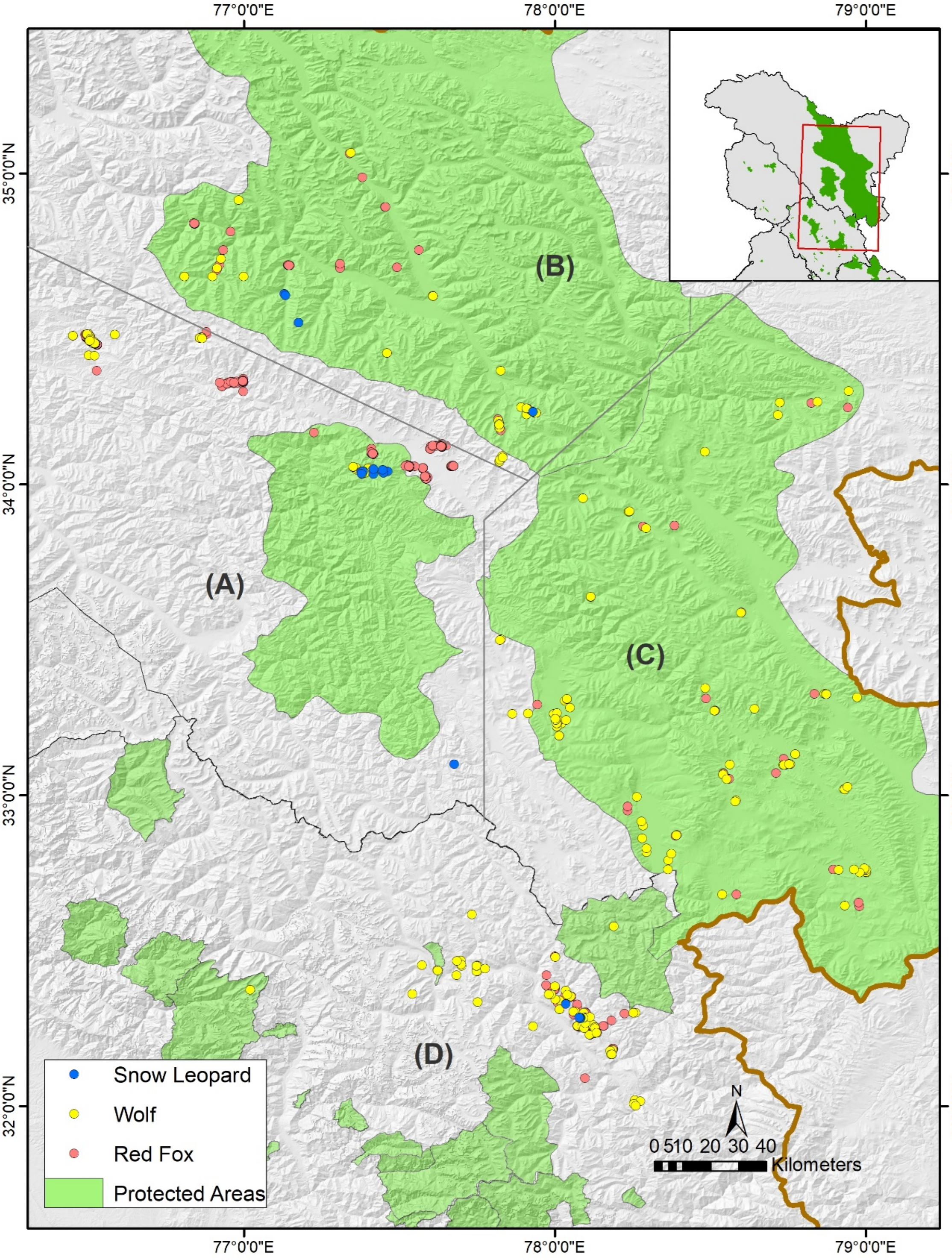

Figure 4.1 *Geographic distribution of the scats of three carnivore species collected from the Trans-Himalayan landscape of Ladakh and Spiti valley, India. The study area was divided into four sub-regions- (A) Western Ladakh that includes Hemis National Park, Zanskar and Kargil, (B) Nubra-Shyok Wildlife Sanctuary, (C) Changthang Wildlife Sanctuary, and (D) Spiti valley, Himachal Pradesh.*

Data of this study has been partially published in two research papers (Reshamwala et al. 2018 & Lyngdoh et al. 2019).

Since the field samples of snow leopard scats were limited, information from the published literature on the diet of snow leopard within the study area was collected and used for comparative analyses. Information on a total of 573 additional scats of snow leopard was collected from three studies- 95 scats from Spiti valley (Bagchi and Mishra 2006), 262 scats from Spiti valley and 43 scats from Ladakh (Suryawanshi et al. 2017), and 173 scats from Hemis national park, Ladakh (Chundawat and Rawat 1994).

4.2.2 Laboratory analyses

Scat analysis is an indirect, non-invasive and unbiased technique for recording frequency of occurrence of prey in the diet of mammalian carnivores; and hence it is used widely (Floyd et al. 1978; Shahi 1982; Jhala 1993; Mukherjee et al. 1994; Habib 2007; Reshamwala et al. 2018). Scats were tagged with species, date, GPS location and condition as recent or old at the time of collection and preserved for lab analysis. The standard method of lab analysis of undigested food content in the carnivore scats was followed to identify the prey species and other food (Mukherjee et al. 1994; Bagchi et al. 2003). Scats were washed in running water through a fine sieve of BSS 120 having a pore aperture width of 125 μm so that the digested material could pass through the sieve. Indigestible items including hair, feathers, bones, claws, teeth, chitin remnants of insects, plant material and human-derived materials (HDM) such as cloth, paper, plastic and rubber were recorded and collected for further identification if required. Dried mammalian hair samples were treated with Xylene and alcohol solution and then examined under a microscope for identification of prey consumed by medullary hair patterns

(Bahuguna et al. 2010). Frequency of occurrence of prey items was used for further statistical analyses (Hayward and Kerley 2005; Lyngdoh et al. 2014).

DNA based identification (Paxinos et al. 1997) was performed for 118 samples collected from Spiti valley. An error of 18.58 % misidentification was found in between the scats of wolf and snow leopard. Red fox scats were identified correctly at all the instances. Identification of red fox scats from those of wolf and snow leopard is possible based on physical characteristics of shape, size and smell (Reshamwala et al. 2018). However, DNA-based identification could not be performed on the remaining scats due to logistic and financial constraints. Therefore, the associated error in separately identifying wolf-dog and wolf-snow leopard scats might reflect in the analyses and results of this study.

4.2.3 Statistical analyses

All the statistical analyses were performed in the open-source program R version 3.6.3 (R Core Team 2020). Relative biomass consumption of different prey items by the wolf was calculated using allometric relationship (biomass consumed per collectable scat/predator weight = $0.033–0.025\exp^{-4.284(\text{prey weight/predator weight})}$) developed by Chakrabarti et al. (2016). The dietary niche overlap among the three carnivore species was tested by Pianka's niche overlap index using randomisation algorithm provided in "EcoSimR" package version 0.1.0 (Pianka 1974; Winemiller and Pianka 1990; Gotelli and Ulrich 2012; Gotelli et al. 2015). The randomized simulated index was generated using 10,000 repeats of the "RA3" algorithm, a conservative approach retaining the species' niche breadth. A hypothesis for diet variations in carnivore species arising due to their functional traits was tested using

Table 4.1 *Predator and prey traits used for RLQ analysis of the trait-based dietary relationship among carnivores in the Trans-Himalayan landscape, India. Traits were categorised in classes. A species could belong to multiple classes within a single trait group.*

Predator traits (R list)	Categories	Codes
Body size (cm)	40-80, 80-120, 120-150	BS1, BS2, BS3
Body weight (kg)	<20, >20	BM1, BM2
Running speed (km/h)	<50, >50	MS1, MS2
Preferred Habitat	Cliff, valley	PF1, PF2
Human proximity preference	Close, away	HD1, HD2
Group formation	Pack-living, pair, single	S1, S2, S3
Prey traits (Q list)		
Body size (cm)	1-10, 10-40, 40-100, 100-150, >150	L1, L2, L3, L4, L5
Body mass (kg)	>3, 3-10, 10-50, 50-100, 100-150, >150	W1, W2, W3, W4, W5, W6
Taxonomy	Bird, ungulate, small herbivore, insect	PB1, PB2, PB3, PB4
Preferred Habitat	Cliff, valley	PH1, PH2
Domestication	Complete, semi, wild	D1, D2, D3
Group size	Large, small, clumped distribution, single	GS1, GS2, GS3, GS4
Body weight to flesh ratio	<50, 50-65, >65	MR1, MR2, MR3
Defence capacity	Both sexes, one sex, none	DS1, DS2, DS3
Running speed (km/h)	0-15, 16-40, 41-80, >80	SP1, SP2, SP3, SP4

trait-based fourth corner analysis (Spitz et al. 2014). This three-table ordination method was originally developed to test the relationship of species traits with the environmental features (Ter Braak et al. 2012). The method has been used to study the dietary relationships among marine predators and prey species, multi-scale niche study of waterbirds and dietary analysis of bats (Ridoux 1994; Scharf et al. 2000; Khatoon 2010; Henry and Cumming 2017; Arrizabalaga-Escudero et al. 2019). Three lists of 1) predator traits (R list), 2) matrix of prey-predator interactions (L list), and 3) prey traits (Q list) were prepared. Predator and prey trait lists (R and Q lists) are provided in Table 4.1. The RLQ analyses were performed in the "ade4" package (Dray and Dufour 2007), following the methods recommended by Dray and Legendre (2008) and Spitz et al. (2014).

Jacobs' selectivity index (Jacobs 1974) was used to determine the prey selectivity of the Himalayan wolf in four geographic regions of the landscape (Figure 4.1). The study area was divided into sub-regions based on geographical features, wild prey species, and agro-pastoralist systems to understand geographic variations in prey choices of the wolf: A) The western Ladakh, including Hemis national park, is comparatively rugged with steep slopes of the Zanskar mountain range where blue sheep and Ladakh urial are sighted commonly. B) Nubra-Shyok WLS, the northern Ladakh, is part of the Karakoram mountain range where river valleys form a typical desert system and glaciers cover a significant portion. Most people in Nubra-Shyok WLS are settled villagers, and wild prey here includes mainly blue sheep and the Asiatic ibex. C) Changthang WLS forms the easternmost region characterized by rolling plains, higher prey diversity (six out of eight ungulates), and nomadic pastoralism. D) The Spiti valley in Himachal Pradesh is a narrow river valley adjoining high elevation peaks in the south and

Changthang plains in the north. The agro-pastoralist community is settled in the villages; however, seasonal pastoralists migrate to the grasslands of the valley from the south during summer. Kibber WLS and Pin valley national park are two main protected areas in the Spiti valley where blue sheep and Asiatic ibex are common prey species. The landscape was girded into 10x10 sq km cells to remove the biases arising due to unequal sampling among the regions. Only ten wolf scats per grid were selected randomly for the preference analysis. Prey availabilities in Ladakh were derived from chapter-3 of this thesis. Literature references were used for wild prey species found in Spiti and the western Ladakh region (Chundawat and Qureshi 1999; Namgail 2009a; Suryawanshi et al. 2017). Livestock availability data were obtained from the Department of Animal Husbandry, Leh. The log-likelihood test ratio was computed to test the differences in prey preference of the wolf across four sub-regions of the landscape (Karanth and Sunquist 2000). All the analyses codes are attached in Appendix-3.

4.3 Results

4.3.1 Dietary pattern of the carnivores

Livestock (cattle, goat, sheep, horse and donkey) was a major contributor to the wolf diet in the landscape (56.46%) (Table 4.2). Among the wild ungulates, the wolf consumed blue sheep (8.26%) and ibex (3.13%). The small prey items such as pika (13.54%) and marmot (6.99%) were quite frequently represented in the wolf diet. Over-representation of the small prey in the wolf diet was, however, corrected when accounted for biomass consumption (Figure 4.2). While blue sheep contributed 10.01% biomass, pika (4.37%) and marmot (4.72%) provided less biomass to the wolf. Compared to the wolf, livestock contribution in the snow leopard diet was quite low (30.01%) (Table 4.2). Blue sheep (30.79%) was the major contributor to the snow leopard diet. Plant items were reported quite frequently in the data obtained from Chudawat and Rawat (1994). Although the data are pooled from literature as well, the geographic scale of the study would adjust for the study-specific biases and errors in reporting the frequency of occurrences in the diet. The red fox is a comparatively small species; therefore, small prey items such as pika (15.66%) and marmots (3.19%) were frequently present in their diet (Table 4.2). However, the fox quite frequently consumed livestock carrions (cattle- 3.07%, goat and sheep- 13.42), fruits and wild seeds (15.05%), and other human-derived materials along with poultry (11.89%).

4.3.2 Dietary niche competition

Although the dietary range of all the three carnivores varied in contribution from each food item, Pianka's index could not establish a significant niche separation among the three carnivores (Pianka's mean observed index= 0.503, randomized simulated mean index= 0.491, p= 0.15). Figure 4.3 illustrates that most food items were consumed by all three carnivore species, varying only in the contribution of each item. Livestock consumption, either by hunting directly or utilizing it through scavenging, was the major source of the niche overlap. Ordination based on RLQ analysis revealed that the consumption of large body-sized prey species such as ibex, argali, kiang, yak, and the horse was associated with the wolf and snow leopard, while small prey such as pika, marmot, hare, birds, and insects grouped with the red fox (Figure 4.4). However, the body size of the prey species could not clearly differentiate between the diet of the wolf and snow leopard. No evidence was found for the effect of prey traits in dietary relationships. Predator morphology traits such as body size and body weight, and habitat preference with relation to human presence significantly affected the variation in prey selection ($p < 0.05$) (Figure 4.4).

Table 4.2 *Relative frequency of occurrence (%) of different prey and food categories in the diet of three carnivores. Wild seeds and apricot were commonly consumed by the red fox.*HDM- Human-derived materials such as cloth, paper, plastic and rubber.*

	Himalayan Wolf	Red fox	Snow leopard
Tibetan argali	2.01	-	0.33
Kiang	2.83	0.19	-
Ladakh urial	1.34	1.07	0.11
Asiatic ibex	3.13	0.21	17.15
Blue sheep	8.26	5.59	30.79
Pika	13.54	15.66	1.72
Marmot	6.99	3.19	3.06
Hare	2.23	5.42	1.89
Birds	1.86	6.22	1.47
Cattle	21.95	3.07	5.43
Goat & sheep	28.72	13.42	12.06
Horse & donkey	5.80	0.09	12.52
Plant	1.04	13.05	11.74
Fruit	0.15	15.05	0.08
Insects	-	5.84	-
HDM*	-	11.89	-
Other (unidentified)	0.15	0.03	1.64

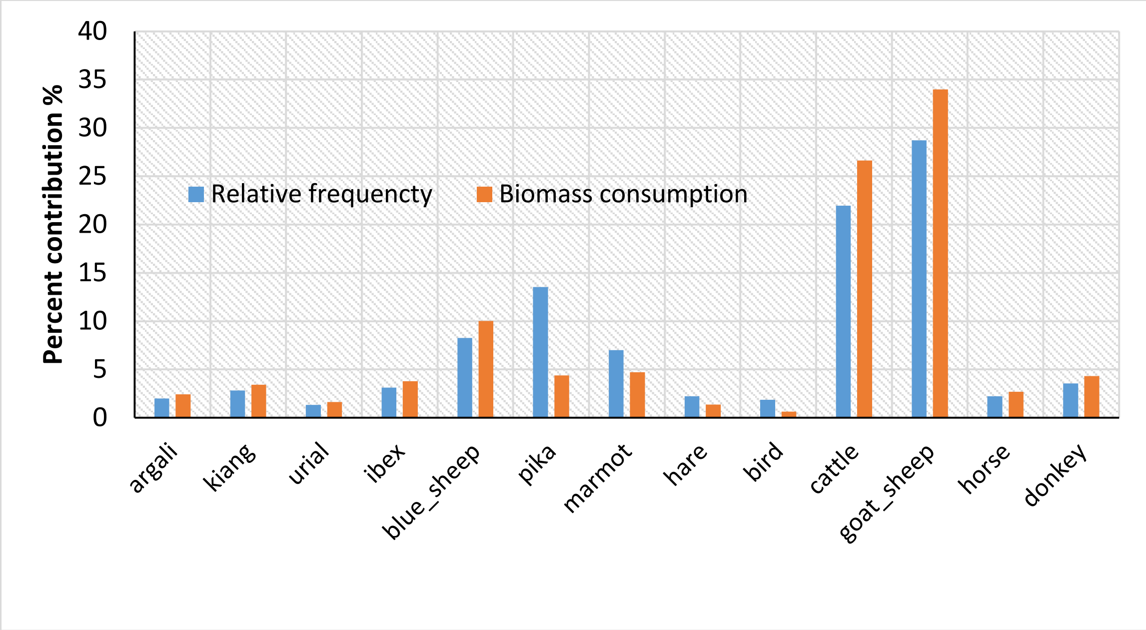

Figure 4.2 *Contribution of different diet categories in the Himalayan wolf diet. Biomass provides a better representation than the frequency of occurrences for small prey items such as pika and marmot.*

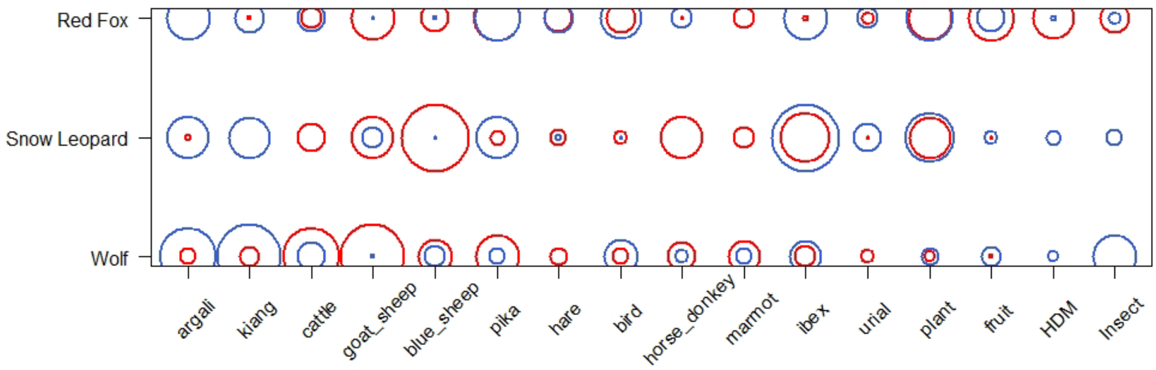

Figure 4.3 *Dietary niche overlap of the red fox, snow leopard and the wolf (Pianka's mean observed index = 0.503 simulated mean=0.491; p=0.15). The graph displays relative observed (red circles) versus simulated (blue circles) consumption of each food item.*

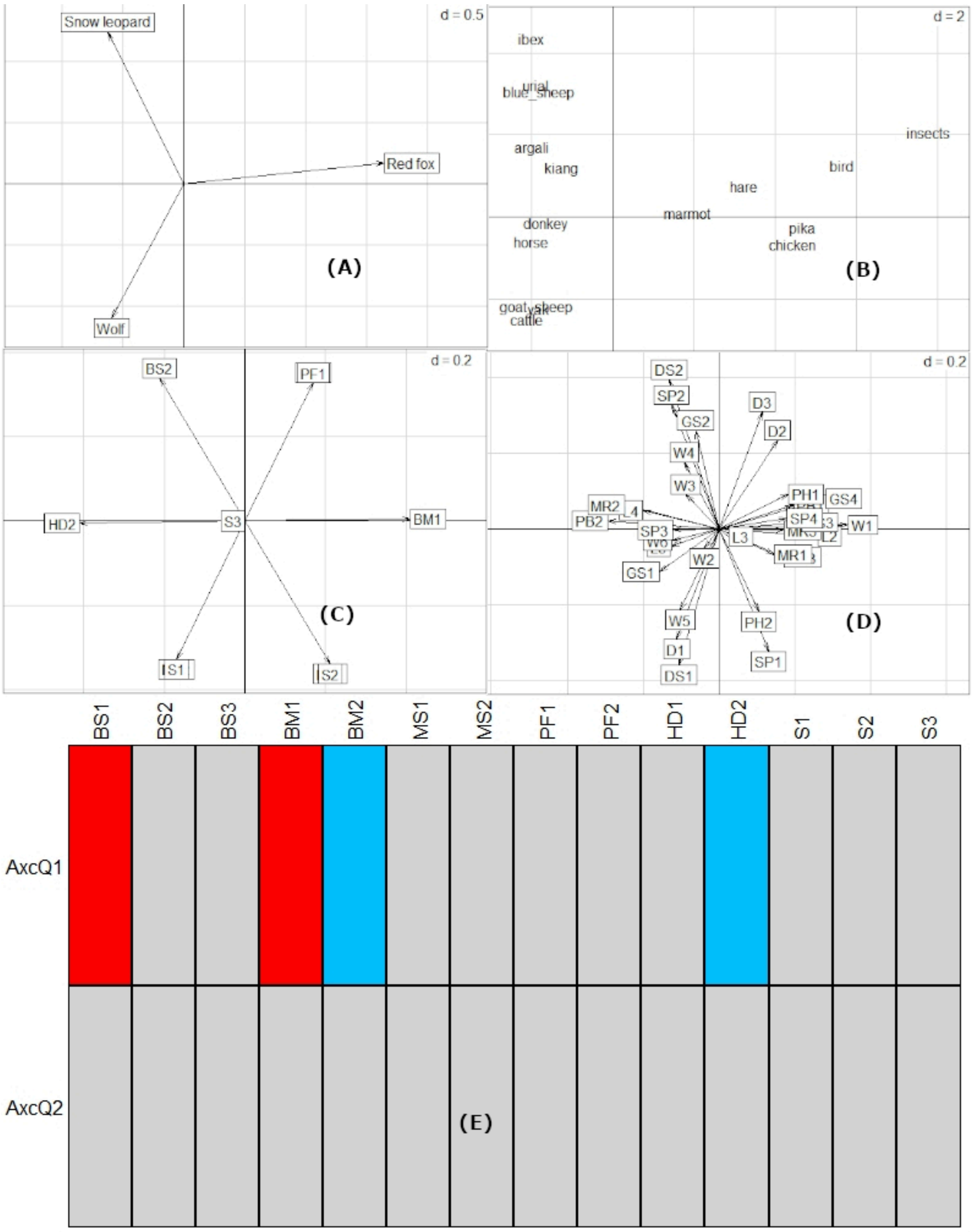

Figure 4.4 *RLQ ordination of the predator (A) and prey raw scores (B) along the first two axes. The ordination is based on the canonical weights of predator (C) and prey (D) traits and their dietary relationships. None of the prey traits influenced the dietary choices. However, predator traits of body size, body mass and habitat preference significantly influenced the dietary relationship of the three carnivores. Red marked traits are significant at p<0.05, while blue marked traits are significant at p<0.1. (Refer the trait codes in Table 4.1).*

4.3.3 Prey preference pattern of the Himalayan wolf

Dietary preferences of the Himalayan wolf varied across all four sub-regions of the landscape (Figure 4.5). Wild ungulates such as argali, blue sheep, ibex and urial were often consumed more than the availability, and small prey items such as pika, marmot and hare frequently showed a negative selection. Preferences for the livestock varied the most across the landscape. A log-likelihood test ratio for prey preferences of the Himalayan wolf showed that statistically significant preferences for prey items did not exist at the landscape level ($G2 = 6.79$, $df = 12$, $p = 0.871$). The landscape was divided into 10x10 sq km grid to visually understand the geographic variation in the consumption of livestock and wild prey. While the livestock consumption was prominent in the western and southern part of the landscape, wild prey items were consumed more frequently in the eastern region where Changthang WLS exists (Figure 4.6). It is to be noted that, despite prevailing nomadic pastoralism, Changthang holds the highest overall wild prey diversity and density compared to rest of the landscape.

4.4 Discussion

Newsome et al. (2016) reviewed the diet of all the grey wolves of the world using 177 studies. The representation from Asia was limited to only 15 studies, and no study from the Himalayan region was included in the review. Later, Lyngdoh et al. (2020) specifically reviewed 22 studies (including a part of the dataset presented in this chapter) on the dietary pattern of the Himalayan wolf in central and southeast Asia. Lyngdoh et al. (2020) found that livestock consumption (54.92%) was widespread in the Himalayan wolf diet across the mountain areas of Asia. A total of 39 prey species were recorded in the wolf diet with highly localized selection for rare species such as Przewalski's horse *Equus ferus przewalskii*. The data in this

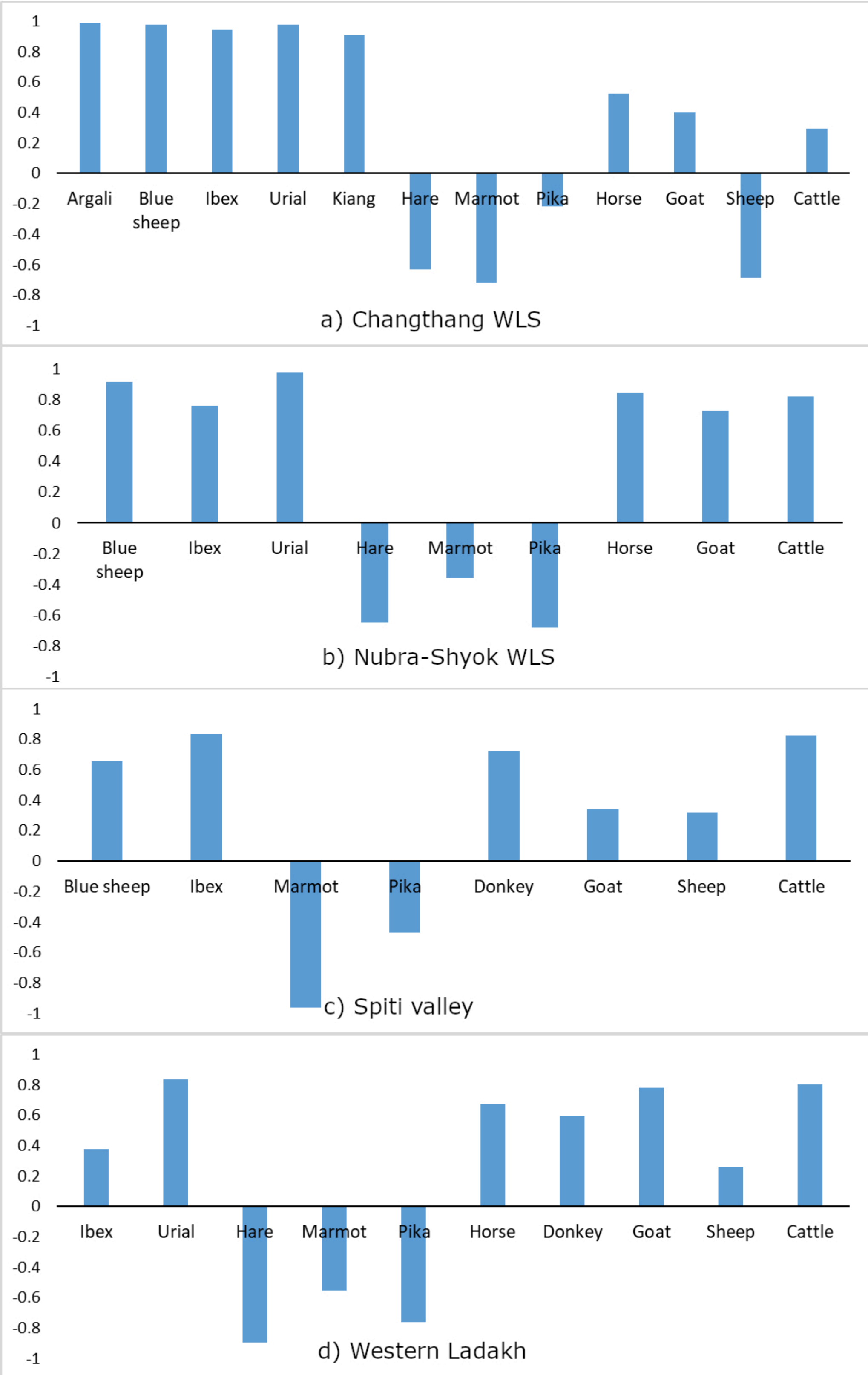

***Figure 4.5** Mean Jacob's index values for prey items of the Himalayan wolf in different sub-regions of the landscape. Positive values indicate relatively higher consumption that the availability and negative values indicate vice versa.*

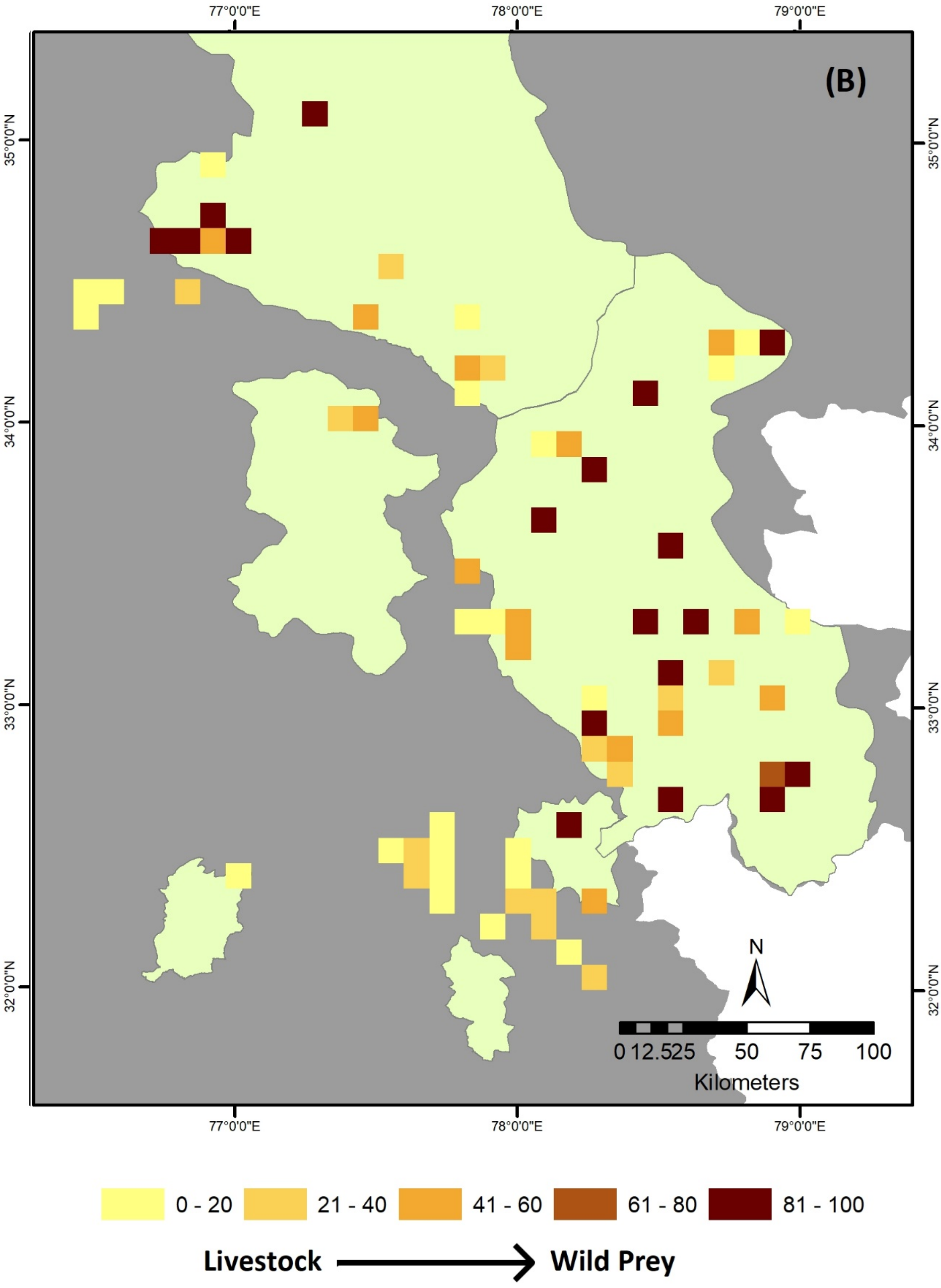

Figure 4.6 *Relative frequency of occurrences of prey items in wolf diet shows that wild prey items were frequently consumed in the eastern part of the landscape while livestock were consumed more in the western and southern part.*

chapter suggest a similar pattern with a high livestock consumption (56.46%) by the wolf in the Trans-Himalayan landscape of India. Tibetan argali is rare and localized wild ungulate species in Changthang WLS, which had the highest predation selection ratio by the wolf (Jackob's index = 0.98). This information is potentially valuable for the conservation of argali, which is one of the most threatened ungulate species in Ladakh with an estimated population of 300-360 individuals only (Namgail et al. 2009). Wolf predation was considered one of the major threats to the conservation of endangered Przewalski's gazelle *Procapra przewalskii* in Qinghai, China (Liu and Jiang 2003).

Predation by the wolf is a hierarchical selection process (McPhee et al. 2012). They usually predate on medium-size prey (Kunkel and Pletscher 2001), but specialisation for hunting the large prey is also reported commonly (Ripple et al. 2001; Feldhamer et al. 2003; Ripple and Beschta 2012). Several studies from the European region found that wolves hunted on the medium-sized prey comparatively more than the large prey such as European bison *Bison bonasus* and moose *Alces alces* (Nowak et al. 2011; Wagner et al. 2012). The wolves in Spiti valley were reported to hunt more on the medium-sized prey, with occasional attacks on large prey, compared to snow leopard which preferred large-sized livestock such as horse and yak (Suryawanshi et al. 2013). The results of this study also show that the wolves in the Trans-Himalayas consumed medium-sized prey such as blue sheep, goat, and sheep more than large-sized prey such as kiang, yak, horse, and donkey (Table 4.2). However, we also found a considerable presence of small prey items in the wolf diet. The behavioural specialisation of the individual wolves to hunt small prey such as marmot have been observed in the field (Mahar, N., pers. observation). The Trans-Himalayan landscape shows extreme weather where prey availabilities might fluctuate with the seasons. In addition, nomadic pastoralism could bring strong seasonal changes in the availability of livestock. Small species in such cases could allow the wolves to switch to locally abundant prey. Newsome et al. (2016) also observed that the Asian studies reported a relatively higher amount of small prey such as rodents than the European studies on the wolf diet.

While the wolves can be considered a diet generalist over a large landscape, site-specific preferences often exist (Figure 4.5). Livestock was highly preferred by the wolf in the western Ladakh and Spiti valley, where wild prey diversity and availability are low compared to other parts of the landscape (Figure 4.5). In Nubra-Shyok WLS, the wolf showed quite similar preferences for wild and domestic prey. Pastoralist practices are the least common in Nubra-Shyok WLS, and domestic prey availability is the lowest. Despite prevailing nomadic pastoralism and a high availability of domestic prey in Changthang WLS, prey selectivity was high for wild prey species. Wolves are known to subsist on livestock throughout their distribution range (Mech and Boitani 2003; Newsome et al. 2016). However, evidence exists that wolves prefer wild prey over domestic prey if the wild prey populations occur at relatively higher densities (Meriggi and Lovari 1996; Newsome et al. 2016). Although index-based preferences often are less reliable since the methods are quite sensitive to the flexibility in availability and use data (Manly et al. 2004). The patterns of site-specific preferences in this study reflect the current ecological dynamics of the landscape, which might fluctuate with the change in domestic and wild prey availability. Recovery of wild ungulate prey is considered an important measure to reduce the extent of livestock depredation by the wolf (Werhahn et al. 2019a). In contrast, Suryawanshi et al. (2017) argued that an increase in wild prey was likely to increase the population of snow leopard, which in turn would intensify the livestock depredation. A similar response was possible in the case of wolves as well. The grey wolf shows both type II and type III responses to wild ungulate prey (Garrott et al. 2007). However, this study showed that higher livestock presence in Changthang WLS did not increase livestock predation (Figure 4.6) because Changthang WLS also had a better availability of wild prey (Chapter-3). The Indian wolf *C. l. pallipes*, the closest sub-species to the Himalayan wolf (Sharma et al. 2004), highly depends on livestock (Shahi 1982; Kumar and Rahmani 2000; Jethva and Jhala 2004; Habib 2007). The Indian wolf also showed a low livestock consumption when blackbuck *Antilope cervicapra* was abundantly available (Jhala 1993).

Intra-guild diet competition among carnivores depends on their evolutionary history together and the availability of the resources (Connell 1980; Chase and Leibold 2003; Hunter and Caro 2008). Three carnivore species of the Trans-Himalayan landscape in India- the wolf, snow leopard, and red fox- exhibited a very high overlap of the food items. Out of 17 food categories, only insects and human-derived material were absent from the diet of snow leopard and the wolf, and Tibetan argali was absent from the red fox diet (Table 4.2, Figure 4.3). Body size and body mass were the most influential predator traits determining the intraguild feeding relationship of the carnivores in this landscape (Figure 4.4). Body size differences of predators are key drivers of their dietary choices, as it influences the ability of carnivores to hunt different prey species and restrict the mesopredators to small prey (Simberloff and Dayan 1991; Monterroso et al. 2020). In this study, the red fox was a small body-sized mesopredator species, resulting in its diet of small animals. Red foxes in this landscape have adapted to utilize garbage from human sources, increasing their densities around the human settlements (Reshamwala et al. 2018). Apricots formed a large chunk of their fruit consumption in western Ladakh, while wild berries were frequently consumed in Nubra-Shyok WLS. Presence of livestock and large wild prey species in the red fox diet, which could be originated from the secondary consumption of the carrions, resulted in its dietary overlap with the wolf and snow leopard (Figure 4.3).

The wolf and snow leopard showed prey-specific variations in consumption frequencies. For example, Asiatic ibex and blue sheep were consumed by snow leopard more frequently compared to the wolf. The wolf in the mountain landscape is often associated with the valleys and flat areas (Paquet et al. 1996), while snow leopard selects high ruggedness areas with cliffs and steep slopes (Watts et al. 2019). Their habitat preferences are also related to their hunting strategies. The snow leopard often hunts individually by ambush method, while wolves are pack hunters using chase down method. Valley flats in the mountain regions are also the areas preferred by humans for settling; hence closeness to human settlement significantly affected the predation choices (Figure 4.4). The human settlements are also associated with the presence of livestock, which was a common prey resource for all three carnivores. Habitat characteristics played a role in the prey preferences of snow leopard and the wolf in other parts of the Himalayas as well (Sharma et al. 2007; Chetri et al. 2017).

Although errors associated with ascertaining carnivore species for scat data exist, it is expected that the misclassification errors were randomly distributed and less likely to alter the observed patterns of predation for coverage of a large landscape and a high number of scats. Feral dogs have a considerable presence in the landscape and known to compete against the carnivorous wildlife for the resources (Ghoshal et al. 2016; Home et al. 2017; Reshamwala et al. 2018). In fact, feral dogs have been reported as top predator of livestock in the Trans-Himalayan landscape (Suryawanshi et al. 2013; Home et al. 2017), further confirmed by the data in chapter-2. A limitation of this study is not to account for the presence of these dogs, its implications on data and analyses. A possible interference competition of wolves and foxes with the feral dogs might be limiting their access to food resources close to human settlements. However, the presence of dogs is clumped and it would be interesting to see a fine scale study on this aspect in future.

Livestock predation by the carnivores and their retaliatory killing is a concern for local economy and conservation (Suryawanshi et al. 2017). Therefore, managing livestock in relation to wild prey is crucial for the Trans-Himalayan ecosystem. Severe reduction of the livestock could result in population decrease for all the carnivores as well as heighten competition especially due to depressed wild ungulate populations. A high niche overlap in the diets of three widespread carnivore species in the Trans-Himalayan landscape indicates that the sympatric carnivores already face intense competition (Hardin 1960; Schoener 1982; Chase and Leibold 2003). Changing pastoralist practices and modernization is leading to decreased livestock availability. Therefore, the management should simultaneously focus on wild prey restoration, which is likely to change the preferences of the wolf and other carnivores. In addition, reducing persecution is also suggested as a more effective method for restoring large carnivores than restoring their prey (Bleyhl et al. 2021), which can be achieved by reduced livestock attacks through guarding methods and changing public attitudes through awareness and providing additional livelihood options (Suryawanshi et al. 2013).

Chapter 5

MODELLING DISTRIBUTION OF WOLF IN THE NORTH-WESTERN HIMALAYAS, INDIA

5.1 Introduction

Wolves in the Asian countries have been studied rarely, though genetic studies generate interest identifying evolutionarily important and distinct lineages in Asia (Aggarwal et al. 2003, 2007; Sharma et al. 2004; Matsumura et al. 2014). The wolf lineages from the Himalayan region in India and neighbouring countries *Canis lupus chanco* has been in the taxonomic debate over the past one and a half centuries (Shrotriya et al. 2012). Recent genetics-based studies on their taxonomic studies have raised the debate further (Chetri et al. 2016; Werhahn et al. 2017; Alvares et al. 2019; Joshi et al. 2020; Wang et al. 2020). However, the unique adaptation to survive the extreme temperatures in the Trans-Himalayan landscape and unique evolutionary history with a 0.8 million years old divergence highlight the importance of the Himalayan wolf lineage (Sharma et al. 2004; Werhahn et al. 2018).

Generating information on the status and distribution of the species is a basic step towards formulating their conservation (Franklin 2009). Mapping the geographic distribution of less known species is a challenge due to insufficient data and poor knowledge about the target species. Habitat modelling is encouraged when knowledge is lacking and data are scant (Larson et al. 2008). Although presence of the wolves is reported from several locations in the Trans-Himalayan landscape and adjoining Tibetan plateau (Hodgson 1847; Pocock 1941; Fox et al. 1986; Chundawat 1992; Fox and Chundawat 1995; Bhattacharya and

Sathyakumar 2010; Maheshwari and Sharma 2010; Chanchani et al. 2011; Matsumura et al. 2014; Chetri et al. 2016; Werhahn et al. 2019b), information on the wolf range in the landscape is limited. Wolf is a challenging species in modelling its habitat suitability, as models fail to account for their adaptability (Mech 2006). However, there has been a complete shift in the modelling theory and analytical methods (Elith et al. 2006), and applying these can give more robust results. Machine learning methods, such as MaxEnt, have got wide attention in species distribution studies in recent years (Phillips et al. 2006; Huettmann et al. 2018). In this study, distribution of the wolf in the north-western Trans-Himalayan landscape was modelled using presence-only MaxEnt modelling method (Phillips et al. 2017).

5.2 Methods

5.2.1 Data on the presence locations

Presence locations of the wolf in Ladakh and Spiti regions were collected by three methods. Locations of the confirmed wolf scats were collected from 2014 to 2018 for the diet study of the wolves in chapter-4 of this thesis. A total of 542 locations were generated from the scat collection data. Another 20 direct sighting locations (live animals and killed animals in wolf pits) were recorded by the field survey teams. Two female wolf individuals of different packs were tagged with GPS-enabled radio-collars in Spiti valley during 2015-2017 in a parallel study on the wolves in Spiti valley (Shrotriya et al. 2017; Lyngdoh 2020). Radio-collaring generated 1,687 fixes over the period of one and a half year from July 2015 to March 2017. A total of 2,249 presence locations were generated by combining all the sources (Appendix-4: Figure 1).

The locations from radio-collared individuals were highly clustered. Therefore, the sampling bias was corrected by resampling the locations to resemble a similar sampling effort across all the locations (Fourcade et al. 2014). One location per gird was randomly selected at the resolution of 4x4 sq km. Since the area coverage of locations from other sources was about four times than that of radio-collared individuals, 1/4th locations out of remaining radio-collaring locations were selected randomly. A total of 93 locations were selected (scat=60, direct sighting= 15, radio-collaring=18) for distribution modelling (Appendix-4: Figure 1).

5.2.2 Environmental predictor variables

Distribution and habitat selection of a species is governed by climatic and habitat factors, resources, competition and disturbance (MacArthur and Wilson 1967). A total of 31 predictor variable layers were collected or generated for the purpose of distribution modelling. Bioclimatic layers (19 variables) were obtained from WorldClim (www.worldclim.org) on 1 sq km resolution (Hijmans et al. 2005). Altitudinal information was obtained from the Shuttle Radar Topography Mission (SRTM) data available at 23x23 sq meter resolution and resampled at 1 sq km. Two variables of slope (in degree and in percent) were calculated using spatial analyst tool in ArcGIS 10.5, calculating the maximum rate of change in value from a cell to its neighbours. Generally used methods to calculate habitat ruggedness, such as land surface ruggedness index (LSRI) (Beasom et al. 1983) and terrain ruggedness index (TRI) (Riley et al. 1999), do not include the variability of topographic aspect and are based on only elevation gradient, thus strongly correlate with slope. Therefore, vector ruggedness measure (VRM) was used in this study, which includes the gradient in slope and aspect both (Hobson 1972; Sappington et al. 2007). The VRM index was calculated by using “vrm” function in the R package “spatialEco” version 1.3-2 (Evans et al. 2020). Quarterly data on normalized difference vegetation index (NDVI) was obtained from Global MODIS for six months (April to October 2013) and averaged. NDVI values range from 10,000 to -1,999, which are then standardized at 1.0 to -1.0. Classified land cover data with land use and land cover classes were acquired from the National Remote Sensing Centre (NRSC 2014). Human population density and wilderness area data were obtained from SEDAC (http://sedac.ciesin.columbia.edu). Nightlight data were downloaded from the National Oceanic and Atmospheric Administration (https://www.ngdc.noaa.gov/). Euclidean distances to glaciers, roads and large waterbodies were calculated using ArcGIS 10.5. The variables were reduced to exclude highly correlated ones based on Pearson's correlation coefficient r, $|r| > 0.75$ (Appendix-4: Figure 2). Since LULC was a categorical variable, it was not checked for the correlation. After reducing the correlation data layers, following 15 layers were used for the modelling purpose: mean diurnal temperature range, isothermality (daily temperature range/annual temperature range), temperature seasonality, mean temperature of wettest quarter, mean temperature of coldest quarter, annual precipitation, precipitation seasonality, elevation, distance to glaciers, distance to water, NDVI, LULC, human population density, vector ruggedness measure and slope (in degrees).

5.2.3 Distribution modelling

There is a range of statistical and machine-learning models available to map species distribution using a variety of algorithms (Pearson et al. 2007; Franklin 2009; Huettmann et al. 2018). MaxEnt has a potential to map the spatial distribution of species with fewer locations and has performed well as compared to other available presence only models (Hernández et al. 2006; Papes and Gaubert 2007; Pearson et al. 2007; Wisz et al. 2008). MaxEnt was long criticised as a black-box algorithm that doesn’t allow user to adjust the modelling algorithm. However, the source codes are now open to public as an R-package that allows more flexibility to fine-tune the model (Phillips et al. 2017).

Based on different hypotheses on animal habitat selection (MacArthur and Wilson 1967), the uncorrelated environmental variables were grouped into three sets: vegetation and topography (Tv), human disturbance (D) and climate (C). The candidate models were then assembled by making combinations of these groups ranging from specific models reflecting only individual sets (e.g., C) to general models containing variables of all three groups (i.e., CTvD) (Kanagaraj et al. 2019). Since there was only one variable (human population density) in the disturbance set, initially six candidate models were developed. Further, three candidate sets of variable combinations were developed by sequentially removing the least contributing variables in all-variable and individual set models (Appendix-4: Table 1).

A set of 10,000 random background points was selected to build the models. Training (75%) and testing (25%) sets were generated for k-fold cross-validation using “block” method, which partitions the datasets into four equal data-size bins according to latitudinal and longitudinal lines. Spatial partitioning is particularly useful in cases of unequal sampling and the landscapes with spatial heterogeneity of the variables (Muscarella et al. 2014). A series of individual MaxEnt models to each of the candidate variable set and spatial partition was built with regularization multiplier values ranging from 0.5 to 3.0 (increments of 0.5) and six different feature class combinations (L, LQ, H, LQH, LQHP and LQHPT; where L = linear, Q = quadratic, H = hinge, P = product and T = threshold) (Muscarella et al. 2014; Kanagaraj et al. 2019).

For each candidate model, 180 individual models (six regularization values ×six feature classes × (four training and testing data bins + one full dataset)) were generated, resulting in a total of 1,620 individual models (180 × 9 candidate models). AUC is the most widespread measure of model selection in MaxEnt, however it is also criticized as an absolute measure in species distribution modelling (Lobo et al. 2008; Radosavljevic and Anderson 2014). Therefore, the most parsimonious models (ΔAICc ≤ 2) were selected out of each candidate set, and a selection procedure of least omission rate followed by the highest AUC value was applied to pick the best model. The top model out the best models for each candidate set was selected based on the lowest AICc and the highest AUC (Appendix-4: Table 2).

The methods were implemented in the open-source program R version 3.6.3 (R Core Team 2020). R package "ENMeval" version 2.0.3 and "dismo" version 1.3-5 were used for implementing the MaxEnt model (Muscarella et al. 2014; Hijmans et al. 2017). All the analyses codes are attached in Appendix-3.

5.3 Results

The model with variables in candidate set CTvD_r2 (all uncorrelated variables except annual precipitation, temperature seasonality, mean temperature of wettest quarter, ruggedness and landuse-landcover), all features and regularization multiplier 2 was selected as the best performing model (Appendix-4: Table 2). The final model fit was further assessed by ROC (receiver operating characteristic) curve on complete set including test and training data (AUC= 0.893, SE= 0.014) (Figure 5.1). The mean temperature of the coldest quarter, isothermality, human population density and mean diurnal temperature range were the main contributing factors in the MaxEnt model (Figure 5.2). Variable response curves for MaxEnt show that prediction probability for the wolf increased with an increase in mean temperature in the coldest quarter, isothermality and human population. The highest probability of wolf distribution was restricted between

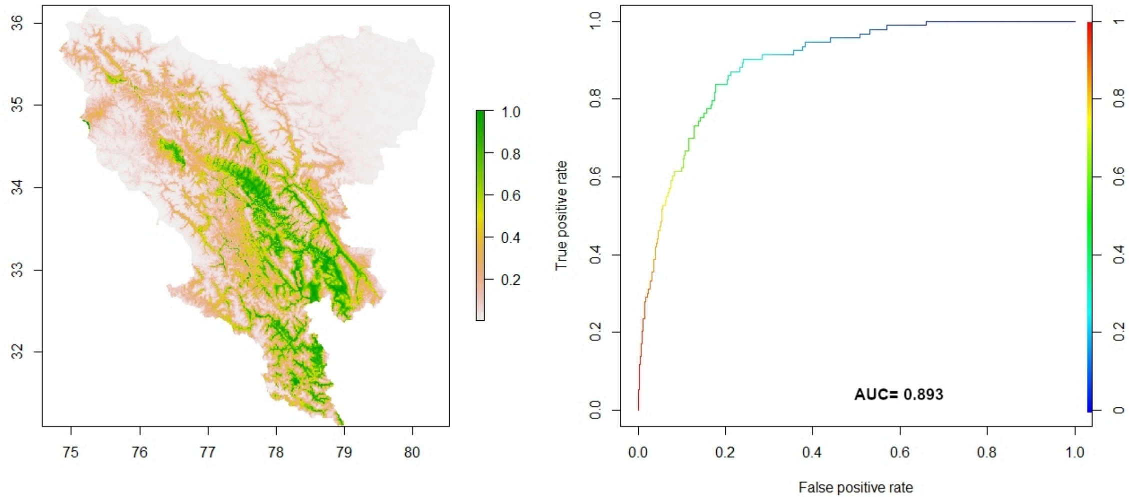

Figure 5.1 *Overview of the model output- (a) MaxEnt prediction of the wolf distribution, and (b) AUC (Area under the curve) of the ROC curve on complete set including test and training data.*

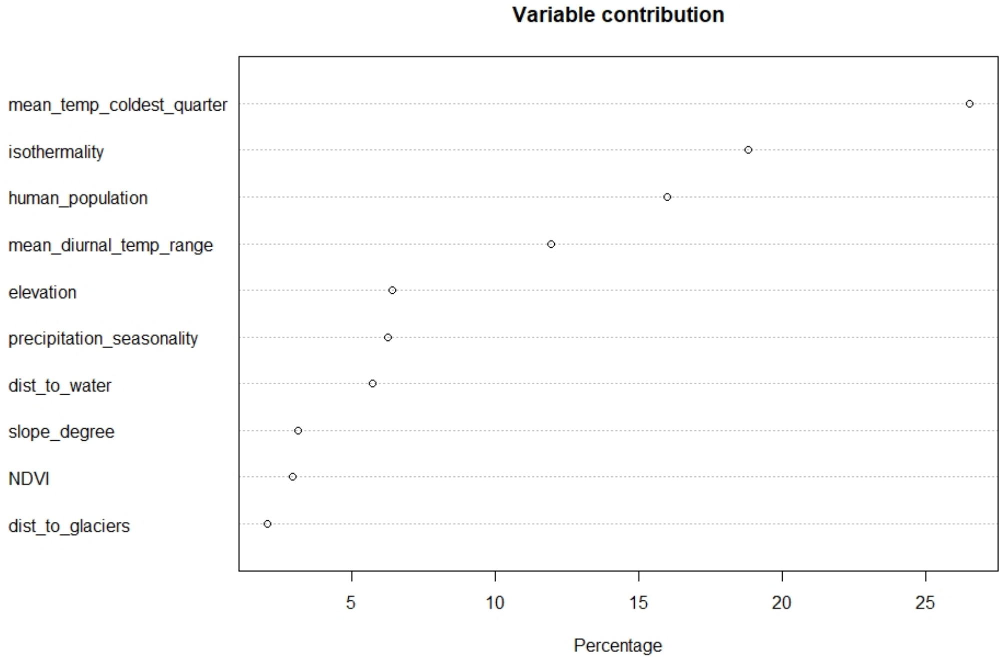

Figure 5.2 *Percent contribution of the variables in the wolf distribution model.*

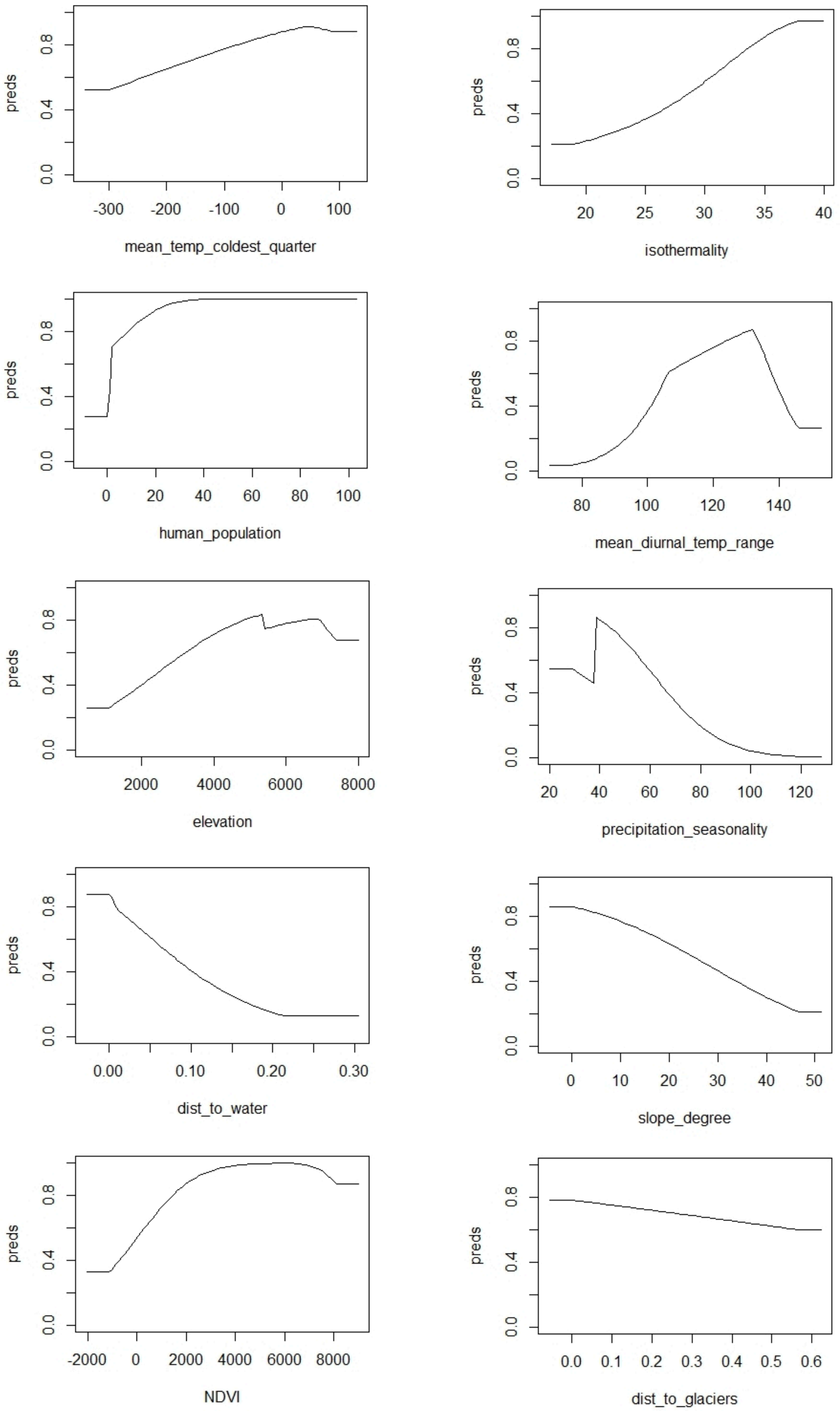

***Figure 5.3** Response of the variables to the probability of wolf distribution based on MaxEnt model.*

10 °C to 14 °C mean diurnal temperate range (Figure 5.3). The output of final model was classified into five equal-size categories of the distribution probabilities- 1) very low (< 0.20), 2) low (0.20- 0.40), 3) medium (0.40- 0.60), 4) high (0.60 – 0.8), and 5) very high (>0.8) (Figure 5.4). A total of 47,176.16 km^2 area in the north-western Trans-Himalayan landscape was found in the later three categories of the probability distribution (medium- 19,235.15, high- 15,118.74 and very high- 12,822.28 km^2). Landscape falling in medium and above classes was considered suitable habitat for the wolf in the Trans-Himalayan landscape of India.

5.4 Discussion

The wolves are considered to be habitat generalists. However, various wolf subspecies and lineages found in varying habitats (Wozencraft 2005) suggest distinguishable habitat selection among different wolves. Land cover as contiguous forest, prey density and availability of water correlate positively while human presence, road density and large water bodies correlate negatively with the distribution of wolves in other parts of the world (Fuller and Keith 1980; Mladenoff et al. 1995; Heptner and Naumov 1998; Whittington et al. 2005; Belongie 2008). Habitat use by grey wolves in North America was strongly correlated with the abundance of prey, snow conditions, absence or low livestock densities, road densities, human presence and topography (Paquet and Carbyn 2003; Belongie 2008). Presence of Iberian wolf *Canis lupus signatus* depended largely on landscape properties, followed by the presence of human and prey (Llaneza et al. 2012). Habitat selection by a close relative of the Himalayan wolf lineage in peninsular India, India wolf *Canis lupus pallipes*, was affected by the presence of prey, a refuge for denning and rendezvous sites and availability of water during critical denning phase (Habib 2007).

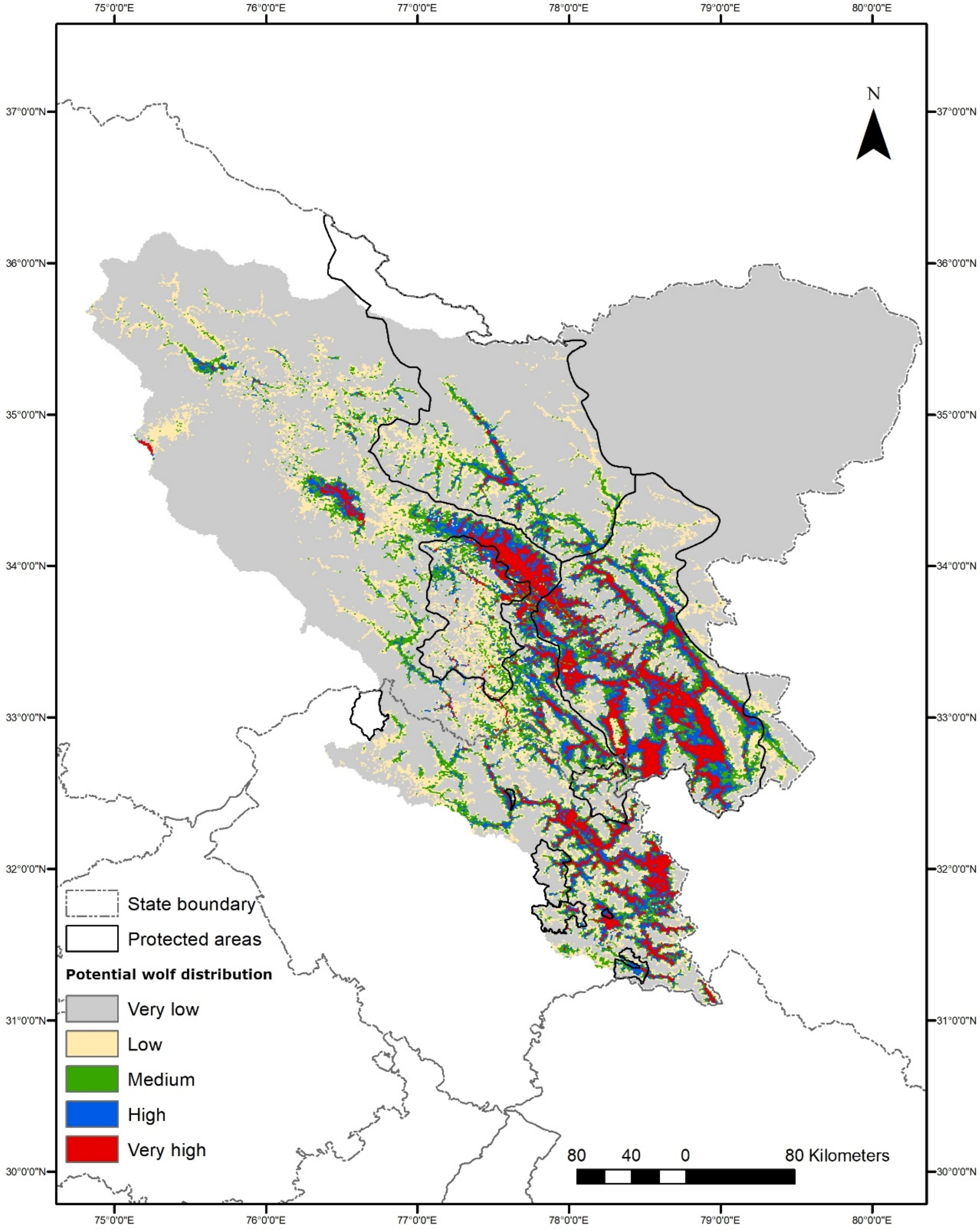

Figure 5.4 *Potential distribution of wolf in the North-Western Himalayan landscape, India. The high probability distribution area of the wolf is spread outside of the protected areas.*

In mountainous areas, wolves are reported to use valley bottoms and lower slopes that generally correspond to the presence of ungulate prey species (Paquet et al. 1996; Boyd-Heger 1997). Humans are also attracted to these same areas for varying purpose as grazing or facility development such as highways (Paquet et al. 1999). Wolves have historically been close to human settlements, allowing domestication and evolution of dogs (Hemmer 1990; Vilà et al. 1997; Coppinger and Coppinger 2001; VonHoldt et al. 2010). The Himalayan wolf distribution in the Trans-Himalayas also corresponds to the valley areas such as Spiti valley, Indus plains in Changthang WLS and Chiktan plains in Kargil district. The top contributing variable in the MaxEnt model (mean temperature of the coldest quarter) indicates that the warmer valleys during the winter season were preferred by the wolves (Figure 5.2). A similar effect of mean temperature of the coldest quarter on the distribution of the Himalayan wolf was also reported from the Trans-Himalayan landscape in the western Nepal (Subba et al. 2017). Although these wolves are known to have developed hypoxia tolerating genetic adaptations (Werhahn et al. 2018; Wang et al. 2020), they prefer to avoid extreme cold regions during winter season within the landscape.

Isothermality, another top contributor to the MaxEnt model, is correlated with the absence of human structures (Figure 5.2). Isothermality is low in the township areas, which would be avoided by the wolf. However, the wolves' distribution increased with an increase in human population. Generally, wolves are found in areas where adequate prey is available along with minimum human interference (Mladenoff et al. 1995). Higher human density in areas of less human structures could link to rural and pastoralist settlements, where availability of livestock as prey could support wolf presence. Arid wolves in Israel were also reported to behaviourally adapt to persist in the vicinity of humans for food subsidies (Barocas et al. 2018). Higher mean diurnal temperature range is an indicator of arid areas. The wolves in the Trans-Himalayas avoided extreme arid parts of the landscape, however showed selection toward mid-ranges of diurnal temperature variation. The wolves selected stable precipitation seasonality and higher NDVI, the areas with higher primary productivity. In the Trans-Himalayas most of the precipitation is received in low lying valleys, where most of the prey resources are available, including both the wild and domestic prey. The extreme slopes and difficult terrains were altogether avoided as these are not resourceful. In the case of Iberian wolves, food availability played a secondary role compared to landscape characteristics, which can offer refuge (Llaneza et al. 2012). Topographical features such as elevation and slope and ruggedness, did not contribute much to the final model in this study. Either the habitat in the Trans-Himalayan region has less variability hence having secondary importance to the wolf, or the habitat features at the coarse-scale of 1 sq. km. are not selected by the species. Further studies using fine-scale habitat variables could reveal more into the reason.

Wildlife populations in the Himalayan and Trans-Himalayan landscapes often occur across the landscape beyond the existing protected area network (Mishra 2001). A similar pattern is exhibited by the Himalayan wolf as well (Figure 5.4). The topography of the landscape had less role to play in the habitat selection of the Himalayan wolf in the study area, while human activity and climatic factors primarily drive their distribution pattern. Conservation management outside protected area network needs to be strengthened, emphasizing on the preservation of climate, increase in prey densities and minimal human interference. The human presence has been a source of livestock as prey item to the wolves for at least three millennia (Schaller 1998). However, the practice of nomadic pastoralism is transforming into other occupations rapidly (Dollfus 2012). Development and construction of human structures, and modification of the habitat are going to impact the wolf presence negatively. Wolf conservation in these areas, therefore, depends on the tricky balance of human presence and the quality of human interference.

Chapter 6

SYNTHESIS

6.1 Discussion and conclusion

The grey wolf *Canis lupus* has been historical ranging in the entire northern hemisphere (Mech and Boitani 2003). Various sub-species and lineages of wolves are known to adopt locally and vary in their morphology, behaviour and ecology (Busch 2018). The appearance of the grey wolf resembles that of domestic dog breeds but differentiated for having a larger head, narrower chest, longer legs, straighter tail and bigger paws (Lopez 1978). It has the largest body size among the members of family Canidae. The average weight of the male is 43-45 kg, whereas the average weight of the female is 36-38 kg (Mech 1981). The colour of fur varies widely from nearly pure white, red, or brown to black, but the coat colour changes with the season and winter fur are comparatively longer and bushy, usually mottled greyish (Sillero-Zubiri and Macdonald 2004). The black colour coat has been associated with wolf-dog hybridisation in North American grey wolf (Anderson et al. 2009); however, the hypothesis is contested (Caniglia et al. 2013). The wolf from the Himalayan region shows morphological adaptations such as well-developed frontal sinuses, unusually elongated muzzle, pale-colouration of the fur and woolliness of its underfur (Hodgson 1847; Blandford 1888). The Himalayan wolf, weighing around 35 kg, is slightly larger than the wolf from peninsular India (Pocock 1941; Shrotriya et al. 2012), which is the smallest of the wolves weighing on average 25 kg (Lopez 1978).

Wolves are highly territorial animals, and they defend their territories from other wolf packs. However, the size of their territories varies widely across the world. The smallest home range of wolf is reported from Portugal, which was only 16 km^2 (Okarma et al. 1998). The largest movement ranges are reported from Mongolian *Canis lupus chanco*, where one male and one female were collared. The collared wolves of Mongolia had two phases of their home ranges. During the resident phase, movement range for the female and male was 1,275 km^2 and 8,959 km^2, respectively. During the extension phase, their movement range increased as much as 6,634 km^2 and 23,920 km^2, respectively (Kaczensky et al. 2008). In most cases, the home ranges of the wolf, worldwide, are in the range of 100-300 km^2 (Peters and Mech 1975; Boitani 1982; Ciucci et al. 1997; Okarma et al. 1998). In India, Jethva (2002) reported the wolf home ranges of three packs and two solitary individuals ranging from 62.5 km^2 to 227.6 km^2 in Gujarat, India. Habib (2007) reported the home ranges of four radio-collared individuals in Maharashtra, varying from 128 km^2 to 216 km^2. Home ranges of three radio-collared Himalayan wolves in the Spiti valley ranged from 827.54 to 3055.45 km^2 (Shrotriya et al. 2017; Lyngdoh 2020).

Howling is used by the wolf as a mean of social-communication as well as for territorial marking (Harrington and Mech 1979). Modern statistical methods have allowed identifying individual wolves by their howling (Root-Gutteridge et al. 2014; Kershenbaum et al. 2016). A study comparing the howl features of the wolves from various parts of the world found that the Himalayan wolf howls are uniquely adapted to communicate in the highly windy environment of the Trans-Himalayas (Hennelly et al. 2017). The Himalayan wolf howl had the lowest mean frequency and coefficient of frequency variation. However, similar howl signature were also reported for Indian peninsular wolf (Sadhukhan et al. 2019). Therefore, acoustic differences between Indian wolf lineages and other wolves need further attention.

Estimating populations of wolves is complicated, and often relies on indirect methods (Marucco et al. 2009; Cullingham et al. 2016). The only available estimate of the wolves in the Trans-Himalayan landscape of India, approximated about 350 individuals in Ladakh and Spiti based on track densities (Fox and Chundawat 1995). In this study, the suitable wolf habitat was estimated to be 47,176 km^2 in the Trans-Himalayas of Ladakh and Himachal Pradesh. The mean minimum convex polygon (MCP) home range of the radio-collared wolves in Spiti valley was 1689.80 km^2 (Lyngdoh 2020). However, MCP home ranges include non-suitable areas as well. Therefore, 95% Brownian bridge movement model (BBMM) home ranges (374.17 km^2, range 283.93–422.17 km^2) could be used to estimate that how many wolf packs can fit into suitable habitat range (Lyngdoh 2020). Based on this information, about 126 wolf packs could exist in Ladakh and Spiti region of India. If a typical wolf-pack size ranges from 3 to 5 individuals, then the population of wolves in this region could be from 378 to 630 adult individuals. Methods based on acoustic signatures also hold promise for accurate and precise population estimation of wolves in the Himalayas in future (Root-Gutteridge et al. 2014)

Taxonomy of the Himalayan wolf is yet to be resolved (Alvares et al. 2019). Latest studies have reiterated that a unique and old lineage of wolves exists in the Himalayas, which has genetic adaptations to survive the extreme environmental conditions of the landscape (Matsumura et al. 2014; Chetri et al. 2016; Werhahn et al. 2017, 2018; Joshi et al. 2020; Wang et al. 2020). These studies also exhibit that the Himalayan wolf lineage may not be restricted strictly in the southern portion of the Tibetan plateau, but might be extended into China towards the north. Tibetan and Himalayan wolves have shown a high admixture (Werhahn et al. 2017; Joshi et al. 2020; Wang et al. 2020). The hypothesis of evolutionary isolation of the Himalayan wolf due to uplift of the Himalayas (Sun and Liu 2000; Jhala and Sharma 2004; Wang et al. 2020) explains the presence of unique genetic markers and adaptations to survive the hypoxia conditions of the high-altitudes (Werhahn et al. 2018). However, information originating from this thesis does not find any behavioural, ecological or geographical barrier facilitating an ongoing separation of the Himalayan wolf from other wolf lineages found in the surrounding landscapes. Except the mountain range of the Himalayas restrict their movement towards south. The wolf is a species of open plains, that can adapt to moderate hilly areas (Busch 2018). The wolves preferred gentle slopes and avoided rugged hilly terrains in the Trans-Himalayan landscape as well (Figure 5.3 & 5.4, Chapter-5). Adverse topography in the greater Himalayas and further ahead does not allow the Himalayan wolf to move towards south. The Kashmir valley is an exception where large open areas are available, and wolves have reached there (Lawrence 1895; Shrotriya et al. 2012). The admixture of the Himalayan wolves with other wolves (Indian wolf and Holarctic grey wolf) is potentially present in the Kashmir valley as well as Gilgit-Baltistan region.

This thesis tested two hypotheses on the Himalayan wolf ecology: 1) the wolf was expected to shift the diet to easily procurable and abundant livestock while successfully minimising the risk of being persecuted, and 2) a threshold level of the human presence was expected as it a major cause of disturbance and persecution while associated with the presence of livestock as prey. Livestock was the dominant prey item in the dietary spectrum of the Himalayan wolf (Table 4.2, Chapter-4). The wolves, however, showed that an increased abundance of wild prey allows them to avoid consuming domestic prey (Figure 4.6, Chapter-4). Similar to the European wolves (Newsome et al. 2016), prey switching by wolves was supported by evidence in the Trans-Himalayan landscape. Human perception towards wolves has remained mostly negative world over (Berg 2001). However, the livelihood practices and presence of feral dogs shaped the public attitude towards the wolves in the Trans-Himalayan landscape of India (Figure 2.7 & 2.8, Chapter-2). The human population density positively influenced the distribution of the wolves, while build-up areas had negative impact (Figure 5.3, Chapter-5). Although the negative influence of the human presence through habitat change and positive effect via the availability of livestock was supported by the data, yet these data could not be analysed to find the optimum human presence threshold for continued wolf survival.

6.2 Conservation recommendations

While climate change and hybridisation have emerged as recent challenges to the wolves in the Himalayan landscape (Hennelly et al. 2015), retaliatory killing remains the single most important threat to them (Mishra 2001; Subba 2012; Suryawanshi et al. 2017). Pastoralism in the Trans-Himalayan landscape is three millennia-old practice (Handa 1994; Schaller 1998; Mishra et al. 2010). Wolves and other species have evolved with the pastoralism in recent history. Pastoralist communities face livestock loss to the predator species and also conduct retaliatory killing of them, particularly wolves. Pastoralists have acquired a more significant role in the Himalayan ecosystem and have become an integral part of the ecological processes of the Himalayas. Wolves in the Himalayas are surviving despite a low abundance of the wild prey because of livestock providing a substantial part of their diet. Decline in the pastoralists practices (Dollfus 2012) without alternate sources of diet could have an adverse effect on wolf survival. Management practices targeting improvement of the wild prey densities would benefit the wolves and other carnivores. Shifting of wolves on wild prey would also reduce the conflict with the pastoralists; which, coupled with active engagement in changing public perception via awareness, compensation and livestock protection, should be another top priority goal for the management. The wolves, along with their prey species, are distributed across the landscape and not restricted to protected areas only (Figure 3.5 & 3.10, Chapter-3; Figure 5.4, Chapter-5). Protected areas in the high-altitudes of Ladakh and Spiti are vast in area and often include inaccessible topographies; therefore, are difficult to manage with intense planning. While snow leopard presence is restricted to steep slope and cliff-habitats (Watts et al. 2019), wolves are spread over open valleys. The similar habitat requirements of humans and wolves bring them close to each other and at conflict. Targeted conservation efforts in such valleys would be the most beneficial to wolf conservation in the Trans-Himalayan landscape of India.

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APPENDIX- 1

Details of the villages covered during the questionnaire survey.

S. No.	Village	Latitude	Longitude	Region (District)	No. of Interviews
1	Akgam	34.3276	77.8304	Nubra (Leh)	1
2	Akshow	33.5126	76.8056	Zanskar (Kargil)	21
3	Alchi	34.2270	77.1703	Leh (Leh)	25
4	Atting Shagar	33.5635	76.7479	Zanskar (Kargil)	28
5	Basgo	34.2137	77.2907	Leh (Leh)	46
6	Bokdang	34.8041	77.0362	Nubra (Leh)	30
7	Buk	32.4436	78.5636	Changthang (Leh)	2
8	Buk anlay	32.7420	78.9557	Changthang (Leh)	2
9	Burma	33.8796	78.2873	Changthang (Leh)	2
10	Chamshan	34.4036	77.3495	Nubra (Leh)	15
11	Chanchas	34.4576	76.8374	Leh (Leh)	1
12	Changmar	34.7673	77.1190	Nubra (Leh)	3
13	Chibra	33.9068	78.2654	Changthang (Leh)	6
14	Chibra-zara	33.9050	78.2562	Changthang (Leh)	8
15	Chilam	33.9871	78.1666	Changthang (Leh)	3
16	Chubi	34.1009	77.3523	Leh (Leh)	6
17	Chulungka	34.8221	76.9391	Nubra (Leh)	6
18	Chumathang	33.2132	78.2100	Leh (Leh)	1
19	Chushul	33.5970	78.6511	Changthang (Leh)	28
20	Dibra	32.4347	77.3232	Changthang (Leh)	8
21	Digger	34.2928	77.8050	Nubra (Leh)	13
22	Digulbuk	32.4626	78.5830	Leh (Leh)	3
23	Disket	34.5512	77.5496	Nubra (Leh)	4
24	Domkhar	34.4564	78.8410	Leh (Leh)	14
25	Durbuk	34.0860	78.1248	Changthang (Leh)	4
26	Earath	33.9659	78.1928	Changthang (Leh)	5
27	Gangkhaldo	32.4614	78.5835	Leh (Leh)	6
28	Garadhi	34.8283	76.9201	Nubra (Leh)	2
29	Hanu	34.1817	76.5844	Leh (Leh)	41
30	Himeshukpachan	34.3193	77.0774	Leh (Leh)	30
31	Hundar	34.5848	77.4717	Nubra (Leh)	28
32	Hundar dok	34.5037	77.4184	Nubra (Leh)	8
33	Hundri	34.6707	77.3905	Nubra (Leh)	14
34	Khaktet	33.7700	78.6193	Changthang (Leh)	1
35	Khaldo	32.4638	78.5904	Leh (Leh)	2
36	Khaltsar	34.4933	77.7118	Nubra (Leh)	5
37	khaltsi	34.1918	76.5253	Leh (Leh)	20
38	Khardong	34.3983	77.6568	Nubra (Leh)	17
39	Khema	34.2462	77.8118	Nubra (Leh)	5

S. No.	Village	Latitude	Longitude	Region (District)	No. of Interviews
40	Khimi	34.5672	77.2555	Nubra (Leh)	10
41	Khungru	34.2845	77.8285	Nubra (Leh)	2
42	Kongsarpo	32.4325	78.3224	Leh (Leh)	2
43	Kongto	34.2917	77.8380	Nubra (Leh)	3
44	Korzok	32.9673	78.2638	Changthang (Leh)	4
45	Kungzee	32.4729	78.5814	Leh (Leh)	3
46	Kyungtso	32.9379	78.5592	Changthang (Leh)	11
47	Lagaa	34.0911	78.1263	Changthang (Leh)	11
48	Lakjung	34.3518	77.3706	Nubra (Leh)	2
49	Lal pahari	32.9616	78.8976	Changthang (Leh)	30
50	Lamayuru	34.1702	76.4606	Leh (Leh)	22
51	Largabgongma	34.6209	77.1252	Nubra (Leh)	11
52	Largabyokma	34.6507	77.1373	Nubra (Leh)	52
53	Liker	34.2756	77.1929	Leh (Leh)	2
54	Lopur	33.3554	78.8676	Changthang (Leh)	3
55	Lukung	33.9982	78.4077	Changthang (Leh)	1
56	Lungser	32.8975	78.3667	Changthang (Leh)	6
57	Maan	33.8633	78.5272	Changthang (Leh)	8
58	Mayrag	33.7979	78.5958	Changthang (Leh)	3
59	Naga	32.4702	78.5847	Leh (Leh)	1
60	Nagurak	33.1427	78.0257	Leh (Leh)	6
61	Namgo	34.1084	78.1132	Changthang (Leh)	1
62	Nangchuduk	33.1426	78.0300	Leh (Leh)	1
63	Neay	34.1554	77.1738	Leh (Leh)	23
64	Nimo	34.2000	77.3381	Leh (Leh)	41
65	Nurla	34.1759	76.5933	Leh (Leh)	13
66	Obayrag Padum	33.4640	76.8779	Zanskar (Kargil)	18
67	Padum	33.4539	76.8771	Zanskar (Kargil)	30
68	panamik	34.4723	77.3195	Nubra (Leh)	10
69	Partapur	34.6118	77.4492	Nubra (Leh)	14
70	Patsathang	34.6999	77.1499	Nubra (Leh)	8
71	Patsathang	34.8944	76.7944	Nubra (Leh)	11
72	Phalanglay	33.9971	78.1493	Changthang (Leh)	2
73	Phobrang	33.9992	78.4077	Changthang (Leh)	1
74	Phyang	34.1897	77.4889	Leh (Leh)	105
75	Pillalsaltsal	33.9313	78.2630	Changthang (Leh)	1
76	Punguk	32.4602	78.5429	Changthang (Leh)	10
77	Punpun	34.0657	78.1488	Changthang (Leh)	8
78	Rantagsha	33.5688	77.5842	Zanskar (Kargil)	16
79	Razonakpo	32.4741	78.3132	Changthang (Leh)	2
80	Remala skyagam	33.6462	76.6327	Zanskar (Kargil)	40
81	Rotsibok	32.4418	78.3308	Changthang (Leh)	2
82	Rukruk	33.4917	76.8711	Zanskar (Kargil)	13
83	Rupsho	33.0331	78.1745	Changthang (Leh)	2

S. No.	Village	Latitude	Longitude	Region (District)	No. of Interviews
84	Saboo	34.1293	76.6274	Leh (Leh)	52
85	Sakti- Taknak	34.0139	77.8198	Leh (Leh)	8
86	Samayrokchan	33.1541	77.5948	Leh (Leh)	1
87	Sankar	34.1025	77.3517	Leh (Leh)	5
88	Saspol	34.2450	77.1600	Leh (Leh)	38
89	Sato	33.8834	78.2860	Changthang (Leh)	8
90	Shachukul	33.9884	78.1065	Changthang (Leh)	15
91	Shayok	34.1763	78.1392	Nubra (Leh)	5
92	Shugukur	34.6859	77.3132	Nubra (Leh)	2
93	Skamphuk	34.6235	77.4348	Nubra (Leh)	12
94	Skindingyang	34.2206	76.5411	Leh (Leh)	8
95	Skuarbuchan	34.2545	76.4312	Leh (Leh)	93
96	Skuru	34.6710	77.2946	Nubra (Leh)	12
97	Sousani	33.5116	76.8061	Zanskar (Kargil)	25
98	Spangmig	33.9073	78.4587	Changthang (Leh)	2
99	Spituk	34.1257	77.5218	Leh (Leh)	31
100	Stara salapi	33.4853	76.8465	Zanskar (Kargil)	33
101	Sumdo	33.2298	78.3659	Changthang (Leh)	1
102	Sumur	34.3716	77.3682	Nubra (Leh)	40
103	Sunudho	34.8250	77.1618	Nubra (Leh)	2
104	Takmachik	34.3835	76.7602	Leh (Leh)	15
105	Tangtse	34.0269	78.1709	Changthang (Leh)	10
106	Tangyar	34.2529	77.8751	Nubra (Leh)	8
107	Tangyar Tokpo	34.2445	77.8623	Nubra (Leh)	13
108	Tasaphuk	33.1455	78.0121	Changthang (Leh)	2
109	Tegazong	32.4138	77.3222	Changthang (Leh)	2
110	Temisgam	34.1951	76.5903	Leh (Leh)	4
111	Thanglasgo)	34.4161	77.4650	Nubra (Leh)	1
112	Tharuk	34.0154	78.1280	Changthang (Leh)	44
113	Thukje	33.2136	78.2054	Changthang (Leh)	10
114	Tia	34.2004	76.5851	Leh (Leh)	68
115	Tigger	34.3854	77.3656	Nubra (Leh)	32
116	Tirisha	34.4420	77.3424	Nubra (Leh)	5
117	Tirit	34.3223	77.3880	Nubra (Leh)	11
118	Tonrian thagan	33.5368	76.7895	Zanskar (Kargil)	25
119	Treshy	34.6620	77.3268	Nubra (Leh)	15
120	Tsaga	33.3308	78.8515	Changthang (Leh)	9
121	Tsomgo	33.9161	78.2664	Changthang (Leh)	1
122	Tungre padum	33.4618	76.4587	Zanskar (Kargil)	22
123	Turtuk	34.8481	76.8304	Nubra (Leh)	47
124	Tyakshy	34.8877	76.8037	Nubra (Leh)	1
125	Udmaru	34.7047	77.2683	Nubra (Leh)	15
126	Upshi	33.4907	77.4917	Leh (Leh)	3
127	Wanla	34.1457	76.4949	Leh (Leh)	45

S. No.	Village	Latitude	Longitude	Region (District)	No. of Interviews
128	Waris	34.8733	77.1217	Nubra (Leh)	12
129	Yangthang	34.3133	77.1203	Leh (Leh)	6
130	Yourthing	34.1033	77.3505	Leh (Leh)	1
131	Yul yogma	34.1162	78.1067	Changthang (Leh)	2
132	Yulkam	34.4234	77.3451	Nubra (Leh)	6
133	Zhung demo	32.8013	78.9420	Changthang (Leh)	5

APPENDIX-2

Questionnaire for Public survey Date:__/__/__ Form no.______ Observer(s) ____________

Village/locality		Area (Write protected area name, or None, if no PA in vicinity)	
GPS location	N	E	Elv.
Block		District (State)	
Village/nomadic group Total Population		No. of household/ families	

Respondent profile Name of the responded______________________ Nomadic/Settler

Cultural identity		Age		Male / Female	Education	
Main occupation		Annual income			Family size	

Grazing Practice

1. How much livestock do you and the village/group own?

Species	Goat & Sheep	Buffalo & Cow	Horse/ Ponies	Donkey/ Mule	Yak	Dzo/ Dzumo		
Own								
Village								

2. Grazing duration a: Supervised ______________________ Unsupervised _________________
   b: At home/winter __________________ At pasture ____________________
3. Who herds your livestock? ________________________ Herding: Local/ Taken to distant pastures
4. Name your main pastures with distances from this locality? ________________________________
   ____
5. Does livestock from other areas/villages also join (Name those)? ____________________________
   ____
6. Is there any Grazing permit policy? Comment __________________________________ YES / NO
   Charges _______________________ Livestock allowed________________________________

Conflict & Wildlife Sighting Information

7. Did you or any person in your information have lost any livestock during last 1 year?

REASONS	Natural Death		Disease		Wolf		Other Carnivores ______________ ______________	
	Own	Village	Own	Village	Own	Village	Own	Village
Livestock Species (Number)								
Where?								
When?								
Loss value (in Rupees)								

8. Have you sighted wolf recently (Number, When, Where)?

____

9. If you encountered any other carnivore species in last 1 year (Species, Number, When, Where)?

____

____

10. What are the other wildlife species sighted directly and/or found in your locality?

____

PERCEPTION

11. Do you believe into co-existence with these animals? (attitude question)

Strongly disagree-5 Disagree-4 Neutral-3 Agree-2 Strongly agree-1

Wolf ☐ Snow Leopard ☐ Fox ☐ Wild Ungulates ☐ __________ ☐

12. How important is the existence of these animals in this landscape to you? (Knowledge question)

Very important-5 Important-4 Neutral-3 Rather important-2 Totally Unimportant-1

Wolf ☐ Snow Leopard ☐ Fox ☐ Wild Ungulates ☐ __________ ☐

How much these animals affect (negatively) your livelihood?

Strongly-4 Moderately-3 Less effect-2 Not much-1 Positively-0

Wolf ☐ Snow Leopard ☐ Fox ☐ Wild Ungulates ☐ __________ ☐

13. How much livestock loss by carnivore species is acceptable for you?

____

14. If numbers exceed acceptable limits what will you do?

____

15. If wolf depredate your livestock what will you do?

____

16. What do you think about wolf population in last 10 yrs? Increasing/ decreasing/ constant
17. What kind of preventive measure do you use to protect livestock from carnivores?
    A. Preventive measures (e.g., overnight watch, trapping, poisoning kill)
    B. Use Frequency- How frequently do you use this measure (in approx. proportion, ratio, percent)
    C. Success- What is the success of these measures (in approx. no., proportion, frequency, ratio etc)
    D. Define success- When do you consider that measure taken was successful

A						
B						
C						
D						

MIGRATION INFORMATION

18. Migration pattern (If possible, provide a map of local area to mark the locations and tracks)
    a. Major locations, b. Duration of stay (from-to), c. Describe the route taken in between

a									
b									
c									

19. Is there any change in the migration and grazing practice? Comment ________________________

____

20. Will you continue the pastoralist lifestyle if other options available? And what are such options are?

____

____

APPENDIX- 3

R programming codes used for various analyses performed in the thesis.

Chapter 2

```
###Ordinal regression of public attitudes

data <- read.csv("…/for_mod2.csv", header = T, na.strings=c("","
","NA"))

#Data preparation as ordinal variable

data$Wolf = factor(data$Wolf, levels = c("1", "2", "3", "4", "5"),
ordered = TRUE)

data$sl_attitude = factor(data$sl_attitude, levels = c("1", "2", "3",
"4", "5"), ordered = TRUE)

data$PA_bi = factor(data$PA_bi, levels = c("0", "1"))

data$Villager = as.factor(data$Villager)

data$religion = as.factor(data$religion)

data$M_bi = as.factor(data$M_bi)

data$education = factor(data$education, levels = c("no", "edu",
"high"), ordered = TRUE)

data$occupation = as.factor(data$occupation)

data$sl_attitude = factor(data$sl_attitude, levels = c("1", "2", "3",
"4", "5"), ordered = TRUE)

data$liv_w = as.factor(data$liv_w)

data$liv_s = as.factor(data$liv_s)

##regression for wolf attitudes

library(ordinal)

data <- na.omit(data)

wm1 <- clm(Wolf ~ PA_bi+religion+M_bi+occupation+Age+lat+long+liv_w,
             data = data)

wm2 <- clm(Wolf ~ PA_bi+religion+M_bi+occupation+liv_w,
             data = data)

wm3 <- clm(Wolf ~ PA_bi+religion+M_bi+occupation,
             data = data)

wm4 <- clm(Wolf ~ PA_bi,
           data = data)

wm5 <- clm(Wolf ~ religion,
           data = data)

summary(wm1) #For summary of the desired model

AIC(wm1) #AIC value of the model
```

```
#Effects
library(effects)
library(MASS)
plot(Effect("occupation", wm2),lines=list(multiline=TRUE))
plot(Effect("PA_bi", wm2),lines=list(multiline=TRUE))
plot(Effect("religion", wm2),lines=list(multiline=TRUE))
plot(Effect("M_bi", wm2),lines=list(multiline=TRUE))
plot(Effect("liv_w", wm2),lines=list(multiline=TRUE))
##regression for Snow Leopard attitudes
data <- na.omit(data)
sm1 <- clm(sl_attitude ~ 
PA_bi+religion+M_bi+occupation+Age+lat+long+liv_s,
           data = data)
sm2 <- clm(sl_attitude ~ PA_bi+religion+M_bi+occupation+liv_s,
           data = data)
sm3 <- clm(sl_attitude ~ PA_bi+religion+M_bi+occupation,
           data = data)
sm4 <- clm(sl_attitude ~ PA_bi,
           data = data)
sm5 <- clm(sl_attitude ~ religion,
           data = data)
summary(sm1) #For summary of the desired model
AIC(sm1) #AIC value for the model
##Wincoxon signed-ranked test comparing attitude for wolves and dogs
data <- read.csv("wolf_dog.csv")
data <- na.omit(data)
library(MASS)
wilcox.test(data$Wolf, data$Dog, paired=TRUE)
```

Chapter 4

```
### Analysis of Pianka's niche overlap
Data.Matrix <- read.csv("…/ecosim_diet.csv")
rownames(Data.Matrix) <- Data.Matrix$Species
Data.Matrix <- Data.Matrix[,-1]
#simulated comparison
library(EcoSimR)
set.seed(123)
```

```
p.mod <- niche_null_model(Data.Matrix, algo = "ra3", metric = "pianka",
                 nReps = 1000, saveSeed = T)
summary(p.mod)
plot(p.mod)
plot(p.mod,type="niche")
#plotting observed vs simulated
Data <- Data.Matrix/rowSums(Data.Matrix)
Ylalbel <- colnames(Data.Matrix)
plot(rep(1:ncol(Data),times =
nrow(Data)),rep(1:nrow(Data),each=ncol(Data)),
     xlab="",ylab="", cex=20*sqrt(t(Data)/pi),col="red",lwd=2,
     main="",yaxt="n", xaxt='n')
Rand.Matrix <- p.mod$Randomized.Data/rowSums(p.mod$Randomized.Data)
plot(rep(1:ncol(One.Null.Matrix),times = nrow(One.Null.Matrix)),
      rep(1:nrow(One.Null.Matrix),each=ncol(One.Null.Matrix)),
      xlab="",ylab="",cex=20*sqrt(t(One.Null.Matrix)/pi),col="royalblue
      3",lwd=2,
      main="Utilization Matrix",yaxt="n", xaxt='n')
axis(2,at=c(1,2,3),labels=c("Wolf","Snow Leopard","Red Fox"), las=0)
axis(1, at=seq(1, 19, by=1), labels = FALSE)
text(seq(1, 19, by=1), par("usr")[3] - 0.2, labels = Ylalbel, srt = 45,
pos = 1, xpd = TRUE)
### RLQ analysis
library(ade4)
R <- read.csv("…/R_pred.csv", skip = 2, header = T)
rownames(R) <- R$X
L <- read.csv("…/L_diet.csv", skip = 0, header = T)
rownames(L) <- L$X
L1 <- apply(L[1:5,], 2, mean)
L2 <- apply(L[6:8,], 2, mean)
L3 <- apply(L[9:11,], 2, mean)
L.n <- rbind(L1,rbind(L2,L3))
L.n <- as.data.frame(L.n)
colnames(L.n) <- colnames(L)
rownames(L.n) <- rownames(R)
Q <- read.csv("…/Q_prey.csv", skip = 2, header = T)
rownames(Q) <- Q$X
afcL.aravo <- dudi.coa(L.n, scannf = FALSE)
```

```
acpR.aravo <- dudi.hillsmith(R, row.w = afcL.aravo$lw, scannf = FALSE)
acpQ.aravo <- dudi.pca(Q, row.w = afcL.aravo$cw, scannf = FALSE)
rlq.aravo <- rlq(acpR.aravo, afcL.aravo, acpQ.aravo, scannf = FALSE)
plot(rlq.aravo)
plot(rlq.aravo$l1)
par(mfrow = c(1, 1))
s.arrow(rlq.aravo$l1)
s.arrow(rlq.aravo$c1)
s.label(rlq.aravo$lQ, boxes = FALSE)
s.arrow(rlq.aravo$mR)
summary(rlq.aravo)
#Fourth-corner analysis
nrepet <- 9999
four.comb.aravo <- fourthcorner(R, L.n,
                        Q, modeltype = 6, p.adjust.method.G = "none",
                        p.adjust.method.D = "none", nrepet = nrepet)
plot(four.comb.aravo, alpha = 0.05, stat = "D2")
four.comb.aravo.adj <- p.adjust.4thcorner(four.comb.aravo,
                  p.adjust.method.G = "fdr", p.adjust.method.D = "fdr")
plot(four.comb.aravo.adj, alpha = 0.05, stat = "D2")
#Combined
testrlq.aravo <- randtest(rlq.aravo, modeltype = 6, nrepet = nrepet)
testrlq.aravo
plot(testrlq.aravo)
Srlq <- fourthcorner2(R, L.n, Q, modeltype = 6,
                  p.adjust.method.G = "fdr", nrepet = nrepet)
Srlq$trRLQ
plot(four.comb.aravo.adj, x.rlq = rlq.aravo, alpha = 0.05,
     stat = "D2", type = "biplot")
testQaxes.comb.aravo <- fourthcorner.rlq(rlq.aravo, modeltype = 6,
                  typetest = "Q.axes", nrepet = nrepet,
                  p.adjust.method.G = "fdr", p.adjust.method.D = "fdr")
testRaxes.comb.aravo <- fourthcorner.rlq(rlq.aravo, modeltype = 6,
                  typetest = "R.axes", nrepet = nrepet,
                  p.adjust.method.G = "fdr", p.adjust.method.D = "fdr")
print(testQaxes.comb.aravo, stat = "D")
print(testRaxes.comb.aravo, stat = "D")
```

```
par(mfrow = c(1, 1))
plot(testQaxes.comb.aravo, alpha = 0.05, type = "table", stat = "D2")
plot(testRaxes.comb.aravo, alpha = 0.05, type = "table", stat = "D2")
par(mfrow = c(1, 2))
plot(testQaxes.comb.aravo, alpha = 0.05, type = "biplot",
     stat = "D2", col = c("black", "blue", "orange", "green"))
plot(testRaxes.comb.aravo, alpha = 0.05, type = "biplot",
     stat = "D2", col = c("black", "blue", "orange", "green"))
### Log-likelihood test ratio
food <- read.csv("…/preypref_loglike.csv")
food.test <- chisq.test(food$ov_use, p=food$av_prop)
#Results of Chi-sq test
food.test
#Likelihood test ratio
g2.test <- with(food.test,2*sum(observed * log(observed/expected),
na.rm=TRUE))
g2.pvalue <- 1-pchisq(g2.test,food.test$parameter)
cat("G2 test for independence: ", round(g2.test,2),"with",
food.test$parameter," df ", "with p-value", round(g2.pvalue,3),"\n\n")
```

Chapter 5

```
###Tuning Maxent model###
library(ENMeval)
library(raster)
library(dplyr)
library(kuenm) # installed with
devtools::install_github("marlonecobos/kuenm")
library(ecospat)
library(ROCR)
library(boot)
set.seed(825) #Setting randomization seed for reproducibility
## presence data, locations were rarefied to resemble similar sampling
effort throughout
Wolf_n= read.csv("…/rarefied_points.csv")
setwd("…/wolf_var") #setting variable dir
#Reading env layers
datafiles = Sys.glob("*.tif")
datafiles #list of predictors
stck = stack(datafiles)
```

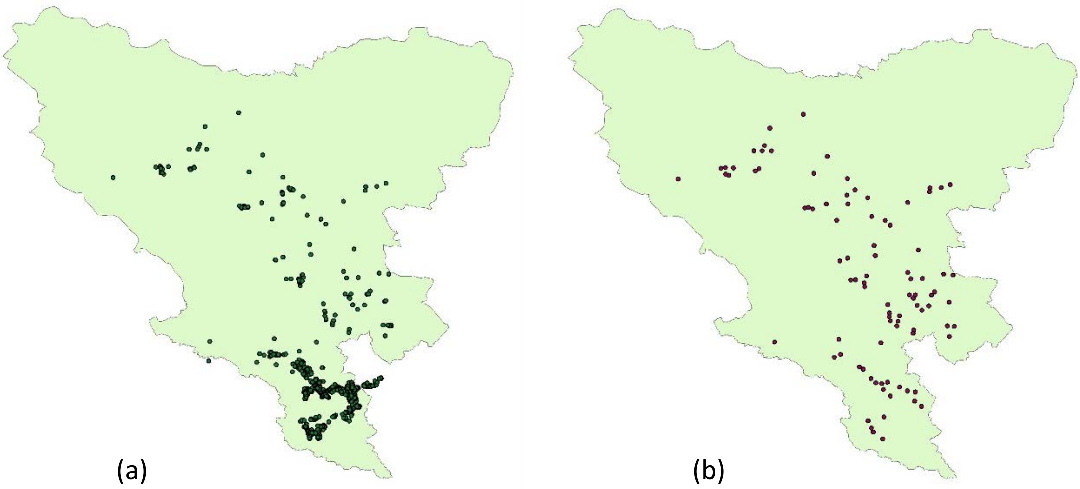
```
# Plot first raster in the stack, the mean annual temperature.

plot(stck$elevation, main="elevation")

points(wolf_n)# add presence points

#Selection of background area

bg_raster <- raster("…/background_raster.tif")

plot(bg_raster)

#Selection of 10000 random background data points

backg <- randomPoints(bg_raster, n=10000, p=wolf_n) %>% as.data.frame()

colnames(backg) <- colnames(wolf_n)

points(wolf_n, col='blue') #add presence points

points(backg) #add background points

#Variable combinations

C <- stack(stck$mean_temp_coldest_quarter, stck$annual_precipitation,
     stck$precipitation_seasonality, stck$mean_diurnal_temp_range,
     stck$isothermality, stck$temperature_seasonality,
     stck$mean_temp_wettest_quarter)

Tv <- stack(stck$elevation, stck$dist_to_glaciers, stck$dist_to_water,
     stck$landuse.landcover, stck$NDVI, stck$ruggedness,
     stck$slope_degree)

CTvD <- stack(C,Tv, stck$human_population)

CTv <- stack(C,Tv)

CD <- stack(C,stck$human_population)

TvD <- stack (Tv,stck$human_population)

CTvD_r1 <- stack(stck$mean_temp_coldest_quarter,
     stck$precipitation_seasonality, stck$mean_diurnal_temp_range,
     stck$isothermality,Tv,stck$human_population)

CTvD_r2 <- stack(stck$mean_temp_coldest_quarter,
     stck$precipitation_seasonality, stck$mean_diurnal_temp_range,
     stck$isothermality, stck$elevation, stck$dist_to_glaciers,
     stck$dist_to_water, stck$NDVI,
     stck$slope_degree,stck$human_population)

CTvD_r3 <- stack(stck$mean_temp_coldest_quarter,
     stck$precipitation_seasonality, stck$mean_diurnal_temp_range,
     stck$isothermality, stck$elevation, stck$dist_to_water, stck$NDVI,
     stck$slope_degree,stck$human_population)

#Custom validation statistics

proc <- function(vars) {

  proc <- kuenm::kuenm_proc(vars$occs.val.pred, c(vars$bg.train.pred,
vars$bg.val.pred))

  out <- data.frame(proc_auc_ratio = proc$pROC_summary[1],

                    proc_pval = proc$pROC_summary[2], row.names = NULL)

  return(out)

}
```

```
#Setting tuning arguments

tune.args <- list(fc = c("L", "LQ", "H", "LQH", "LQHP", "LQHPT"), rm =
c(0.5, 1, 1.5, 2, 2.5, 3))

#Combination model with block partitioning

e.mx.C <- ENMevaluate(wolf_n, C, backg, algorithm = "maxnet",
                      tune.args = tune.args, partitions = "block",
                      user.eval = proc, parallel=T, numCores=6)

e.mx.Tv <- ENMevaluate(wolf_n, Tv, backg, algorithm = "maxnet",
                       tune.args = tune.args, partitions = "block",
                       categoricals='landuse.landcover',
                       user.eval = proc, parallel=T, numCores=6)

e.mx.CTvD <- ENMevaluate(wolf_n, CTvD, backg, algorithm = "maxnet",
                       tune.args = tune.args, partitions = "block",
                       categoricals='landuse.landcover',
                       user.eval = proc, parallel=T, numCores=6)

e.mx.CTv <- ENMevaluate(wolf_n, CTv, backg, algorithm = "maxnet",
                        tune.args = tune.args, partitions = "block",
                        categoricals='landuse.landcover',
                        user.eval = proc, parallel=T, numCores=6)

e.mx.CD <- ENMevaluate(wolf_n, CD, backg, algorithm = "maxnet",
                       tune.args = tune.args, partitions = "block",
                       user.eval = proc, parallel=T, numCores=6)

e.mx.TvD <- ENMevaluate(wolf_n, TvD, backg, algorithm = "maxnet",
                        tune.args = tune.args, partitions = "block",
                        categoricals='landuse.landcover',
                        user.eval = proc, parallel=T, numCores=6)

e.mx.CTvD_r1 <- ENMevaluate(wolf_n, CTvD_r1, backg, algorithm =
                        "maxnet", tune.args = tune.args,
                        partitions = "block", categoricals=
                        'landuse.landcover', user.eval = proc,
                        parallel=T, numCores=6)

e.mx.CTvD_r2 <- ENMevaluate(wolf_n,CTvD_r2, backg, algorithm =
                        "maxnet", tune.args = tune.args, partitions =
                        "block", user.eval = proc, parallel=T,
                        numCores=6)

e.mx.CTvD_r3 <- ENMevaluate(wolf_n, CTvD_r3, backg, algorithm =
                        "maxnet", tune.args = tune.args, partitions =
                        "block", user.eval = proc,
                        parallel=T, numCores=6)
```

```
e.mx.CTvD@results  #Results of desired model with full set
e.mx.CTvD@results.partitions ##Results of the partitions of model
#model selection
res <- eval.results(e.mx.CTvD_r2) #enter the candidate model
opt.seq <- res %>%
  filter(delta.AICc <= 2) %>%
  filter(or.10p.avg == min(or.10p.avg)) %>%
  filter(auc.val.avg == max(auc.val.avg))
opt.seq
mod.seq <- eval.models(e.mx.CTvD_r2)[[opt.seq$tune.args]]
mod.seq$betas
plot(mod.seq, type = "cloglog")
pred.seq <- eval.predictions(e.mx.CTvD_r2)[[opt.seq$tune.args]]
plot(pred.seq)
#ROC curve
prs <- extract(pred.seq, wolf_n)#predictions at presence locations
abs <- na.omit(extract(pred.seq, backg))#predictions at presence
locations
combined <- c(prs, abs) # combine into a single vector
label <- c(rep(1,length(prs)),rep(0,length(abs))) # labels: 1=present,
0=random
pred <- prediction(combined, label) # labeled predictions
perf <- performance(pred, "tpr", "fpr") # True / false positives, for
ROC curve
plot(perf, colorize=TRUE) # Show the ROC curve
performance(pred, "auc")@y.values[[1]] # Calculate the AUC
#Bootstrap SE
AUC <- function(p,ind) {
  pres <- p[ind]
  combined <- c(pres, abs)
  label <- c(rep(1,length(pres)),rep(0,length(abs)))
  predic <- prediction(combined, label)
  return(performance(predic, "auc")@y.values[[1]])
}
b1 <- boot(prs, AUC, 100) # do 100 bootstrap AUC calculations
b1 # gives estimates of standard error and bias
#Write raster files
writeRaster(pred.seq, "…/wolf_pred.tif", overwrite=TRUE)
```

APPENDIX- 4

Supplementary information for the distribution modelling of the Himalayan wolf using MaxEnt.



(a) (b)

Figure 1 *(a) The presence locations of the Himalayan wolf obtained from various sources (scats- 542, sightings- 20, radio-collaring fixes- 1,687). (b) A total of 93 locations were selected for distribution modelling after rarefication.*

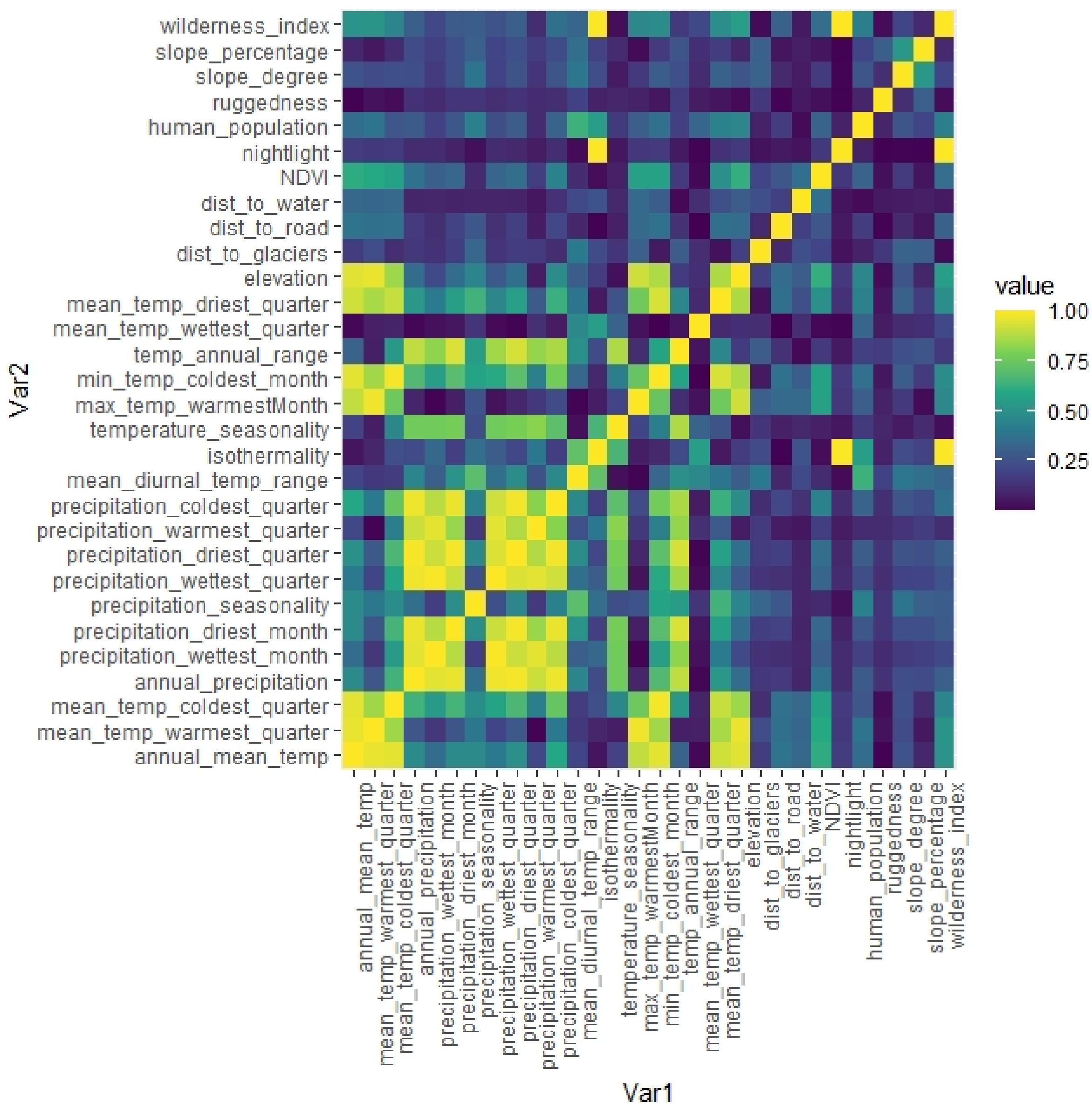


Figure 2. *The Pearson's correlation matrix of predictor variables used in distribution modelling.*

Table 1. *List of candidate variable-set models compared for modelling distribution of the wolves in the Himalayas using MaxEnt.*

Model	Model Variables	Model Category	No. of Variables
C	Mean Temperature of Coldest Quarter, Annual Precipitation, Precipitation Seasonality (CV), Mean Diurnal Temperature Range, Isothermality, Temperature Seasonality, Mean Temperature of Wettest Quarter	Climate	7
Tv	Elevation, Distance to Glaciers, Distance to Water, Landuse Landcover, NDVI, Ruggedness, Slope (degree)	Topography and vegetation	7
CTvD	Combination of climate, topography, vegetation variables and Human Population Density	Combination set	15
CTv	Combination of climate, topography and vegetation variables	Combination set	14
CD	Combination of climate variables and Human Population Density	Combination set	8
TvD	Combination of topography, vegetation variables and Human Population Density	Combination set	8
CTvD_r1	Combination of all uncorrelated variables except low contributing Annual Precipitation, Temperature Seasonality and Mean Temperature of Wettest Quarter	Combination set	12
CTvD_r2	Combination of all uncorrelated variables except low contributing Annual Precipitation, Temperature Seasonality, Mean Temperature of Wettest Quarter, Ruggedness and Landuse Landcover	Combination set	10
CTvD_r3	Combination of all uncorrelated variables except low contributing Annual Precipitation, Temperature Seasonality, Mean Temperature of Wettest Quarter, ruggedness, Landuse Landcover and Distance to Glaciers	Combination set	9

Table 2. *Evaluation metrics of the top models selected based lower AICc, lower test omission rates and higher test AUC in MaxEnt distribution of the wolf. Overall best performing model based on lower AIC is given in bold. See Table 1 in this appendix for abbreviations and details of the models. FC= Feature combinations, RM= Regularization multiplier*

Model	FC	RM	Mean AUC (test)	Variance AUC (test)	Mean Omission Rate (10th percentile)	Variance Omission Rate (10th percentile)	AICc	ΔAICc (within variable set)
C	LQHP	1.5	0.786	0.157	0.303	0.336	2099.845	0.000
Tv	LQ	1	0.750	0.051	0.140	0.055	2188.506	1.084
CTvD	LQH	2	0.812	0.117	0.324	0.273	2114.782	0.000
CTv	LQH	1.5	0.789	0.155	0.346	0.344	2106.684	0.000
CD	LQH	1.5	0.797	0.139	0.314	0.327	2109.769	0.000
TvD	LQHPT	2	0.782	0.080	0.139	0.105	2145.314	1.772
CTvD_r1	LQHPT	2	0.812	0.113	0.356	0.279	2095.878	0.000
CTvD_r2	**LQHPT**	**2**	**0.817**	**0.110**	**0.356**	**0.299**	**2083.281**	**0.000**
CTvD_r3	LQ	0.5	0.842	0.084	0.140	0.130	2094.203	1.283