

SPATIAL ECOLOGY AND PREDATION PATTERN OF WOLF IN SPITI VALLEY, HIMACHAL PRADESH, INDIA

A THESIS SUBMITTED BY
SALVADOR LYGDOH
FOR THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
WILDLIFE SCIENCE



SAURASHTRA UNIVERSITY
RAJKOT – 360 006

UNDER THE GUIDANCE OF
DR. BILAL HABIB
(SUPERVISOR)



भारतीय वन्यजीव संस्थान
Wildlife Institute of India

JUNE – 2020



29th June 2020

Certificate

This is to certify that the thesis of **Mr. Salvador Lyngdoh** titled “**Spatial Ecology and Predation Pattern of Wolf in Spiti Valley, Himachal Pradesh, India**” is an original piece of work submitted to the Saurashtra University, Rajkot, for the award of the **Doctor of Philosophy in Wildlife Science**

Mr. Salvador Lyngdoh 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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Acknowledgements

"Go where you feel most alive"

Anonymous

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I am incredibly humbled and indebted to my faculty colleagues who have in so many ways, directly or indirectly shared some burden so that I could do this work in full concentration. I thank especially Dr. S.P. Goyal, who continues to encourage and inspire with his ever young mind and enthusiasm towards the field of wildlife science in the Institute and beyond. I thank Dr. Nigam for his support due to which significant parts of my radio-collaring work could be accomplished. I thank Dr. B.S. Adhikari for the long discussions on many aspects of Himalaya during this course. I thank Dr. Sivakumar for his words of motivation that has helped me in this work. I thank Dr. Amit, who has somewhat shared my workload and helped me focus on this study. I sincerely thank Dr. Sathyakumar for sharing his knowledge of the Himalayan region with me through these many years. I thank Drs.

Damar, Gopi, Gautam, Gupta and Uniyal for their support. I thank Dr. Asha for her advice in the course of this study.

In the course of this study, my most fond memories and dearest companions were made in the hostel. I recall those long post-midnight sessions where the best ideas came from. I thank Puiia, Jimmy, Rao, Divya, Selvan, Prudvi, Tawquir, Kamal, Bibek, Zaffar, Athar, Kunzes, Asif Hussain and many others who had helped me in some way or the other in this work. I thank the then Hostel Warden, Dr. Hussain, for being kind to us and encouraging the free spirit among us. I thank Shivam for his help in the field.

My littles, Yumi, Obi, Zorro and Kube for their company. I have learned many a thing or two from them.

The Spiti Wildlife Division is a fantastic unit. The enthusiasm backed with the simplicity and hard work of the division is extraordinary in the conditions. I thank Sh. Rajesh Sharma and Sh. Rajeev Sharma, Former DFOs of the division. Sh. Devender Chauhan has been one of the most excellent field managers in the region. His immense knowledge and network have helped me during this fieldwork. I thank the Himachal Pradesh Forest Department, O/c the Chief Wildlife Warden, and the Wildlife Wing for their support in working along with the many parts of the state. I am thankful to Dr. Sandeep Rattan, who so swiftly aided in providing essential meds for the operation all the way from Shimla.

The people of Spiti are one of the hardest and simple-hearted folk I have ever been fortunate to meet and live amongst. They work tirelessly towards uplifting one another. I have learned the essence of community life in living amongst the valley peoples. I thank the people of Kibber, Langza, Suluk, and especially Mane for the constant support and patience that they have had with me in my initial days. I thank Yarphel and his Chamo (other half) for their hospitality and friendship during this time. I remember the cold winters we had spent in trying to trap wolves together. The success would not have been achieved without their undying kindness and extremely wonderful food. The warmth of the tandoor so indigenously effective and the fragrance of juniper every morning will always stay with me. I thank namo Tsering for entertaining us throughout the many cold and dull days. I thank Dorje for his caravan of all terrain mules, Namgyal, for his food and logistics, Namtak, for his excellent driving, Sushil, for his knowledge of the field. Gempo and Tsering for our wonderful excursions to Ladakh and Pare Chu. I thank Rajender and Naveen, our driver who made many things possible when the road seemed impossible. I thank my good friend Dr. Sanath for accompanying me to the field in the course of this study and trapping wolves. I appreciate the never tiring womenfolk of

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I thank students, Kalzang, Bhaskar, Ujjit, Bhawna, Shiv, Nidhi, Meghma, Bhooresh, Rupali, and Hussain, who have done their work sincerely so that during many instances I was able to focus on this work. I thank Lauren for her many insights and discussions on wolves.

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..Dedicated to the Himalaya and its Wolves

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..Dedicated to the Himalaya and its Wolves

List of Figures

S.No	Figure	Page
1	Fig 2.1. Study Area depicting Spiti region in North India with locations of scats	14
2	Fig 3.1 Dietary spectrum for collated data across 22 studies.	32
3	Fig 3.2 Box plot showing Relative frequencies of overall prey type consumption by Wolves of Asian High rangelands	33
4	Fig 3.3 Area-wise percentage frequency of occurrence of prey items in the diet of wolves	34
5	Fig 3.4. Multi-Model inference showing relative weights of predictors	35
6	Fig 3.5. Ivlev's selectivity Index for various prey species	36
7	Fig 3.6. NMDS plot showing regional prey choices in various zones.	37
8	Fig 4.1. Study Area depicting Spiti region in North India with locations of scats	63
9	Fig 4.2. Response with respect to wolf conflict and attitudes of villages in Spiti Region	64
10	Fig 4.3. Percentage relative frequency of occurrence of prey items in wolf scats from Spiti region	65
11	Fig 4. 4. Box Plot of cases of livestock depredation claimed consumed across categories of predators	66
12	Fig 4.5. Wolf conflict hotspots modelled through Model Selection.	67
13	Fig. 4.6 Marginal response curves of variable layers used (n=13).	62
14	Fig. 4.7 a) Average omission and predicted are of wolf conflict. b) Sensitivity and specificity along with c) jackknife of AUC shown for each variable.	69
15	Fig. 5.1 Study Area with wolf location and Villages in the Spiti Landscape	81
16	Fig. 5.2a Environmental layers used	95
17	Fig.5.2b Histogram of layer versus wolf re-location	95
18	Fig 5.3. Angular auto-correlation of wolf trajectory for non-discretized data	96
19	Fig 5.4 Distance traversed by collared wolves. Graphs show valleys and peaks in terms of wolf movements	97
20	Fig. 5.5. FPT of individual wolves. Graph depicts intensity and tortuosity of movement within 10 km radius	98
21	Fig.5.6. MCP bootstraps of individual wolves i.e Dhankar, Kunzum and Leica	99
22	Fig 5.7. Kernel Home Range of Individual	99
23	Fig.5.8. UD, RD and ID of three individual wolve	100
24	Fig 5.8a Comparative UDs of wolves in the study area	101

25	Fig 5.8b Comparative IDs of wolves in the study area	102
26	Fig 5.8c Comparative RDs of wolves in the study area	103
27	Fig.5.9. AKDE (weighted) of three individual wolves with time kriging of movement paths	104
28	Fig.5.10a. Home Range of Dhankar with various Methods	105
29	Fig.5.10b. Home Range of Kunzum with various Methods	106
30	Fig.5.10c. Home Range of Leica with various Methods	107
31	Fig.5.10d. Winter Home Range of Leica	108
32	Fig.5.10e. Summer Home Range of Leica	109
33	Fig.5.10f. Winter Home Range of Kunzum	110
34	Fig.5.10g. Summer Home Range of Kunzum	111
35	Fig.5.10h. Winter Home Range of Dhankar	112
36	Fig.5.10i. Summer Home Range of Dhankar	113
37	Fig.5.9. BCPA plots showing change in behavioral states of individual wolves over time. Last row indicates changes in movement speeds.	114
38	Fig.5.10. Outlying Mean Index (OMI) Analysis for individual wolves. Individuals show strong selection for areas with higher domestic ungulate presence	115
39	Fig .5.11 Canonical Outlying Mean Index (CANOMI) analysis plot. Individual wolves show strong correlation with first axis and domestic ungulate availability	116
40	Fig.5.12. K-select analysis plot. Habitat selection by individual wolves shows Dhankar selected habitats with more sheep or goat presence strongly	117

List of tables

S.No	Table	Page
1	Table 3.1. Prey Size class and Ivlev's index of prey preference.	38
2	Table 5.1. Details of individuals collared and fixes used	93
3	Table 5.2. The Minimum convex polygon and Kernel density estimates of home range	93
4	Table 5.3. Biased Brownian Movement Kernel Density estimates with Intensity, Recursion and Utilization distribution of wolf individuals	94
5	Table 5.4. Seasonal home ranges of individual wolves	94

Table of Contents

S.No	Title	Page
1	Chapter 1 - Executive Summary	1
2	Chapter 2- Introduction	6
2.1	Context	5
2.2	Status, Distribution and Taxonomy of the Himalayan Wolf	6
2.3	Study species	7
2.4	Objectives	9
2.5	Study area	11
3	Chapter 3 - Dietary spectrum in Himalayan Wolves: Comparative analysis of prey choice in conspecifics across high elevation rangelands of Asia	20
4	Chapter 4 - Predation by Himalayan Wolves: Understanding conflict and co-existence amongst Spiti Bhot community and large carnivores in High Himalaya	46
5	Chapter 5 - Ranging behaviour and habitat selection by individual wolves in the Spiti Landscape	77
6	Chapter 6 - Conclusions and Management Implications	122



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I also certify that the research work was appreciated by all who remained present and the minor comments made are incorporated in the thesis.

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Certificate for Plagiarism Check


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Table of Contents

S.No	Title	Page
1	Chapter 1 - Executive Summary	1
2	Chapter 2- Introduction	6
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2. Chapter 1 - Introduction

2.1 Context

The Indian trans-Himalaya, spans over 186,000 km², is known for sparsely distributed vegetation and relatively low species diversity. Nevertheless, the area harbors many rare and endangered plant and animal species (Kala 2000) and also a highly threatened biogeographic zone due to its fragility (Rodgers and Panwar 1988). Elsewhere included the region encompasses a total of 2.6 million km², covering the Tibetan plateau and the Tibetan marginal mountains in the rain shadow of the Greater Himalayan range and has a unique agro-pastoral dynamics that has changed or enabled co-existence through many millennia (Handa 1994, Schaller 1998). The region supports a variety of wildlife which is unique to it (Mishra *et al.* 2004).

Over the years, the trans-Himalayan region has undergone a variety of changes in the landscape due to growing human pressure. This has impacted several wildlife causing resource competition, increased conflicts and decline of habitat quality (Mishra 1997, Mishra *et al.* 2003, Bagchi *et al.* 2004, Mishra *et al.* 2004, Bagchi and Mishra 2006). The unique mammal assemblage of the region is intricately shaped by predator, prey and anthropogenic factors (Bagchi *et al.* 2004). Thus, conservation efforts especially in the Himalayas are critically dependent on reliable information of prey predator relationships (of which the wolf is the major contributor) where resource is scarce and external pressures of human interference co-effect (Linnell and Strand 2000, Mishra *et al.* 2003, Mishra *et al.* 2004, Wegge *et al.* 2009). In the recent years there has been a huge development in techniques and tools that have enabled researchers in studying animal ecology. These techniques have not only provided valuable information but also aided in decision making processes by saving critical habitat with scientific evidence as their backbones. One of the primary goals of a designing an ecological study is determining the abundance and

distribution of any particular organism or species. New possibilities of remote sampling may provide new insights to animal ecology. But there are key challenges that pertain to resource partitioning, guild structures, community level implications of predation and also habitat use from an animal's perspective (Boitani and Powell 2012). In the case of the wolf in Indian trans-Himalayas, basic information on home range, diet, population, conflict level is already lacking, any further answers to any ecological questions will depend on such baseline data primarily.

Ecology is fundamentally spatial, with ecological processes occurring on heterogeneous landscapes (Cagnacci *et al.* 2010, Morales *et al.* 2010). In the context of an animal's use of space, knowledge of such nature provide 'live' point of contact between ecology and evolution (Cagnacci *et al.* 2010). Thus, to begin to understand why animals move in space is to be able to answer as to why animal use a resource at a given time and scale. Unraveling such complex questions can lead us to answers on animal behavior and fitness (Urbano *et al.* 2010). Such information on a species' use of resource which may be space or biomass in a given continuum of time is vital for wildlife management, conservation and also for designing habitat suitability models (Palomares *et al.* 2001, Houle *et al.* 2010). In understanding not only the specie's natural history but movement patterns on a daily, seasonal and annual basis, recent technology has aided vastly (Gaillard *et al.* 2010, Mech and Cluff 2011).

2.2 Status, Distribution and taxonomy of the Himalayan Wolf

Our Knowledge of the wolf's lineage in India was highlighted recently (Sharma *et al.* 2004a, Aggarwal *et al.* 2007) but a detailed study of this cryptic species remains challenging and deserves more academic as well conservation emphasis. Though, there have been a handful of studies of wolves from the peninsular India, the wolves in trans-Himalayas have received much lesser academic or conservation attention. The wolf in the trans-Himalayas has been proposed to be listed as a separate species and of very high

conservation value (Aggarwal *et al.* 2003) since they are genetically unique. Previous studies have shown that the wolves in this landscape belong to a lineage which is probably one of the most ancient. It is also hypothesized that these wolves played no role in the modern day domestication of dogs. However, ecological data on wolves from the trans-Himalayas is needed to determine if mechanisms exist that could have led to isolation of wolves in the Trans-Himalayas that may support a separate species concept of these wolves. This study will hence provide a background in an ecological context keeping in mind earlier genetic studies.

Home range, movement, predation patterns and habitat selection are key factors that are needed to understand the ecology of animals. Wolves constitute an important part of the mega-fauna in the Himalayan region as an umbrella species (Sharma *et al.* 2007). In an agro-pastoral landscape, the patterns of wolf prey interactions, particularly domestic prey will shapes attitudes of local communities towards it. British India records estimate the numbers of wolf killed to be around 100,000 between the early 20th century (Knight 2004) and till date major reasons hindering wolf conservation in the area is human-wildlife conflict due to alleged livestock depredation (Mishra 1997, Bagchi and Mishra 2006, Namgail *et al.* 2007). Thus, this information will help in understanding proximal causes of such conflict and determine zones and patterns of conflict which are of a complex nature. The Spiti Valley, offers such an opportunity where genetically the wolves may be distinct and ecological mechanisms that may have led to such distinctions need to be validated. There also exists over millennia of pastoralist interactions that have shaped the ecology of the system. Thus, this study will help in addressing issues related to the ecology and conservation of the wolves in the trans-Himalayan region. This work contributes to the existing knowledge about predation ecology of the Himalayan Wolf along with ranging and habitat use. This doctoral work lays the foundation of undertaking studies to understand species' adaptations of living in extreme environmental conditions and would

be helpful for informing strategies to promote its conservation through the knowledge of its spatial ecology and also transboundary implications. The study also allows for the appraisal of high end GPS telemetry for long ranging and cryptic species such as the Himalayan Wolf of the rugged mountainous terrain.

2.3 Study Species

After man the wolf is the only other terrestrial animal that has the largest distribution in the world until recent time (Mech 1970). Despite its large range it has disappeared from nearly one third of its range. The Red List of the IUCN-World Conservation Union classifies the wolf as Least Concern but several local population are listed as endangered (Mech and Boitani 2010.). CITES (Convention on International Trade in Endangered Species of the Wild Fauna and Flora (3.3.1973) lists the wolf in Appendix II (potentially endangered species), with the exception of Bhutan, Pakistan, India and Nepal where it is listed in Appendix I (species in danger of extinction). In India the Tibetan wolf *Canis lupus chanco* sub-species is listed in Schedule I of the Wildlife Protection Act, 1972.

Wolves were exterminated from much of Europe and Americas during the 19th century due to which the current distribution has taken shape. In the last two decades there have been efforts to revive wolf populations around the world. In the cases of Europe, largest populations exist in Eastern Europe and the Balkans. Other countries like France, Portugal, Germany, Czech republic, Hungary etc. have small numbers of wolves (Delibes 1990, Boitani 2000, Salvatori and Linnell 2005). At present wolves occur primarily in wilderness and remote areas, especially in Canada, Alaska and northern USA, Europe, and Asia from about 75°N to 12°N (Goldman 1937, Mech and Boitani 2010). India inhabits two sub species of wolves which are smallest when compared to their conspecifics around the world, the Indian wolf (*Canis lupus pallipes*) and Himalayan or Tibetan wolf (*Canis lupus chanco*) (Aggarwal *et al.* 2003, Sharma *et al.* 2004c). The only estimate population of the Tibetan wolf by Fox and Chundawat (1995) is estimated to be around 350 numbers . The

range of the Himalayan or Tibetan wolf in India where Trans- Himalayan Habitat exists, it extends from the Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh.

The wolf is known to be present in regions of Ladakh and Tibet were earlier described by British hunters and mammologists in the last century. Hodgson has described a wolf from Tibet (*Canis lupus chanco*), sometimes called the 'white wolf' by sportsmen who cross the Himalayas. It is a larger animal than the Indian wolf, with white face and limbs, and no dark tip to the tail, which is fully brushed (Jerdon 1874). Pocock (1941) says "The colour of the pelt varies seasonally: on the winter coat, the back and tail are variegated by black and white or buff contour hairs, which are most defined on the back, where they form a black and white saddle running from the shoulders to the loins. The wool beneath the contour hair is of a 'brightish buff' to clear grey colour, while the belly and outer side of the legs are buff or whitish. Occasionally, a dark stripe of varying intensity may be present on the forelegs. The ears are 'drabby grey' or rich 'ocherous'. The crown and muzzle are closely tinted with black speckles, which extend below the eye on to the upper cheeks and ears, isolating a white spot. The chin is varying from blackish to almost white". The contour hairs of the winter fur measure 100–120 mm (3.9–4.7 in) on the shoulders, 70–80 mm (2.8–3.1 in) on the back and 40–60 mm (1.6–2.4 in) on the flanks It is a smallish subspecies that rarely exceeds 45 kg (Lydekker 1900, Pocock 1941, Geptner *et al.* 1972).

There are three species of wolves recognized currently, the gray wolf *Canis lupus*, the red wolf, *Canis rufus* and the Ethiopian wolf, *Canis simiensis*. The gray wolf is the only true wolf having over 32 sub species or races distributed over the world. Recently, however there have been revisions through molecular phylogenetic studies, there are approximately 13 subspecies of the Gray wolf (Sharma *et al.* 2004b). Two geographically isolated populations and allopatric races exist in the India subcontinent, which are

believed to be very ancient and probably played no role in the domestication of canids (Aggarwal *et al.* 2003, Sharma *et al.* 2004, Werhahn *et al.*, 2017) i.e. the Himalayan wolf or known as Tibetan wolf (*Canis lupus chanco*) which occurs in the Himalayas and Trans-Himalayas and the Indian Wolf (*Canis lupus pallipes*) of peninsular India. The Himalayan wolf is known to be an ancestral lineage of extant gray wolves, their special place in world has been argued to be placed as a separate species altogether (Aggarwal *et al.* 2007, Zhang and Chen 2011). These results show the uniqueness of the Indian populations of wolf and demand an effective conservation strategy as well as encourage scientific curiosity which is completely absent.

2.4 Objectives

Past studies of wolves in India have been limited mainly to the peninsular region. In the current study focusses on the ecological aspects of the wolves of the Trans-Himalayan landscape. This region is characterized by low prey and growing anthropogenic influences in the form of pastoralist practices. Over time wild prey and predators may have adapted or limited themselves against such anthropogenic influences. With respect to the Himalayan wolf, the strategies that it has developed to cope with seasonality, abundance of prey, habitat choice and traditional pastoralist practices are critical factors that have shaped its long term survival in this region. Therefore, the wolf has probably adapted itself within this environment that is a mosaic of wild and anthropogenic influences. With this background, following hypotheses were developed which are to be tested in the study to help understand the specie's resilience and thresholds that may also aid in its conservation:

1) *Hypothesis 1: Habitat use governed by availability or disturbance*

The understanding of spatial use of wolves is subjected to multiple facets. These facets can be understood as diet of the animal, habitat use and temporal patterns in spatial use. These are known important factors which determine spatial ecology of wolves. Habitat selection

is a hierarchal process that causes disproportionate use of sites relative to its availability while maximizing its survival (Johnson 1980). Habitat selection by wolves, however, within a home range will be governed by specific habitat features, groups or communities with time and space. The habitat selection by wolves within and between home ranges is expected to be multi-scale and governed by disturbance gradients and habitat features. Critical (denning and rendezvous sites) habitat sites are important for wolf to survive. Choice of these habitat use by wolves is determined by characteristic features and will be limited by availability or alternatively by human disturbance.

Objective: To study the ranging and movement patterns of wolves within the landscape

Objective: To study habitat selection by wolf within a wolf home range

2) *Hypothesis 2: Prey choice is determined by availability and accessibility*

In the Spiti Valley as well as adjacent areas wolves alone are perceived to be a major cause of livestock mortality (Mishra 1997, Namgail *et al.* 2007). However, actual levels of depredation are not known. Over the years, there has been a significant increase in livestock numbers and the resultant conflicts in the region. The probable factor for the conflict may lie in the fact that wolves are known to shift their diets according to relative decline in wild prey availability (Meriggi and Lovari 1996, Sidorovich *et al.* 2003, Capitani *et al.* 2004) . Thus, wolf diet in this region will be influenced by relative availability of wild and domestic prey.

Objective: To determine predation patterns of wolf.

2.5 Study Area

The Spiti catchment area which is divided by the Spiti River is a cold semi-arid region of the state of Himachal Pradesh. The greater Himalayas are to the south east of the valley while on the north of it lays Ladakh and east lays Tibet. The Spiti River forms its

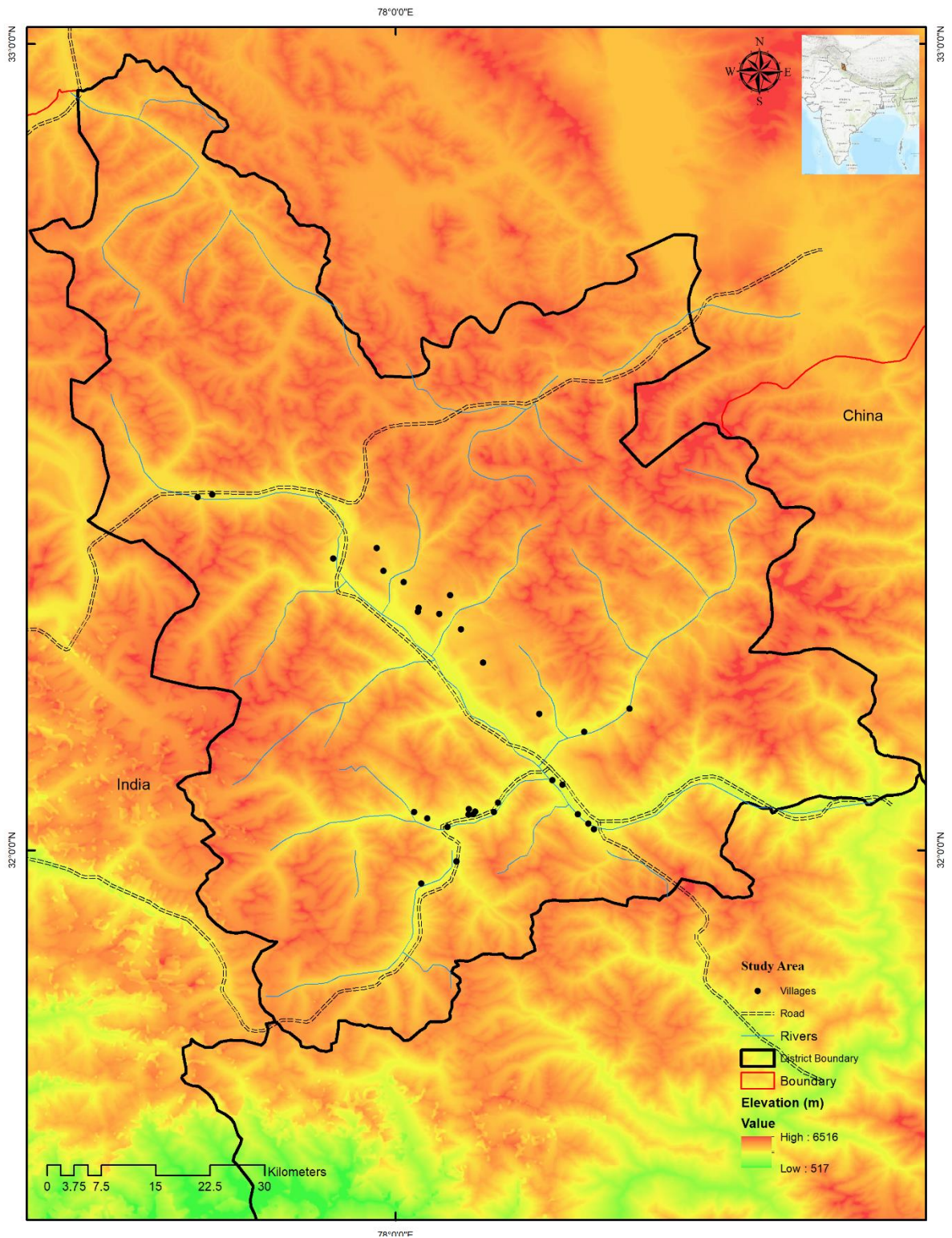
headwaters at Kunzum la and runs meandering down to Kinnaur district to join Satluj River at Khab. It is situated at the north of the great divide of non-monsoonal zone.

The Intensive study area comprises of Kibber Wildlife Sanctuary (WLS) (32°5 to 32°30 N and 78°1 to 78°32E) and surrounding areas of Spiti valley. Kibber WLS was established in the Spiti Region (Lahaul and Spiti District) of the Indian state of in 1992 for conservation of trans-Himalayan wildlife. The sanctuary occupies an area of 1400 Km² in the river Spiti's catchment. It is a mountainous cold desert, where altitudes range between 3600 m and 6700 m above mean sea level. Temperatures range between 230°C and 3°C in winter and between 1°C and 28°C in summer. The vegetation of this area has been broadly classified as dry alpine steppe (Champion & Seth 1968).

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

Thirteen villages are located along the boundary of the sanctuary, supporting a total human population of 1985, according to the 1991 census. The main occupations of the inhabitants are agriculture and livestock rearing. Most agriculture- related activities are restricted to the short growing season (from May to September). The main crops cultivated are barley, *Hordeum vulgare*, and green peas, *Pisum sativum*. Livestock includes goats and sheep, cattle, 'dzomo' (a female hybrid of cattle and yak), and yaks. Donkeys are the beasts of burden, while horses, apart from being used for religious ceremonies, are mainly raised for trade. The predominant cultural setting of the region is Indo-Buddhist . The community residing permanently in the valley practice Buddhism and have close linkages with the flora and fauna of the region.

Fig 2.1. Study Area depicting Spiti region in North India



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3. Chapter 3

Dietary spectrum in Himalayan Wolves: Comparative analysis of prey choice in conspecifics across high elevation rangelands of Asia

3.1 Abstract

The Himalayan wolf is one of the most basal among wolf lineages in the world today. It inhabits mostly the high elevations, northwards from the Himalayas (1500 - 5000 m) in the Asian region. I conducted a meta-analysis to understand the dietary habits of Himalayan wolves and wolves of the high rangelands of Asia from seven countries (n = 22). I found 39 different prey items reported across the distribution of the Himalayan wolf from a total of 2331 scats (average of 105.95 ± 20.10 scats per study). Comparison of the Relative Frequency of Occurrence of different prey species shows that domestic prey consumption ($48.21 \pm 5.61\%$) across the zones or continent was similar to wild prey consumption ($42.94 \pm 5.25\%$). Small wild prey species constituted approximately ($24.53 \pm 3.77\%$) of the total wolf diet. Wolves of the Asian Highlands consumed relatively larger prey ($40.01 \pm 5.42\%$) than small prey ($25.19 \pm 3.85\%$) or medium-sized prey ($23.17 \pm 3.78\%$). Wolves consumed a larger proportion of domestic ($54.92 \pm 5.94\%$) than wild prey ($36.13 \pm 6.12\%$) in areas that had regular livestock grazing and vice versa. East, west and central Himalayan and Central Asian wolves consumed mostly large wild and domestic prey. On the contrary, wolves in the Qinghai Tibet Plateau, Inner Mongolia, and the Karakoram consumed a relatively higher proportion of smaller sized prey and livestock. Overall, wolves utilized mostly domestic livestock and marmots (Ivlev's index, 0.22 – 0.77). High localized utilization of Przewalski's horse (*Equus ferus przewalskii*, 0.94) was recorded, whereas Goral (*N. goral*) and Pika (*Ochotona* spp) were particularly underutilized (-0.99 and -0.92) in wolf diet. A landscape or trans-boundary approach is advocated to restore natural large wild prey, for such a relic lineage species and reduce human-wolf conflicts.

3.2 Keywords

Wolf diet, Carnivore, Himalaya, Ancient Lineage, Prey Predator, Nomadic Pastoralism, Trans-Boundary

3.3 Introduction

Wolves are a charismatic species that have been extensively studied across the Americas and Europe (Mech & Boitani, 2010). Their role as an ecosystem regulator through trophic cascades has been well documented (Ripple *et al.*, 2001; Ripple & Beschta, 2004; Halofsky & Ripple, 2008). Wolves were once hunted to near extinction, however, over a period of time, increased public awareness towards the species has help garnering strong legal protection, favorable media coverage and furthered ecological research (Mech, 1995; Ripple & Beschta, 2007; Chapron, Andren & Liberg, 2008; Imbert *et al.*, 2016). Yet, persecution remains as one of the biggest obstacles to wolf recovery around the world (Newsome *et al.*, 2016), including the Himalayan wolf.

The Himalayan wolf is a subspecies of the grey wolf (*Canis lupus*), found in the cold and hypoxic high altitude ecosystems of the Himalayas and the Tibetan Plateau, extending into China, Manchuria and Mongolia (Zhang *et al.*, 2014). Their unique ancient lineage was highlighted recently via several taxonomic and evolutionary studies. However, there is limited understanding of iwts ecology, behaviour, and habitat requirements primarily due to its cryptic nature and the unforgiving landscape that it inhabits (Sharma, 2001; Aggarwal *et al.*, 2007; Werhahn *et al.*, 2017).

The high altitude rangelands of Asia are harsh grounds, interspersed with transhumant pastoralist. Wolves here have survived through a history of human interference (Bagchi & Mishra, 2006a; Namgail, Fox & Bhatnagar, 2007). They forage on domestic livestock, small prey, and even garbage. Therefore, wolves are often considered to be no less than a marauder of

livestock and have been consequently persecuted despite legal protection. The Himalayan wolf or highland wolf, also known as the Woolly wolf or Tibetan wolf also shares its range with another apex predator, the endangered snow leopard (*Panthera uncia*). Depredation by these sympatric species has led to increased conflicts and perhaps, reduced their acceptance by the local people (Suryawanshi *et al.*, 2013a).

Many studies on the feeding ecology of wolves have focused on the geographical variability, its trophic ecology and prey selection (Okarma, 1995; Meriggi & Lovari, 1996; Capitani *et al.*, 2004; Mech & Boitani, 2010; Newsome *et al.*, 2016a). However, information on wolf diet is limited from the Asian region. Newsome *et al.* (2016) reviewed only five out of 177 studies on diet from this region and found these wolves to mostly rely on small prey, rodents, and domestic livestock. On the contrary, in North America and Eurasia including the Arctic, wolves frequently fed on medium to large sized prey. One of the main reasons for such difference cited by Ripple *et al.* (2015) is that, in Central Asia for example, the expansion of wool production for international export has reduced many large herbivore habitats. Livestock competition has also created a significant threat to large herbivores in India, China, and Mongolia with consequent impacts on their predators like wolves (Ripple *et al.*, 2015).

The current review aims to bridge the information gap on diet and feeding ecology of Himalayan wolves. This study will inform better on diets of wolves from the Asian High elevation rangelands and complement existing knowledge on the species. In Asia, wild prey densities are low in many areas where wolves occur. We hypothesized that Himalayan wolves mostly preyed on domestic prey in areas with historical grazing practices. Alternatively, in undisturbed natural areas, wolves should utilize more wild prey. We conducted a meta-analysis with the following objectives:

- a) to understand wolf prey choice with respect to the Tibetan/Himalayan wolves of Asia in particular,

b) to investigate the levels of domestic and wild prey share in difference sub-regions within their habitat range, and

c) to understand the determinants of dietary choice in such regions with respect to prey characteristics and environmental variables.

3.4 Methods and study area

i) Collating data on Himalayan wolves from Asia

Data on Himalayan wolf diets across high altitude rangelands from Asia were collected through published sources using a keyword search in google scholar. Keywords, Tibetan wolf diet, Himalayan wolf diet, Mongolian wolf diet, *Canis lupus chanco*, *Canis lupus laniger* and wolves from central Asia were used. Available literature was also reviewed from Newsome *et al.*, (2016). The study was also supplemented with unpublished literature and field collected scats (n = 118) from the Spiti region where diet information was missing. We also tabulated data on grazing pressure in terms as limited or regular grazing based on the studies found.

ii) Prey potential zones and diet representation as Relative Frequency of Occurrence (RFO)

Data were tabulated as a) absolute frequency of occurrence i.e. FOO (number of occurrences of each prey item in scats /total number of scats *100) and b) relative frequency of occurrence i.e. RFO (number of occurrences of each prey item in scats /total number of occurrences of all prey items *100). We used RFOs of all studies for overall comparisons. RFOs represented as percentages avoid the ambiguity of over-representation and standardize the prey item occurrences. To estimate biomass consumed per unit scat, we used the correction factors provided for wolves (Weaver, 1993a; Wachter *et al.*, 2012a). Weaver, (1993) used a regression-based correction factor to address biomass consumed by wolves based on body weights of prey which was later refined by Wachter *et al.* (2012), for cheetah and simultaneously for wolves through an exponential equation that is more realistic in ecological terms. However, I used both for comparative purposes. The weight of prey used for biomass calculation was 3/4th of the

female weight of prey (Hayward *et al.*, 2006; Lyngdoh *et al.*, 2014).

We divided the data on wolf diet into seven zones based in the wild prey uniqueness and physiography (Schaller, Junrang & Mingjiang, 1988; Lyngdoh *et al.*, 2014). Zone 1, the North-west and Afghanistan areas encompass, i.e., the Karakoram and Pamirs (KA). Zone 2 included Western Himalayas and parts of India, i.e., Ladakh and Himalayan parts (WH). Zone 3, comprises of the Central Himalayan region, i.e., mostly the Dolpa and Nepalese Himalayas (CH). Zone 4, encompasses the Eastern Himalayan region (Sikkim and Bhutan Himalayas- EH). Zone 5, includes the central Asian region which includes the Tien Shan and surrounding rangelands (CA) while zone 6, encompasses the Mongolian region (IM) and zone 7, comprises of the Qinghai Tibet plateau region (QTP). These regions are known to have a unique prey base, distinct from each other (Schaller, 1988; Bagchi & Mishra, 2006; Jumabay-Uulu *et al.*, 2014; Lyngdoh *et al.*, 2014; Chetri, Odden & Wegge, 2017). In Zone 2 – 4, blue sheep and Ibex are dominant prey, while in Zone 5, Argali is known to occur widely. In zone 6, the Mongolian region, the presence of red and roe deer is also known to drive snow leopard diet (Nakazawa *et al.*, 2008). Zone 7, QTP region consists mostly of small wild and domestic prey (Yan *et al.*, 2006; Van Duynes *et al.*, 2009; Zhang *et al.*, 2014). Thus, these zones differ in their major prey species diversity and abundance. These zones also differ physio-geographically and are well separated from each other (Fig 3.1).

iii) Prey choice and Niche overlaps

To analyze prey utilization and selection by wolves, Ivlev's selectivity index (IVI) was used using the formula, $D = (ri-pi)/(ri+pi)$ where, ri is the proportion of species i among the total kills at a site and pi is the proportion of species i in the available prey community. We used availability data of prey abundance (n =19, Table 3.1) from published literature from similar study on snow leopard for comparability and compatibility from Lyngdoh *et al.*, 2014. Prey availability data for Red deer (*Cervus elaphus*) and Przewalski's Horse (*Equus ferus przewalskii*) was obtained from

Burbaité & Csányi, (2010) and King *et al.*, (2014) respectively. Estimates of Tibetan wild ass (*Equus kiang*), Tibetan Gazelle (*P picticaudata*) and Goral were used from Bhatnagar *et al.*, (2006); Duckworth & MacKinnon, (2008) and Leslie, (2010) respectively. The utilization preference of prey species is presented along a gradient of -1 to +1 such that the values range from +1 (maximum use) to -1(maximum avoidance). We excluded various prey types such as garbage, invertebrates, plant or vegetative matter and insect as they could not be quantified in terms of biomass.

We used Pianka's index to examine the degree of dietary niche overlap between each zone (Pianka, 1966). RFO of prey species items in scats from these zones identified were used in null model simulations of Pianka's dietary niche breadth, with relaxed and zero states retained. RFOs were tabulated for each species and zones in program Ecosim (Lyngdoh *et al.*, 2014). The Observed Index was calculated for the data, whereas the Mean and Variance of Simulated Index were calculated for the set of simulated matrices (n = 1000 simulations). Ecosim uses randomization algorithms that generate a simulated matrix. A probability test was computed to compare the observed mean niche overlap index to the overlap from the simulated matrix. We also calculated species richness between the zones using Ecosim (Acquired Intelligence Inc. Kesey-Bear, Pinyon Publishing 2011).

iv) Determinants of wolf diet in high altitude rangelands

To assess what factors would influence wolf diet across the zones, for prey species identified, I extracted information on the species latitudinal and longitudinal extent based on IUCN red list and available literature. Size, height, length, home range, group size, elevation range, habitat, and prey species behavior (nocturnal or diurnal) were considered as predictor variables. Prey items such as plant and insects, as well as the vegetative matter, were excluded from this analysis. Variables such as height and longitudinal extent were highly correlated with length and latitudinal extent respectively and were excluded from the model set of predictors. Eight of ten

variables were subjected to a general linear model (GLM) with main effects only with Frequency of Occurrence (FOO) as the dependent variable. Best fit models were chosen from possible of 256 (2^8 variables) candidate models through an automated model selection and multi-model inference with the GLMs using *glmulti* package in R (Calcagno & de Mazancourt, 2010). Top models that described wolf prey choice were ranked as per $+\Delta 2$ within the least AICc value. The importance value for a particular predictor or its relative importance was estimated by the sum of the weights/probabilities from the models in which the variable appeared

We used Non-metric dimensional scaling (NMDS) with six environmental variables and ANOSIM with Bray Curtis similarity index in PAST software (Hammer, Harper, & Ryan, 2001). FOO, Latitudinal Extent, Longitudinal extent, Weight, Length and Home range were variables considered in order to determine dietary patterns across 7 zones and different prey species.

3.5 Results

We found 22 studies (Fig 3.1) on Himalayan/Tibetan/Mongolian and central Asian (Holarctic) wolves. There were 39 different prey items reported (Fig 3.2) across the distribution of the Himalayan wolf from 2331 scats with 105.95 ± 20.71 scats per study. The mean RFO in scats of wolves for large prey was $40.01 \pm 5.42\%$, medium prey was $23.17 \pm 3.78\%$ and small prey (including domestic) was $25.19 \pm 3.85\%$ (Fig 3.2). The northernmost study that reported on wolf diet was from Dalaihu Nature Reserve, Mongolia, while the southernmost was from Wangchuck Centennial National Park, Bhutan. The western and easternmost studies that reported on wolf diets were from Chitral, Pakistan and Saihanwula Nature Reserve, Inner Mongolia, PRC. Wolves consumed domestic prey ($54.92 \pm 5.94\%$) in higher proportion in heavily grazed areas than in areas in with limited grazing ($36.13 \pm 6.12\%$). Similarly, in sites with only limited or no grazing pressures from livestock, wolves utilized more wild prey (56.62 ± 9.39) than its domestic counterpart (32.88 ± 9.28)

3.5.1 Consumption patterns and overlaps

A comparison of RFO of various prey species showed that domestic prey consumption across the zones or continent was higher (48.21%) than the wild prey consumption (42.94%). Small wild prey species constituted approximately 24.53% of the wolf diet (Fig - 3). Wolves also relied on subsidies such as garbage or insects (mean = 11.61% ± 3.93). Although, diet did not vary significantly across the seven zones, wolves chose their prey differentially between prey types (ANOVA 2 factor, df = 3, 18; $P_{\text{prey}} = 0.0006$; $P_{\text{zones}} = 0.92$). Among all zones, the highest average consumption of wild prey was reported from the central Asian region (80.84 ± 8.34 %), followed by western Himalayan zone (34.13 ± 11.12 %), while the lowest was from the east Himalayan zone (22.66 ± 20.52 %). Similarly, the average domestic prey intake was highest for the Western Himalayan zone (64.18 ± 8.06%) and lowest for the central Asian zone (14.70 ± 8.34%). Small prey was the highest consumed component in the QTP region (47.06 ± 10.94 %). Other subsidies like plants and invertebrate prey were highest for the central Asian zone (40.19 ± 2.29 %, Fig 3.2).

Diet overlaps (diet similarity) across zones was 29.86 % (± 2.04). Simulated indices were estimated to be 19.33% (± 0.04). Observed mean niche overlap was significantly greater than expected by chance ($0.99 \leq P \leq 0.003$). The standardized effect size was 3.88. The observed variance was not statistically different from the null model ($0.21 \leq P \leq 0.78$). The highest overlap was between east Himalayan and western Himalayan zone (61%). The lowest overlap was between eastern Himalayan and inner Mongolian zone (0.05%). ANOSIM showed that there were no significant differences in the dietary patterns of the wolves across the study areas ($P = 0.09$, mean rank between = 1182, mean rank within = 1129)

3.5.2 Determinants of Prey Choice and Regional patterns

Out of 256 candidate models (Supplementary Material, Table 4-5, Annex 6), the best-fit model showed that the 'home range' ($t = 2.91$, $p < 0.05$) and 'length' were the best predictors of prey

consumption, 'FOO' ($AICc=201.33$, $p = 0.005$, $R^2_{adj} = 0.25$). Across all possible models (taking their relative weights into consideration), multi-model inference estimated variable 'home range' was a consistent predictor (92.34 %, $p = 0.002$, Fig 4), followed by longitudinal extent ('longex' = 48.78%, $p = 0.03$) and 'length' (36.77% , $p = 0.06$, Fig 3.3). Wolves preferred large and ubiquitous prey as explained by 'home range' and 'longitudinal extent', which were important contributors to the diet choice amongst various studies.

Ordination (NMDS) revealed 97.8 % and 11.4 % of the information on the first axis and second axis, respectively, with 0.029 stress (Fig 3.6). The latitudinal and longitudinal extent showed a strong positive relationship with both the axis, while the home range showed a negative correlation. Length, weight, and size of prey showed a negative relation with *axis 1* and positive with *axis 2*. The zones, i.e., Eastern Himalaya, Central Asia, Western Himalaya, and Central Himalayan areas aligned positively towards large wild and domestic prey. On the other hand, wolf diet from the regions of Qinghai Tibet Plateau, Inner Mongolia, and the Karakoram showed affinities for mostly smaller sized prey and livestock, as they were closer to groups of species that had large latitudinal and longitudinal extents.

3.5.3 Overall prey preferences

Wolves of the high rangelands of Asia utilized domestic livestock more than wild prey. *Equus ferus przewalskii* (IVI: 0.94 ± 0.42 , Fig 3.5) was utilized the most with respect to its availability, followed by *E.f.cabbalus* (IVI: 0.85 ± 0.30) and *Bos* spp (IVI: 0.69 ± 0.14). Amongst the wild species, *Cervus elaphus* (IVI: 0.22 ± 0.34) and *Marmorata* spp (IVI: 0.33 ± 0.22) were also utilized positively. Wolves of the Asian Highlands underutilized *Naemorhedus goral* (-0.99 ± 0.41), *Ochotona* spp (IVI: -0.87 ± 0.27) and wild prey (Table 3.1, Fig 3.5).

3.6 Discussion

Our study observed that Himalayan wolves, like other Highland wolves of Asia, significantly

utilized domestic prey. This result is consistent with the conclusions of earlier studies as well (Hovens & Tungalakutja, 2005; Newsome *et al.*, 2016). The differences in broad prey type (wild, domestic, small wild prey and other subsidies) consumed across the Himalayan wolf range and other non-Himalayan wolf ranges (Central Asia) were not significant. This could be attributed to a high quantity of domestic prey overlaps in the wolf diet across these rangelands. However, wolves still utilized wild prey in larger quantity in some areas where livestock grazing occurred in limitation. Our results indicate that wolf populations may be facing extreme threat due to extensive dependence on domestic prey and consequent livestock depredation related conflicts in much of its range. These regions are mostly low in productivity and highly overstocked. As conflict levels are difficult to ascertain from scatological analysis alone future investigations of such aspects may provide a more in-depth perspective.

3.6.1 Prey consumption patterns: a comparison

The wolf is known to be a euryphagous animal that can feed on wild and domestic prey (Bibikov *et al.*, 1983). Existing studies have reported a range of values (25 to >70%) of the percentage composition of domestic prey (RFO) in wolf diet (Fig. 3.1-3.3). In the regions of Spiti (WH), Chiktan (WH) and Chitral (KA), wolf conflicts may be very high due to lack of wild prey and increasing anthropogenic threats such as overstocking (Bagchi & Mishra, 2006a; Suryawanshi *et al.*, 2013). Many studies in Trans-Himalaya have reported a low abundance of natural prey and poor livestock husbandry techniques resulting in depredation by large predators (Anwar *et al.*, 2011; Jackson & Ahlborn, 1989; Mishra, 1997; Subba, 2012; Boitani, Phillips, & Jhala, 2018). In certain cases, livestock depredation levels may be an outcome of individual pack traits as well (Kudatkin 1979 in “Wolves of the World,” Mech & Boitani, 2010). On the other hand, Central Asian wolves may still have high wild prey available to consume. Historically, wolves have been known to feed on the saiga antelope (*Saiga tartarica*), argali (*Ovis ammon*) and also roe deer (*Cervus elaphus*) in the Central Asian highlands, although we did not come across any

study related to saiga consumption (Bibikov, 1973).

3.6.2 Diet and Human-Wolf Conflict

Wolves are known to choose their prey based on wild prey abundance, vulnerability, pack stability, dispersal nature, habitat accessibility as well as husbandry regime in human-dominated landscapes (Imbert *et al.*, 2016). Patterns of wolf diet across these regions show that wolves consumed mostly large and domestic prey (40 % and 48.21% respectively). The adaptability of wolves in human-dominated landscapes and conflict perceptions in socio-cultural context may vary. For example, in the Spiti valley in India, despite high depredation levels of local livestock (66%), predominant socio-religious sentiments, indifference, and awareness allow wolves to co-exist (Rangarajan, 2005; Agarwala *et al.*, 2010). In Mongolia, since the herdsman were aware of co-existing wolves, techniques such as close guarding of livestock caused wolves to switch back to wild prey predation (Van Duyne *et al.*, 2009). Likewise, in many parts of Central India, Kyrgyzstan and Mongolia, vigilant packs or individuals have been able to survive amidst human persecution and proximity.

Consequences of conflict due to prey un-availability can also hinder key conservation goals. For example, predation due to lack of prey by wolves on localized and threatened endangered animals such as Przewalski's horse in Mongolia is of critical concern. Therefore, it is essential to address prey restoration and livestock security to reduce conflict and achieve conservation goals (Bibikov *et al.*, 1983b; Bhatnagar *et al.*, 2006; Suryawanshi *et al.*, 2017; Ghoshal *et al.*, 2018).

3.6.3 Characteristics of wolf prey in the Asian highlands

Energetic constraints of large carnivores make them prone to conflict as they need large prey (Carbone *et al.*, 1999). Our study observed that wolves preferred large and ubiquitous prey in general. This is also evident from the biomass consumed per scat, which showed higher returns from consuming large prey (50-200 kg, Fig 3.2). Twelve out of twenty-two studies showed that

at least 50% of wolf diet consisted of domestic livestock. However, we also found seven studies that showed considerable wild prey utilization (56.62%) from sites that had limited domestic grazing pressures. Areas like Hustai, Wangchuk, and Sarychat-Ertash where limited grazing pressures exists, natural wild prey can thrive. Interestingly, wolves in Chitral (Shabbir *et al.*, 2013) and Qinghai Tibetan plateau (Liu & Jiang, 2003) significantly utilized small prey (>40%). In the Qinghai–Tibetan Plateau, until 1989, prohibitory laws against hunting were non-existent (Jiang *et al.*, 2012). About 1.5 million wild animal skins, 271,742 wildfowl, and 2.6 million tonnes of game meat were sold between 1965 and 1975 (Jiang *et al.*, 2012). As a result, large prey may have become scarce for wolves. This may have led to their increased dependence on domestic or smaller prey in the region (Liu & Jiang, 2003; Imbert *et al.*, 2016; Suryawanshi *et al.*, 2017).

3.6.4 Conclusions

Wolves are top predators and require large landscapes. As a generalist species, wolves also have wide-ranging ecological roles in such systems. It is important to recognize that in the long run, for the survival of such species; reduction of conflict with humans; habitat and prey restoration is crucial. In the case of the Himalayan wolf, a true Asian wolf and most basal lineage amongst all wolves, a transboundary strategy for prey and its protection or management in some areas to increase acceptance and conserve the species within its exclusive range is needed. Greater number studies on wolves with respect to its food web ecology; prey-predator dynamics and encouraging community participation for human-wolf conflict mitigation in such sensitive landscapes is advocated at policy and managerial levels.

Fig 3.1 Dietary spectrum for collated data across 22 studies. Graphs indicate the percentage mean relative frequency of occurrence with a standard deviation of prey in wolf diet.

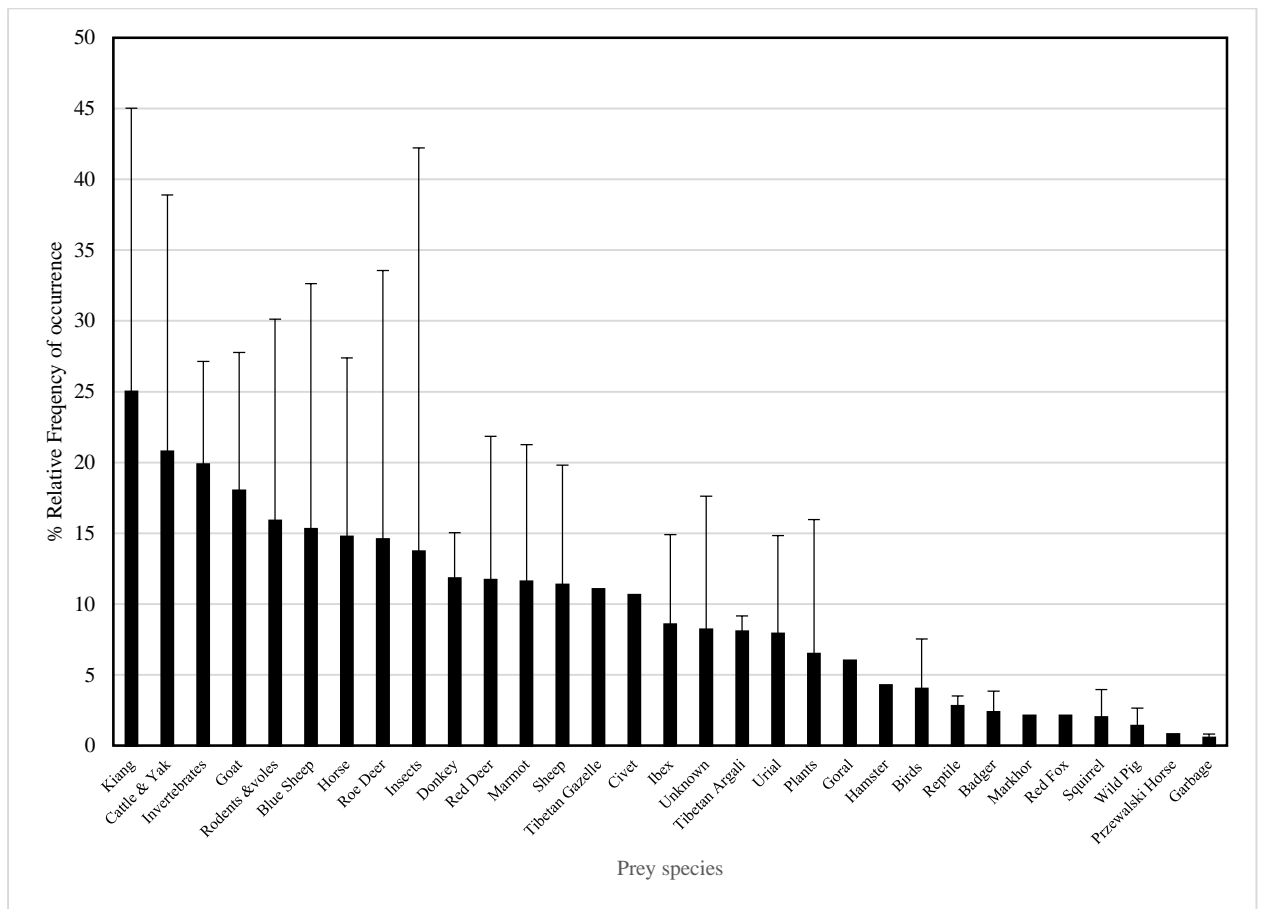


Fig 3.2 Box plot showing Relative frequencies of overall prey type consumption by Wolves of Asian High rangelands. Red crosses denote mean of the point. Black dots indicate outliers. Lines indicate the range. Bounds indicate 1st and 3rd quartile range.

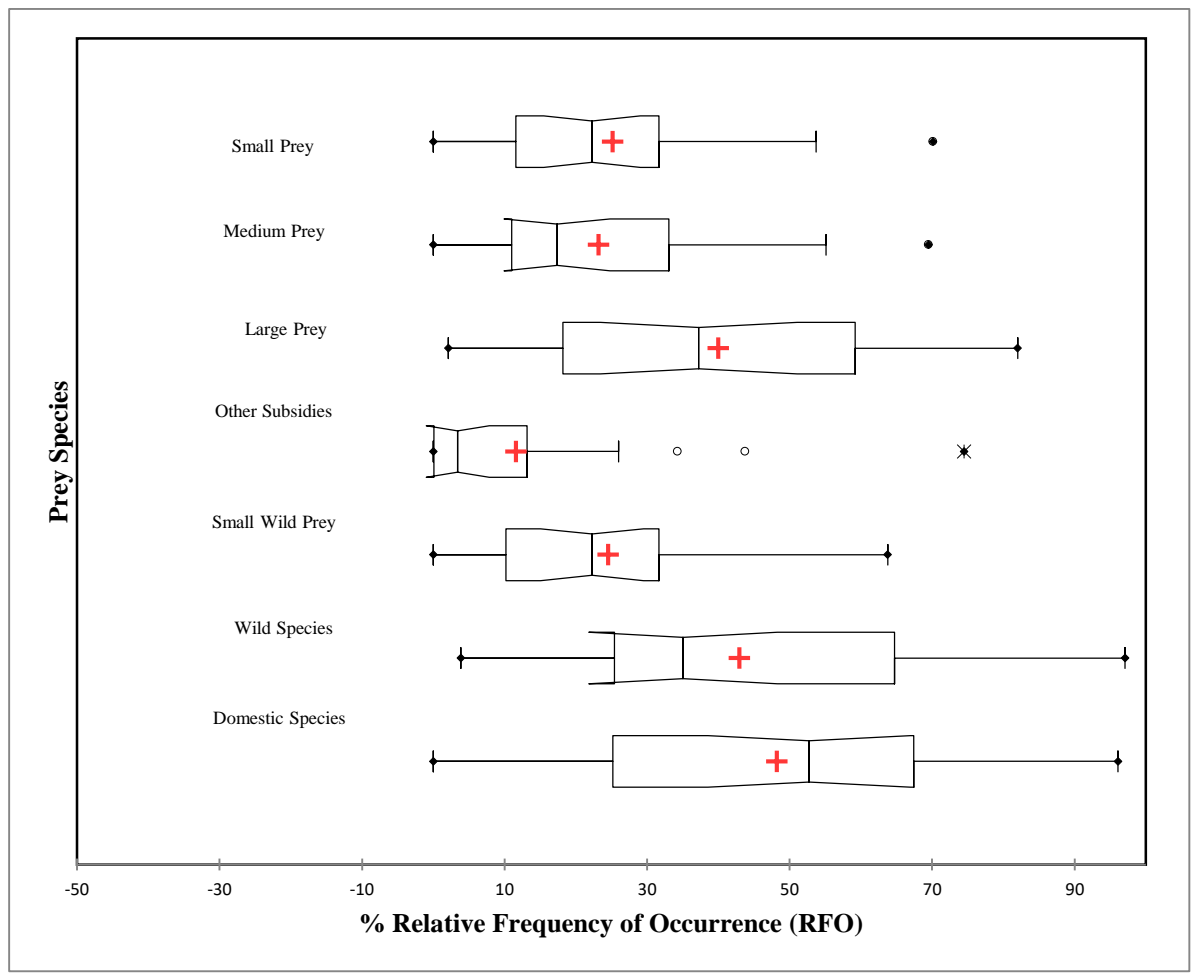


Fig 3.3 Area-wise percentage frequency of occurrence of prey items in the diet of wolves

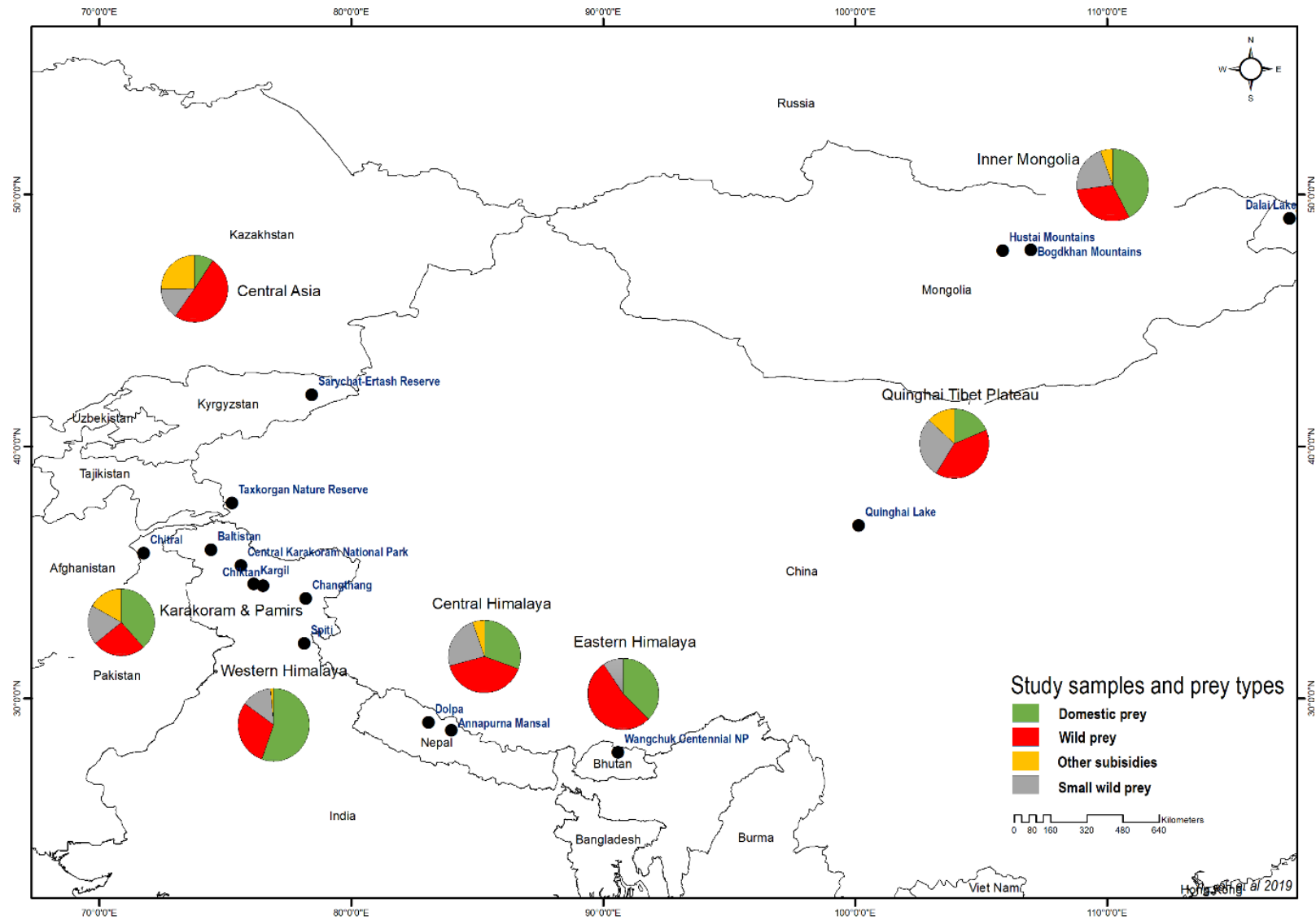


Fig 3.4. Multi-Model inference showing relative weights of predictors. Home range and longitudinal extent (*longex*) of species were the most important contributors in the diet of Himalayan wolves.

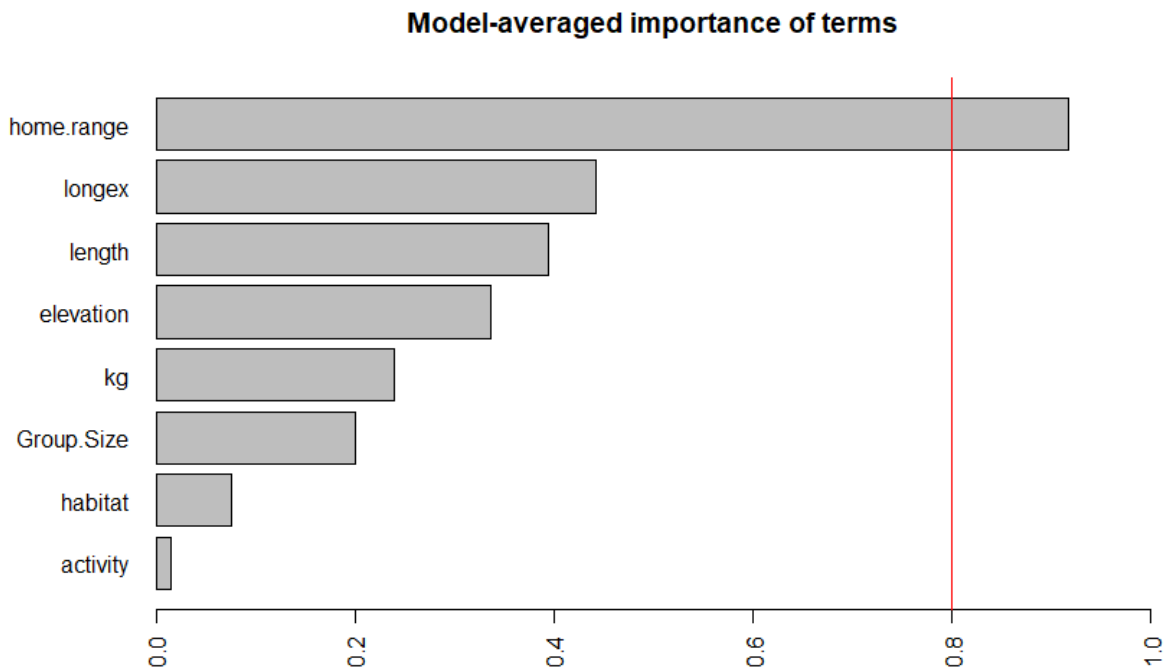


Fig 3.5. Ivlev's selectivity Index for various prey species

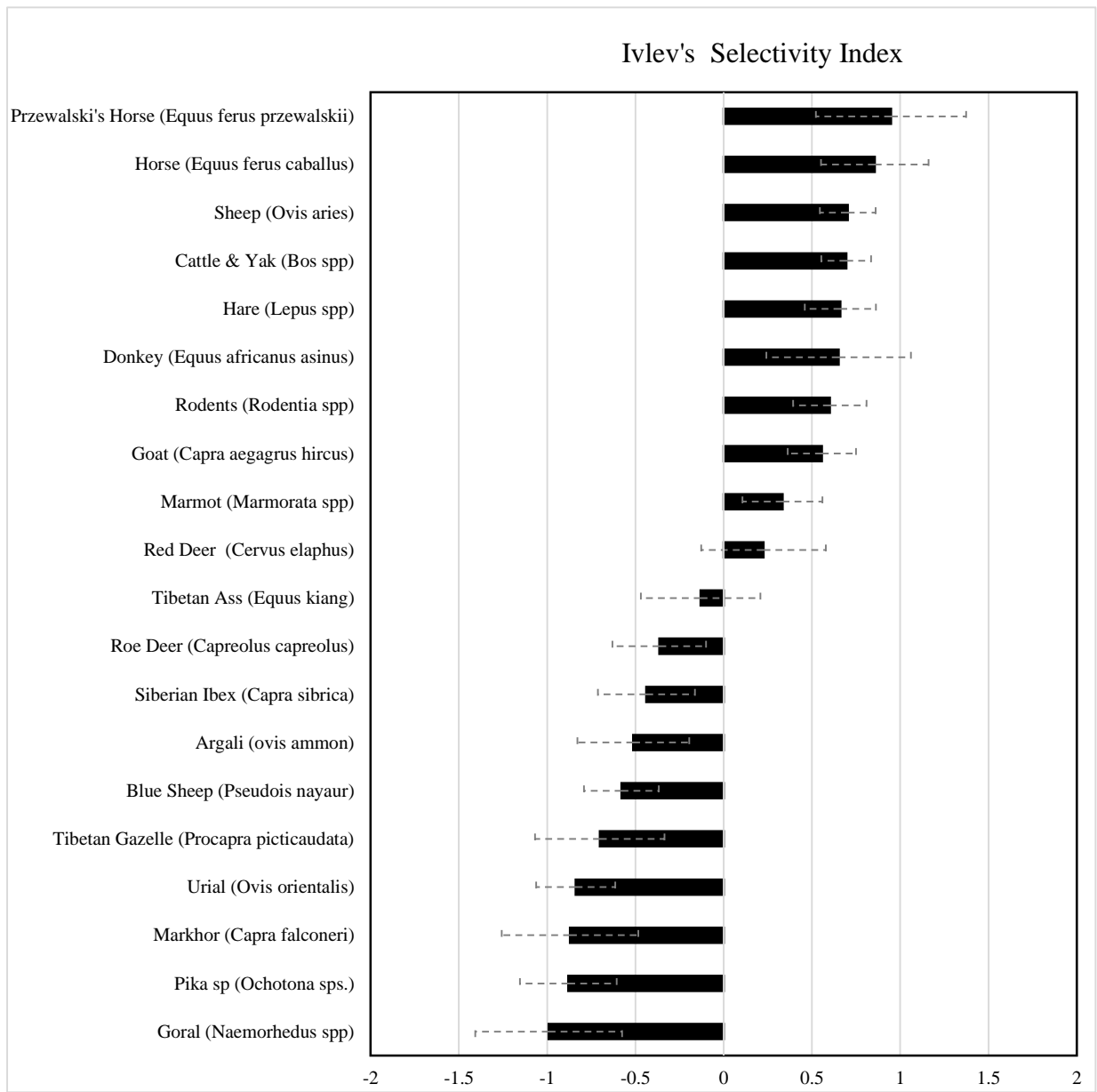


Fig 3.6. NMDS plot showing regional prey choices in various zones. KA-Karakoram and Pamirs, IM-Inner Mongolia, EH – Eastern Himalaya, CA- Central Asia, CH- Central Himalaya, WH-Western Himalaya, QTP- Qinghai Tibet Plateau. Environmental variables considered were the home range, body weight, length, RFO-Relative Frequency of Occurrence, longitudinal, and latitudinal extent.

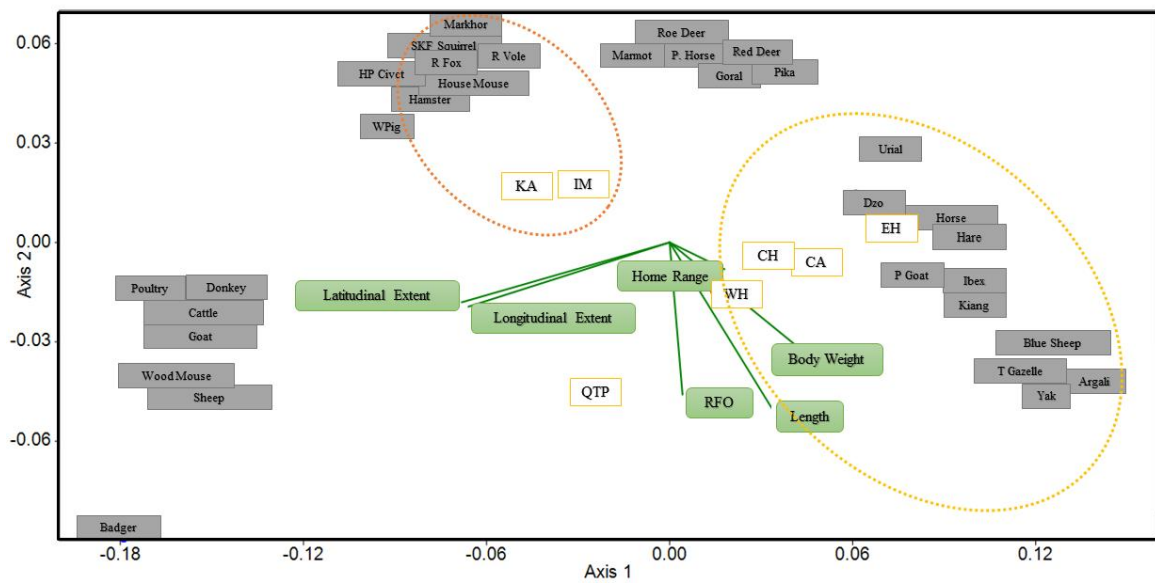


Table 3.1. Prey Size class and Ivlev's index of prey preference. +tive indicates utilized more than available and vice versa.

Prey (N)	Scientific name	Prey Size Class	% Relative Frequency of Occurrence (RFO)	SD +1	Preference	SE
Kiang	<i>Equus kiang</i>	Large	25.00	20.02	-0.13	0.34
Cattle & Yak	<i>Bos spp</i>	Large	20.76	18.12	0.69	0.14
Invertebrates		Other subsidies	19.85	7.28		
Goat	<i>Capra aegagrus hircus</i>	Medium	18.00	9.76	0.56	0.19
Blue Sheep	<i>Pseudois nayaur</i>	Large	15.29	17.35	-0.58	0.21
Horse	<i>Equus ferus caballus</i>	Large	14.75	12.64	0.86	0.30
Roe Deer	<i>Capreolus capreolus</i>	Medium	14.57	18.99	-0.36	0.26
Insects		Other subsidies	13.71	28.50		
Donkey	<i>Equus africanus asinus</i>	Large	11.81	3.25	0.65	0.41
Red Deer	<i>Cervus elaphus</i>	Large	11.69	10.16	0.23	0.35
Marmot	<i>Marmorata spp</i>	Small	11.58	9.69	0.33	0.23
Sheep	<i>Ovis aries</i>	Medium	11.36	8.46	0.70	0.16
Tibetan Gazelle	<i>Procapra picticaudata</i>	Medium	11.05		-0.70	0.37
Civet		Small	10.63			
Rodents & voles	<i>Rodentia spp</i>	Small	9.40	7.52	0.60	0.21
Lepus spp	<i>Lepus spp</i>	Small	8.87	10.59	0.66	0.20
Ibex	<i>Capra sibirica</i>	Large	8.55	6.35	-0.44	0.27
Unknown		Other subsidies	8.20	9.41		
Tibetan Argali	<i>ovis ammon</i>	Large	8.06	1.12	-0.51	0.32
Urial	<i>Ovis orientalis</i>	Large	7.90	6.93	-0.84	0.22
Plants		Other subsidies	6.47	9.50		
Goral	<i>Naemorhedus goral</i>	Medium	6.00		-0.99	-0.42
Birds		Small	4.02	3.52		
Reptile		Small	2.79	0.73		
Badger		Small	2.35	1.49		
Markhor	<i>Capra falconeri</i>	Large	2.12		-0.87	0.39
Red Fox	<i>Vulpes spp</i>	Small	2.12			
Squirrel		Small	1.99	1.97		
Wild Pig	<i>Sus scrofa</i>	Large	1.40	1.27		
Przewalski Horse	<i>Equus ferus przewalskii</i>	Large	0.80		0.95	0.43
Garbage		Other subsidies	0.54	0.27		
Pika	<i>Ochotona spp</i>	Small	2.97	2.00	-0.88	0.27

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4. Chapter 4

Predation by Himalayan Wolves: Understanding conflict, culture and co-existence amongst Indo-Tibetan community and large carnivores in High Himalaya

4.1 Abstract

The wolves in the Hindukush-Himalayan region belong to one the most basal lineages within *Canis lupus*, yet little is known about its ecology, distribution, and behavior. We predict wolf distribution, analyse diet patterns in contrast with other Asian wolves and conflict perception using ecological, social and remotely sensed information. We collected scats (n = 283) of wolves, and other predators over a period of 3 years (2014-17). Wolf diet constituted mostly of domestic prey (79.02 %) while wild prey constituted to 17.80% of wolf diet over the three years. Village surveys recorded only 4% of the respondents confirmed wolf presence and perceived them as a possible threat to various livestock. Over, 98% of the respondents claimed that wolves were not safe for livestock and were averse to its presence. MaxEnt marginal response curves of wolf scats depicted the model to have positive responses to animal location, landuse-landcover, village population, village density and wolf depredation. We found that perceived levels of depredation by who claimed wolves mostly fed on domestic stock was significantly different from the actual diet consumed by wolves ($\chi^2 = 99.64$, p-value <0.0001). Wolf conflict hotspots categorized as very high conflict zone was 8 km², high conflict zone was 14 km², medium conflict zone was 61 km², low conflict zone was 91 km² and negligible or no data zone below threshold was 5573 km². It is advocated that conflict and negative perceptions towards wolves may be managed through a holistic conservation strategy in sync with tradition, enhances capacity and promotes livestock security.

4.2 Keywords

Canis lupus chanco, Maxent, scat analysis, livestock depredation, cold desert, Buddhist, Trans

4.3 Introduction

Grey wolves (*Canis lupus*) are found throughout the Northern Hemisphere. In the Indian Subcontinent, these are represented by two geographically isolated broadly allopatric populations [1]. One population of wolves extends from the upper Hindukush-Himalayan region of India across the two northernmost states of Himachal Pradesh and Jammu and Kashmir [2]. This wolf population is well adapted to the cold environment and is known as the Himalayan wolf, *Canis lupus chanco* [3–5]. Found in the arid and hypoxic high altitude ecosystems of the Himalayas and the Tibetan Plateau, extending into China, Manchuria and Mongolia [6,7] these ‘woolly’ wolves descended from a unique ancient lineage. Their taxonomic ambiguity has been debated for over 165 years due to a complex evolutionary history [3,7]. Most studies agree though, that the Himalayan wolf is the basal taxon within the phylogeny of the wolf and wolf-dog clades [4]. Its ancient divergence, unique distribution, shallow within-clade divergence and adaptation to hypoxia make the Himalayan wolf of India, Tibet, and Mongolian regions a distinct Evolutionary Significant Unit [4,7,8]. However, there is still a limited understanding of its ecology, diet, and behaviour. It is estimated there may be no more than 350 wolves individuals in the Himalayan landscape [2]. Negative interactions with humans in a resource scarce landscape also makes this species prone to conflict and extinction [8–10].

Wolf populations have been significantly reduced by human control due to conflict for various reasons [11]. Historically wolves originally lived almost throughout North America and Eurasia. However, negative attitudes against wolves throughout the world, allowed them to be viewed as a threat to personal safety, an object to subdue and an impediment to progress and civilization [12]. Wolf depredation of stock convinced government aided ‘legal’ extirpations across many areas in the Europe, United States and Canada. Subsequently, wolves became absent in many areas, for example, in 1966, the wolf was declared functionally extinct in the Scandinavian

Peninsula [13]. Wolves were almost systematically exterminated until 1940 in the United States of America by government-backed programs since the 19th century [14]. Nearly, all mortalities in Scandinavia, Italy, Germany and England were reported from poaching or vehicle strikes [11]. Despite long standing persecution, it is noteworthy that in recent times, large carnivores including wolves have been documented to be recolonizing parts of their former ranges in Europe [15,16].

In, the Asian context, a major cause of Human-Wolf conflict has been livestock depredation [3,5,17,18]. Unavailability of wild prey and natural habitats has driven wolves to subsist mainly on livestock and life outside protected areas which makes it prone to conflict, social dislike and retaliation [5,19,20]. In India, however, attitudes towards wolves have been less destructive. Tolerance of communities has probably aided survival and depredation is seen to be part of the occupation [17,21]. In general, damages by wildlife including wolves have been tolerated due to many religio-cultural sentiments. Today, despite complex human wolf associations, in many Indian landscapes, they continue to survive *vis-a-vis* disturbance and other human induced factors [22]. However, no matter how great the tolerance, persecution remains as one of the biggest obstacles to wolf recovery [20,23], including the Himalayan wolf [17,24] whose genetic singularity and small population, makes its more vulnerable to extinction [3,4,25,26]. Apart from such threats, feral dogs also may pose potential negative impacts on wolf conservation efforts [27,28].

Ecological attributes of such conflicts, and environmental characteristics of the areas where they occur is largely missing [29]. Studies on the actual damage caused by wildlife species that can tease apart the actual damage and perceived damage are missing. Management strategies from

research that are used for conflict mitigation call for a more nuanced approach, taking into account the behavior and [ecology](#) of the species concerned [30]. The current study aims to understand ecological attributes of human-wolf conflict through the use of telemetry, scatological and distribution modelling techniques [31–33]. The human wolf conflict scenario in Spiti, India may be considered representative of the situation in the Himalaya. Therefore, we investigate a) dietary choices of Himalayan wolves b) we map and delineate wolf conflicting hotspots in the scope of its movement, diet and public perception. And, c) we describe prevailing perceptions towards large carnivores in socio-cultural context of study area and compare it to other areas in Trans-Himalayan landscapes. We expect that wolves will be in conflict within human use areas that most closely match their own ecological needs in terms of food and space.

4.4 Study Area and Methods

The Spiti catchment area (Fig.4.1) which is divided by the Spiti River is a cold semi-arid region of the state of Himachal Pradesh. The greater Himalayas are to the south east of the valley while on the north of it lays Ladakh and east lays Tibet. The study area comprises two protected areas of Kibber Wildlife Sanctuary (WLS) (32°5 to 32°30 N and 78°1 to 78°32E) and Pin Valley National Park (NP) in the south west corner of the Spiti Catchment area. Kibber WLS was established in the Spiti Region (Lahaul and Spiti District) of the Indian state of in 1992 for conservation of trans-Himalayan wildlife. It is a mountainous cold desert, where altitudes range between 3600 m and 6700 m above mean sea level. Temperatures range between 23°C and 3°C in winter and between 1°C and 28°C in summer. The vegetation of this area has been broadly classified as dry alpine steppe (Champion & Seth, 1968).

Large mammalian fauna of the area includes bharal (*Pseudois nayaur*), relatively few ibex (*Capra ibex*), and their predators, namely the snow leopard and the wolf. Other fauna includes the red fox, *Vulpes vulpes*, pale weasel (*Mustela altaica*), stone marten (*Martes foina*) and the

Himalayan mouse hare (*Ochotona* spp). Nearly 45 species of birds were identified, including several species typical of this alpine habitat, such as chukar (*Alectoris chukar*), and Tibetan snowcock (*Tetraogallus tibetanus*).

The local agro-pastoral community, largely Buddhist, are concentrated in village clusters largely along the main Spiti River. There are approximately 60 villages through the length and breadth of the valley. Most agriculture- related activities are restricted to the short growing season (from May to September). The main crops cultivated are barley (*Hordeum vulgare*) and green peas (*Pisum sativum*). Livestock includes goats and sheep, cattle, ‘dzomo’ (a female hybrid of cattle and yak), and yaks. Donkeys are the beasts of burden, while horses, apart from being used for religious ceremonies, are mainly raised for trade. The region has traditionally practiced systems of grazing whereby nomadic as well as resident herders frequent this landscape. In this vast landscape (~ 4000, (Sharma *et al.*, 2015) the study was concentrated much towards higher elevation regions of the area (> 3000 m) from villages surrounding Pin valley NP and Kibber WLS.

4.5 Data collection

4.5.1 Village surveys

In order to determine livestock depredation and large carnivore presence, questionnaire surveys (Fig.1) using a semi structured questionnaire [41] among the locals across 35 villages were conducted between 2015-16. The questionnaire surveys were distributed systematically to represent most of the study area covering altitudes on 3000-4300 m. We conducted the questionnaire surveys in compliance with national ethical guidelines of conduct [42], verbal consent from the respondents and maintained confidentiality of individual identity of the respondents. A sighting of wolf (*shanku*) was confirmed by showing respondents photographs of different canids and noting details of their presence, sighting, and depredation including possible scavenging. The questionnaire only noted claims by respondents into various categories

such as presence, visual confirmation through sighting or signs or depredation or scavenging. Depredation events were noted in response to questions relating to number of livestock lost due to a carnivore. Any ambiguity in the confirmation was not recorded. In total 200 households were surveyed randomly with 3-4 households minimally in each village. The unit of sampling was considered to be a household. The questions were also focussed on household characteristics such as demography, income, grazing distance, livestock holding and carnivore presence or depredation by other carnivores (Annex 1. Supporting information for questionnaire used).

4.5.2 *Data on wolf food habits*

Sign surveys were conducted throughout the landscape with approximately 1000 km tracked and 300 man days of effort through post winter and pre-winter surveys. Trails, river banks, hill tops, village periphery and grazing pastures were searched on foot for signs of a large predator as well as other meso-predators. We collected scats (n = 283) of wolves and other predators over a period of 3 years (2014-17). All scats collected were labelled with location and time references. Scats were analysed with standard scatological techniques to determine diet choices in wolves. Scat samples were washed and examined under the microscope for medullary patterns to identify different prey species based on standard methods [35,43]. Relative frequencies of occurrence [35] of species were calculated. Biomass consumed was calculated using Consumed mean prey mass (kg) per wolf to excrete one collectable scat as a function of mean prey body mass (x kg) provided per feeding experiment by [44] correction factor 1 (CF1), $y = 1.798(1 - \exp(-0.008x))$ as well as the conventional correction factor, $y = 0.439 + 0.008x$ [45]. We compared data on diet and perceived depredation by large carnivores as well as other carnivores using Pearson's correlation co-efficient and χ^2 test. We also performed correlations to determine relationship between perceived depredation and livestock population. Information of wolf diet was also compared with data from Lyngdoh et al 2020, [5] using descriptive statistics was used to compare relative frequency of occurrence between common prey consumed with that of the rest of Asia.

4.5.3 DNA verification of select scats

Wolf scats were collected through field observations and traversing areas of regular movement trajectories of collared wolves in the landscape. Domestic dog scats could also be easily confused for wolf scats therefore, we collected scats from areas that were devoid of active presence. For example, areas that were too close to villages or human settlements would have heavy dog presence as also confirmed through site visits during interviews and too many scats of dogs as well. Further, to confirm wolf scats and observer error, DNA extraction from only sample scat samples (n=118) were done by using QIAamp stool DNA kit (QIAGEN, Germany) in a dedicated room to avoid contamination with some minor modification [4]. We did not sequence fox scats as fox scats are easily distinguishable due to their small size and quantity. We targeted 148 bp region of the mitochondrial Cytochrome b gene for identifying species using carnivore-specific primers (Ferrell et al, 2000) and all the scat samples were PCR amplified. All PCR reactions were performed on Applied Biosystems thermal cycler (ABI, 2720) in a reaction volume of 10 µl containing 1X PCR buffer, 2.5 mM of MgCl₂, 200 µM of each d-NTP, 1.25 µg BSA, 4 pM of each primer and 0.25 U of Taq DNA polymerase (Genie) and 1 ul of genomic DNA. The PCR cycling conditions were as follows: initial denaturation at 95°C for 3 mins, followed by 32 cycle of denaturation at 94°C for 30 sec., primer annealing at 55°C for 50 sec. min, primer extension at 72°C for 40 sec. with a final extension at 72°C for 10 min.

Amplified PCR products were cleaned up using Exo-SAP treatment to remove residual oligonucleotides and dNTPs prior to DNA sequencing. Forward and reverse primers of the Cytochrome b gene were used for setting up the cycle sequencing reaction. Unbound ddNTPs were removed by using alcoholic precipitation method and subjected for sequencing to ABI 3130 Genetic Analyzer (Applied Biosystems). Sequence Qualities were determined using Sequence Analysis v 5.2 software (Applied Biosystems) and validated by Sequencer v 4.7 software (www.genecode.com). All good quality sequences were compared with NCBI/GenBank (<http://www>.

ncbi.nlm.nih.gov/) database using BLAST tool and species were confirmed with most homologous sequences (100%) available from NCBI database. Multiple sequence alignment (MSA) was performed using CLUSTAL was implemented in BioEdit v 7.0.9.0 software (Hall 1999).

4.5.4 Wolf Tracking

The study area was extensively searched for wolf dens, signs and scat to determine probable areas of wolf activity. Before initiating the trapping procedures, the entire area was pre-monitored for presence of wolves. On confirmation, camera traps were laid in the area to ascertain possible movement pattern and probable movement path. Based on results, 15 to 20 padded leg-hold traps (Duke 3 coil spring rubber jaw trap, 3OS – RJ, Duke Company, West Point, MS 39773, USA) were set concealed in a circular manner along the sites the wolves frequent; around a live bait or partially consumed kill (whenever available). The trap sites were also laced with coyote & wolf gland lure and food lure (Hawbaker & Sons, wolf gland lure 100 and Hawbaker & Sons, coyote food lure no. 10 Stanley Hawbaker and Sons, Fort Loudon, Pennsylvania, USA), in order to increase the possibility of wolf encountering the trap. Once set, traps were kept undisturbed and were manually checked at every 1 hr interval from a distance of 500 m with help of a binocular. The core capture team, which included an experienced biologist, a wildlife health professional and two assistants camped at a distance of 1 to 1.5 km from the trap site, so as to minimize the response time, thereby minimizing the possibility of trap-related injuries. Animals captured were held by a snare pole and a nylon net. Animals were sedated in the hind quarters using cyclohexane (Ketamine) and a tranquilizer (Xylazine) by injection (Kreeger *et al.* 1988, Mech and Boitani 2003, Boitani and Powell 2012). Animals were fastened with GPS collars (Globalstar Satellite System/Iridium) once trapped, principally to locate their movements.

Regular fixes at 5 hour intervals were made to provide information on a cyclic basis. A total of

760, 471 and 519 fixes were used for three wolves, Dhankar (male), Kunzum (female) and Leica (female) in winter respectively. All calculations were carried in R using Adehabitat package for calculation of Minimum Convex Polygon (MCP) and kernel utilization distribution (KUD) (Calenge *et al* 2011)

4.5.5 Human - Wolf Conflict Modelling

We used a presence only modelling Maximum Entropy (MaxEnt) algorithm, which finds the probability distribution of maximum entropy, that is the most spread out or closest to uniform with limited information about the target species [46–48]. 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 [49–52]. Wolf predation events were used from scat locations of 214 of 283 collected and GPS labelled sample points to account for livestock predation. Environmental layers of wolf presence records were obtained from data of three wolf packs that were GPS collared from a period of 2015-2017. Regular fixes were obtained and presence points of individuals were thus used from 2,602 locational fixes that were recorded. A total of 11 environmental layers were used to model wolf potential utilisation in terms of livestock depredation. We generated layers from Digital Elevation Model (30 m), Forest cover map (FSI, 2014), Topographic Heterogeneity Map, Ruggedness Index [53] and slope.

Similarly, to account for spatial distribution of carnivore caused livestock mortality kernel density maps were developed for livestock depredation claims by respondents for wolf (wolf depredation) and snow leopards (snow leopard depredation). Livestock density layer was generated through village surveys and kernelled. Kernel density calculates the magnitude per unit area from point or polygon features by using a kernel function described by Silverman (1986) to fit a smoothly tapered surface to each point or polygon [54]. Point data were used input then ‘population’ field was selected from the attribute, where ‘population’ field was used to

weigh some features more than others. Subsequently, kernel density analysis was performed in a geo-spatial environment using ArcMap RELEASE 10.7.1 (Environmental Systems Research Institute). Following layers were then used as response variables as continuous layers in ASCII format to create various species distribution models.

Table 5.1. Variables used for modelling Human Wolf Conflict

S.No	Layer	Source	Scale/Cell Size
1	Digital Elevation Model	Shuttle Radar Topography Mission (SRTM)	1:50,000, 30m
2	Topographic Heterogeneity	Riley et al 1995, DEM	1:50,000; 90m
3	Forest Cover Map	Forest Survey of India, 2014	1:50,000; 23.5m
4	Livestock Density Layer	Kernel layer village questionnaire surveys	1:50,000; 100m
5	Ruggedness Layer	Terrain ruggedness index (TRI) is a measurement developed by Riley, et al. (1999)	90m
6	NDVI (90m)	Normalised Differential Vegetation Index from Landsat 8	90m
7	Slope	DEM generated	90m
8	Snow leopard depredation	Kernel layer village questionnaire surveys	100m
9	Wolf depredation	Kernel layer from household questionnaire survey	100m
10	Wolf presence	Kernel density layer from GPS telemetry	100m

11	Village population density	Kernel density layer from Census of India (2011)	100m
12	Village density	Kernel density layer of village locations	100m

4.5.6 Model validation and selection

The predictive performance of the model was estimated using area under the curve (AUC) derived from relative operating characteristic (ROC) plots. To select the best model parameters we compared different models with a combination of the “feature class” and “regularization multiplier”. MaxEnt provides different types of restrictions (“feature class”) in the modelling stage such as lineal (L), quadratic (Q), product (P), threshold (T), and hinge (H). We used all the possible combinations of these features. The used regularization (beta) multiplier values; 0.25, 0.5, 1, 2, 3, 4 and 5 were based on Morales et al, 2017 [55]. Models with lower multipliers tend to over fit data however, higher multipliers may lead loss in capturing species relations to various environmental components [56]. Combining features classes and regularization multipliers, we assessed a total of 42 models for each case study, plus the default auto-feature with 5000 background points.

Evaluating whether competing models are significantly different from one another was done in ENMTools [57]. We compared all the generated models by utilizing the corrected Akaike information criterion (AICc) available in the software ENMTools version 1.4.4 [57]. The process of choosing the best model using AICc has some limitations that can have an impact on the final results. Results of simple model selection implemented by ENMTools should be carefully interpreted because uncertainties of each parameter values may not be fully incorporated for calculation of AICc. The AICc can excessively penalize over parametrization, which can lead to choosing the wrong model. Despite this fact, simulation have shown that AICc perform fairly well [58]. We selected the best model and ran 30 replicates with cross validation to test for model

consistency and used the averaged best model to finally generate a conflict map in Arc Gis 10.6. The final cumulative output was used to depict conflict values from 0-100. We selected cumulative values of 75-100 as very high, 50-75 as high, 25-50 as medium, 0-25 as low conflict zones and < 0 as no data or negligible zones [59].

4.6 Results

4.6.1 Wolf diet

DNA tests confirmed 101 of 118 scats that responded to amplification belonged to *Canis lupus* with 99% match in the genbank BLAST database. We found 105 scat samples that were sequenced successfully on amplification. We classified 85.75% of scats correctly as suspected wolf scats were confirmed through NCBI Blast Sequences, which means 12.25% of the scats were misidentified. Out of a total of 118 scats 11% of the scats did not produce any results. Wolf diet constituted mostly of livestock (79.02 %) while wild prey constituted to 17.80% over the three years. Remaining prey items which amounted to 3.16% were unidentifiable or made up vegetative matter. In comparison to wolf diets from Asia, wolf diets of Spiti showed $44.45\% \pm 7.25$ (SE) of cattle or yak as prey item in terms RFO compared to $12.04\% \pm 3.65$ in rest of Asia. Similarly, goat or sheep was 14.63% higher in average to their consumption in other parts of Asia. (Fig 3). Conversely, Blue sheep (4.01 ± 2.08 vs 16.78 ± 8.45) and Ibex (3.05 ± 0.4 vs 9.34 ± 2.68) were lower in the study area.

4.6.2 Perceived Human-Wolf conflict

Village surveys recorded only 4% of the respondents confirmed wolf presence and perceived them as a possible threat to various livestock (Fig 2 & Fig 4). Over, 98% of the respondents of the total surveyed claimed that wolves were not safe for livestock and were averse to its presence. Similarly, 97% of the respondents claimed snow leopards also were a threat to livestock. Claims by 97% of the respondents were that feral dogs as well posed a threat to livestock apart from wolves and snow leopards. We found that villages which reported higher livestock numbers also

reported higher livestock depredation ($P = 0.56$, $r^2 = 0.31$). Mean livestock depredation cases reported was 5.25 ± 4.71 (S.D), 7.70 ± 9.54 and 8.83 ± 6.05 for wolf, snow leopard and all predators (including wolf and snow leopard) respectively. Claims of wolf depredation showed higher correlation with livestock population in villages ($P = 0.67$, $r^2 = 0.47$) than snow leopard depredation ($P = 0.56$, $r^2 = 0.35$). We found that perceived depredation (claims of depredation) was significantly different from the actual proportion of diet pattern exhibited by wolves ($\chi^2 = 99.64$, p-value < 0.0001).

4.6.3 *Wolf conflict hotspots*

It was observed that the 50% MCP home ranges of wolves were 338.59 ± 122.80 km². The 50% Kernel Utilization Distribution (KUD) Home Ranges were 86.38 ± 81.50 km². The 95% home ranges were 1044.26 ± 56.27 km² and 449.53 ± 407.99 km² for MCP and KUD respectively. Across 42 models we found Auto Model with all features was the best model (beta multiplier = 4, AICc = 2791.86, Fig 5-7). The averaged model output generated a regularized training gain was 1.81, training AUC was 0.94. Test AUC was 0.92 ± 0.04 . The average algorithm convergence reported was 227.33 iterations with an average of 5057.03 background points. Wolf depredation (43.65 ± 4.1 %), Animal location (18.07 ± 2.75 %) and Village population density (17.54 ± 1.5 %) constituted as the top three variables that contributed to AUC. The environmental variable with highest gain when used in isolation was animal location, which had the most useful information by itself. Similarly, decrease in the gain was most when animal location was omitted, therefore generated the most information that was present in the other variables. Marginal response curves depicted the model to have positive responses to animal location, landuse and landcover, village population, village density and wolf depredation. Marginal curves were negative to slope, ruggedness and terrain heterogeneity. Curves showed peak like responses for elevation, NDVI and Livestock density. We found area denoted as very

high conflict zone was 8 km², high conflict zone was 14 km², medium conflict zone was 61 km², low conflict zone was 91 km² and negligible or no data zone below threshold was 5573 km².

4.7 Discussion

We found that wolves of Spiti largely preyed on large domestic prey [5]. Similar studies from the adjoining landscape of the regions reflect comparable patterns [17,21]. A review of dietary habits of grey wolves [5,23] showed wolves from India preferred mostly medium sized wild ungulates and domestic prey. The results of the review [23] present mostly dietary habits of peninsular wolves of India, the current study thus adds to the existing information. Similarly, Zhang et al. (2009) found that in Dalai Lake Natural Reserve, Mongolia; livestock formed much of the wolf's diet probably due to overabundance of livestock. These patterns of prey consumption are more in common across central Asia, where Mongolian wolves co-occur in likewise agro-pastorally occupied landscapes [5].

It is important to consider that attitudes towards large carnivores are shaped not just by religion or culture but gender, education, and awareness of wildlife law as well [60]. Semi structured questionnaire surveys revealed there is a perceived negativity and conflict between agro-pastoralists and wolves (more than snow leopards), which were claimed to be the main causes of livestock mortality. The northern part of the study area (Kibber WLS and adjacent areas) reported more conflict in terms of wolf predation while the south western part (Near Pin Valley NP area) reported relatively greater conflict arising due to snow leopards. Retaliatory killing of wolves are reported to occur despite unclear perceptions that the snow leopard is responsible for most kills of livestock [36], but this practice has slowly been discontinued largely due to conservation awareness, enforcement as well as religio-social sentiments of the predominant Buddhist communities of the region [18,40]. Quantitative surveys across Ladakhi villages in neighboring union territory north of the study area also report that people generally exhibited

significantly negative attitude toward wolves than snow leopards [60]. In Hemis, Northern India, 64% of the respondents were found to be positive towards snow leopards, while, over three-quarters of respondents (78%) perceived wolves negatively [61]. Similarly, in Nepalese Himalaya, the herding communities were much more antagonistic to wolves rather than snow leopards even though the latter caused much more economic losses [62]. We did not investigate causes of perceived negativity towards wolves, but we suspect that such biases against wolves can be attributed similarly to lack of knowledge about species ecology and less with its relative presence [24,63–65].

Our results showed that perceived levels of livestock depredation did not emulate actual levels of depredation in concurrence with earlier studies [24,66]. We found disparities in terms of type of prey and quantity of livestock consumed as claimed by respondents against scatological analysis. We also found that livestock constituted major prey in the diet of wolves from Spiti unlike similar studies from the Asian context [5]. Wolf depredation is lower than expected given its exposure to domestic livestock. Similar findings have been report from the Northern Rocky Mountains where, wolves accounted for less than 0.04% of the total losses or 0.01% of all predator caused mortalities [63]. The reason why perceived conflict is taken as real conflict for wolves in our study area, is probably due to local attitudes that may have over a long time festered negativity and persecution rather than co-existence. In Nepal, Kusi et al, 2020 [62] also point out that local customs and beliefs of snow leopards rather than wolves in sacred Buddhist literature, coupled with longstanding conservation narrative of the former may be responsible for a fragmented attitude towards both these large predators. Conservation agendas recognize wolves as a least concern species globally which does not give on ground the attention of a priority species [67]. Therefore, complex cultural legacies, legal controls, global priorities which may neglect local nuances and scientific or conservation bias may have festered perceptions against

wolves in the Himalaya as well. In view that both species of snow leopard and wolf occur in the same landscapes we suggest that future efforts towards the former's conservation, must accommodate in tandem conservation of the latter as well.

The simplicity and ease of use of Maxent has prompted many researchers to use the software [33]. We avoided default settings and approached the modelling process to arrive at an optimal regularization parameter, which may differ if push button approaches are used. The three variables that were important permutation terms were animal location, village density and slope. Scat locations, which correlated, well with animal location were thus a very good indication of conflict hotspots that could serve as reliable data in cases where animal locational data is not available. In terms of percent area of conflict, scale appeared less significant. However, it is important to note that the scat presences correlated well with village population which is not unexpected as wolves fed largely on livestock. It is rare for communities living with wolves to be not aware of their presence in proximity [20]. Wolves operated at peaks of 3300 mts with gentle slopes, which was expected. This may be also due to competition with sympatric species such as snow leopard which prefer more rugged and cliff like terrain [68,69]. Snow leopards significantly were found to preferred cliff-dwelling wild ungulates, whereas wolves preferred typically plain-dwellers and hence evolved within such niches [4,69]. A better sampling strategy where both wolves and snow leopards are tracked through GPS telemetry could reveal finer differences in habitat use by individual species.

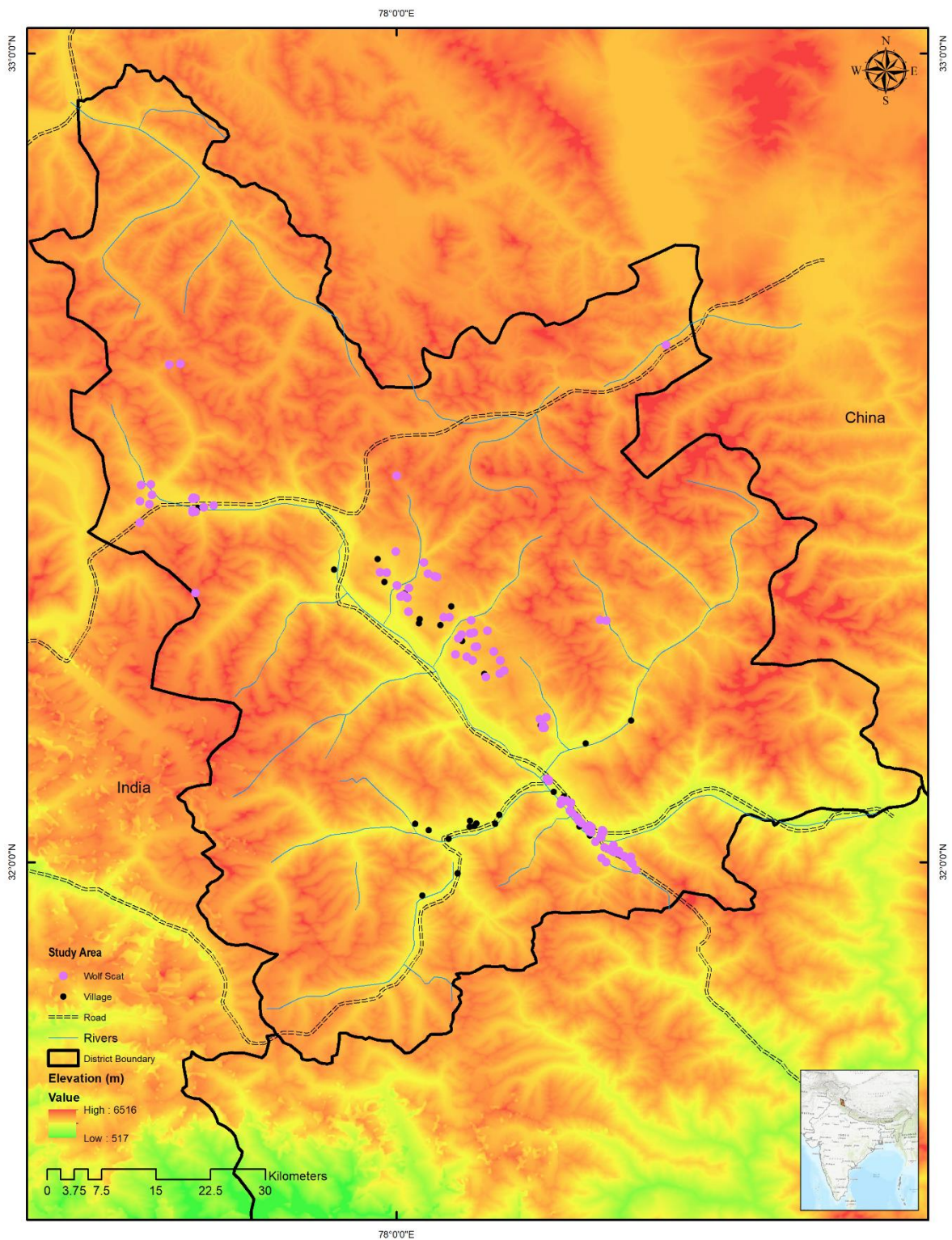
Therefore, conflict hotspots depicted were in areas that had low topographic heterogeneity and, decreasing ruggedness, which were probably historically colonized by humans as well. Wolves utilised areas that were undulating and gentler in their slopes. Whether this is driven by

competing species or niche exclusion in terms of space and prey needs to be examined in detail. Wolves selected area with optimal livestock densities and villages that maintained their rural characteristics. This means it was unlikely to find wolf depredation with increasing urbanization, however fragmented landscapes with a mosaic of urban to natural settings may allow co-existence [20,70,71]. However, it does not imply that decreasing livestock would reduce chances of wolf presence. Studies have shown that wolves may choose to predate or switch to wild prey if available in good numbers by livestock as well [5,23,72]. Predominantly selected areas of wolf depredation were agriculturally inclined villages with good livestock and accessible terrain or topography. From field observations, it is clear that in this landscape of limited and short flowering periods, herds may be concentrated in productive pastures as seen with responses to NDVI, which are very often occupied by domestic livestock. This may have led to prey switching amongst wolves due to sheer likelihood of great contact over the past, depressed wild prey availability over wolf generations. The implications with respect to future climate changes which predict greater energetic costs due to reduction in niche overlaps between natural prey-predators in this landscape may exasperate existing levels of conflict with wolves [73].

Human-wolf conflict is global, however their management strategies have been specific, regional, complex and also controversial [73]. The wolf is a top predator that has the capability to drive trophic cascades across large landscapes [74–76] of the Himalaya. Its conservation thus, is linked with securing not only the landscape but the people and the region as a whole. In Spiti, a stronghold for Himalayan wolves, cultural ethos and wildlife have been primary reasons for tolerance to large predators [18]. Therefore, non-lethal methods which can enhance livestock security, promote wild prey densities, eradicate feral dogs and foster tolerance must be advocated in the short and medium term [20,77].

Cultures that raise livestock have strongly disliked wolves [63]. The section of Himalayan community which relies on pastoralism is sizeable [78,79]. Despite this huge dependency, pastoralism can contribute positively to biodiversity conservation [80]. Therefore individuals knowledgeable about herding and pasture management, trained in conservation and ecology, able to design management experiments, and develop novel but tradition-based holistic management practices are essential in the long term [81]. Raising awareness and development of professional capacities through a regularized curricula and applicability of such methods for especially rangeland management must be piloted through field trials and policy framework. Capacity building, development of partnerships, decentralization, horizontal and vertical linkages is essential for conservation management of large carnivores in the Himalaya [82]. This approach may also aid in informing the stakeholders towards timely interventions in order to ensure survival of last remaining populations of an ecologically unique and evolutionarily significant Himalayan wolf, its prey and habitat.

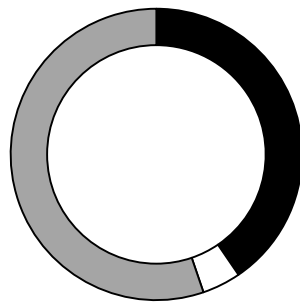
Fig 4.1. Study Area depicting Spiti region in North India with locations of scats



1 **Fig 4.2. Response with respect to wolf conflict and attitudes of villages in Spiti Region revealed through semi structured questionnaire**
 2 **surveys from 35 villages and 200 households**

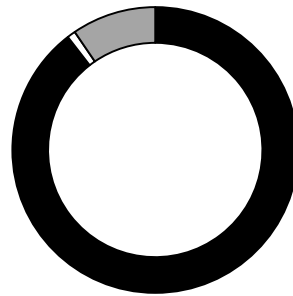
3

a. Have you seen wolves in Spiti?



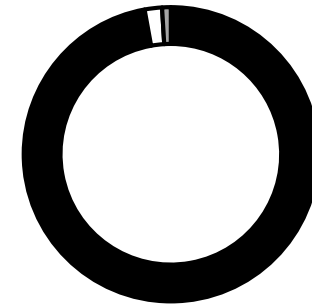
■ No □ No response ■ Yes

b. Do you hunt or scavenge on wild meat?



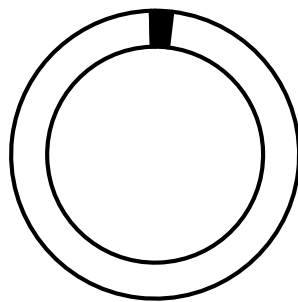
■ No □ Yes ■ Yes (practiced earlier)

c. How often do you consume wild meat?



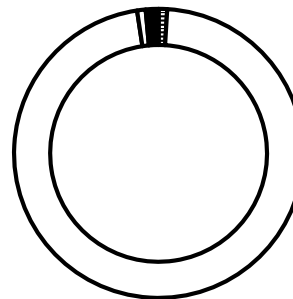
■ No □ Yes ■ Occasionally

d. How Is livestock depredation related to wolves?



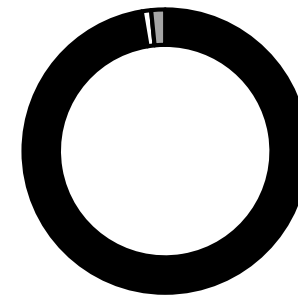
■ Not a problem □ Livestock not safe
 ■ Better if not there

e. How Is livestock depredation related to snow leopards?



■ Not a problem □ Livestock not safe
 ■ Better if not there ■ Don't know/Not seen

f. Are there other carnivores causing livestock depredation?



■ Feral dog □ Red fox ■ No Response

Fig 4.3. Percentage relative frequency of occurrence of prey items in wolf scats from Spiti region in comparison with wolves from 21 studies across Asia (Lyngdoh et al 2020) across years (2015-2017, n = 283). Filled bars indicate percentage and whiskers indicate ± 1 SE.

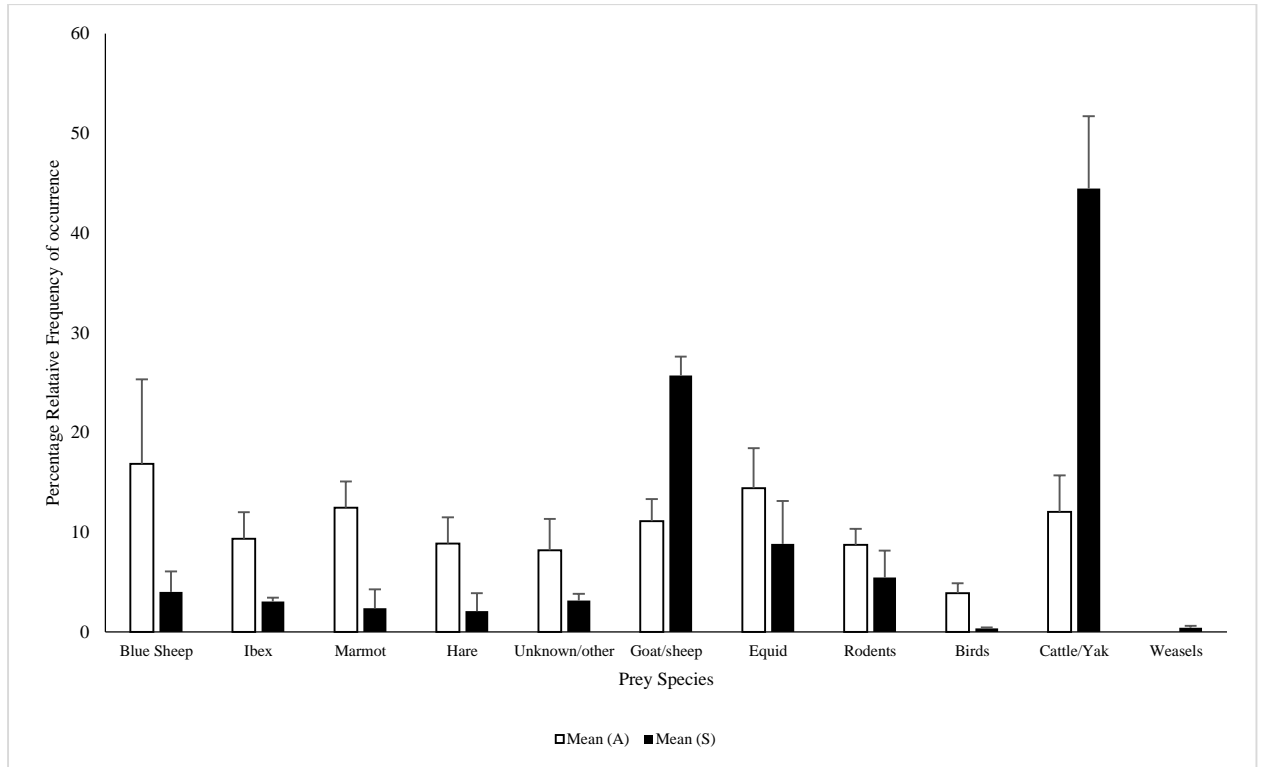


Fig 4.4 Box Plot of cases of livestock depredation claimed consumed across categories of predators. Red dots indicate mean depredation cases. Yellow and green filled dots indicate outliers.

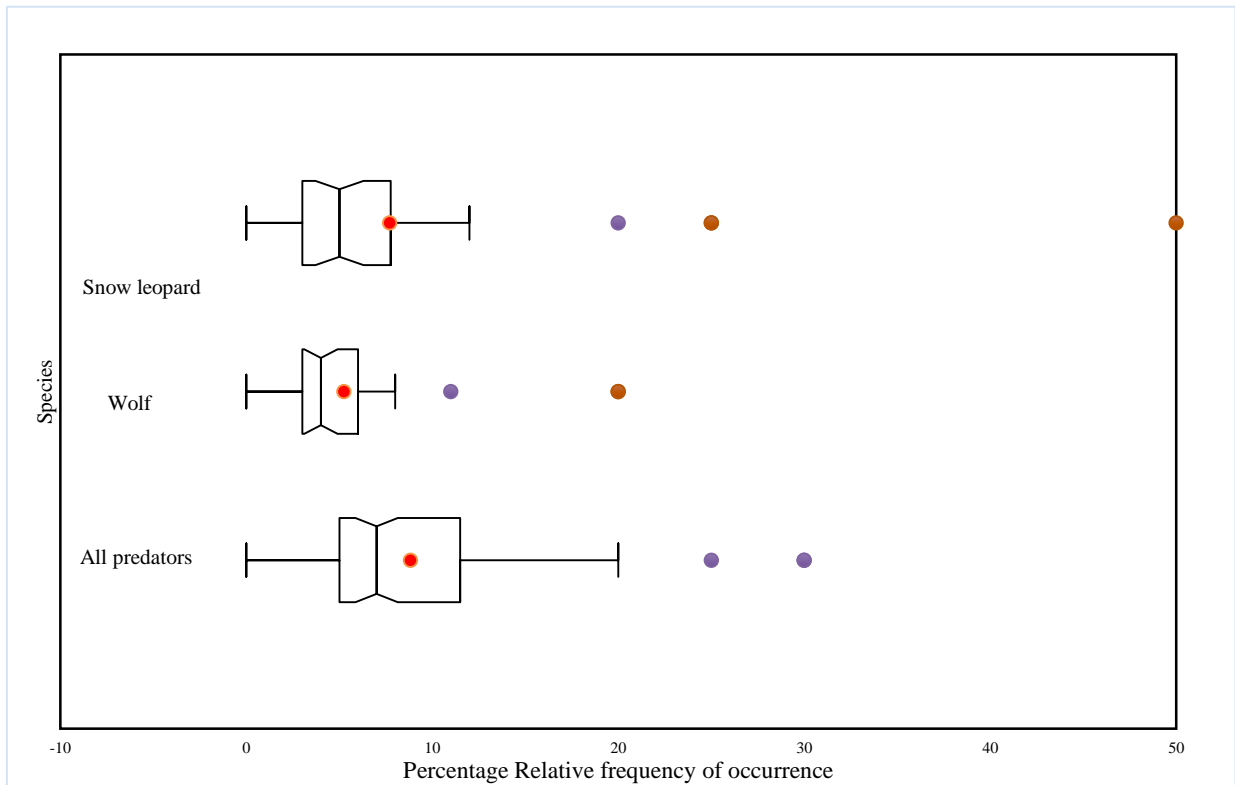


Fig 4.5. Wolf conflict hotspots modelled through Model Selection.

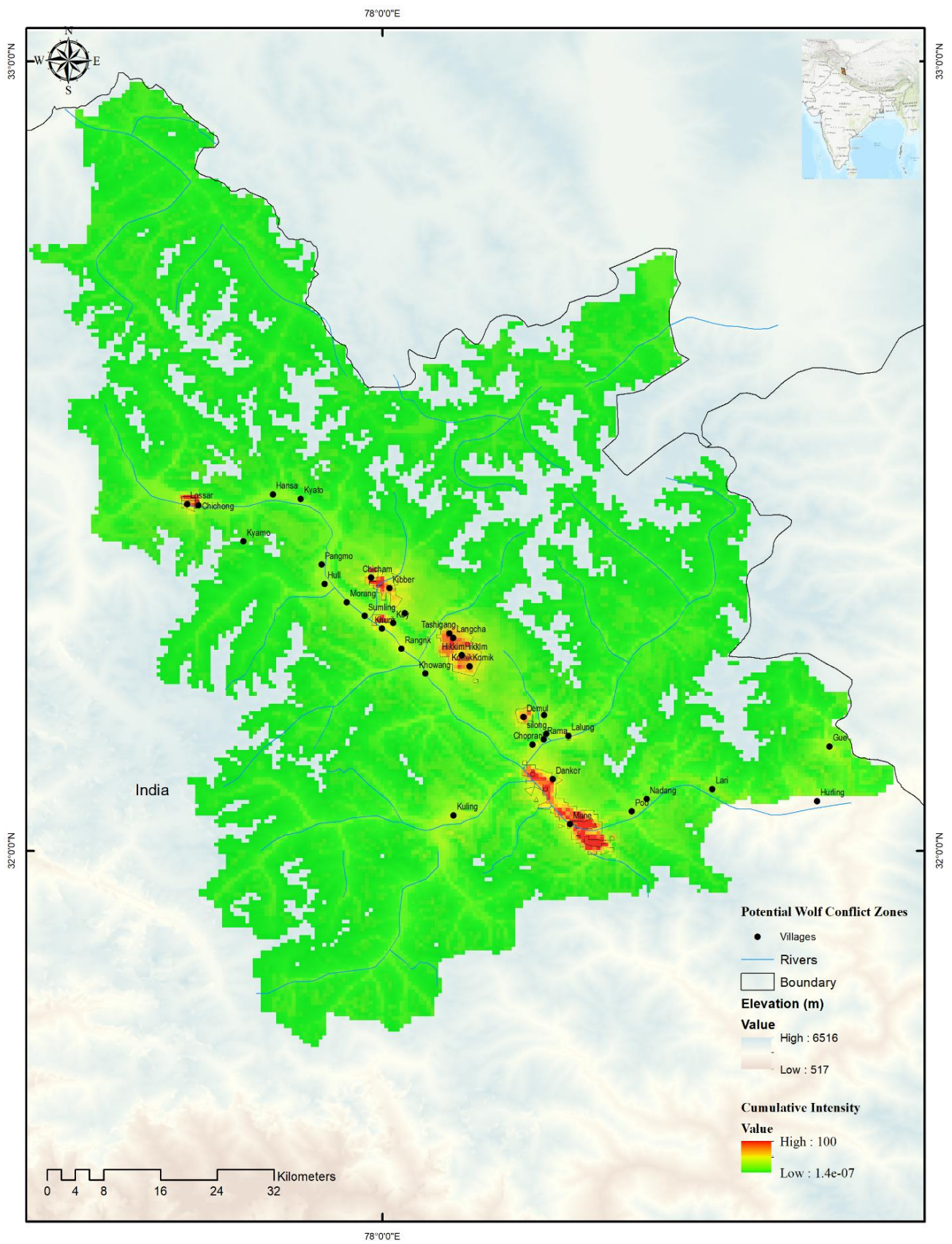


Fig. 4.6 Marginal response curves of variable layers used (n=13). Marginal response curves of LULC not shown as response was did not show any pattern.

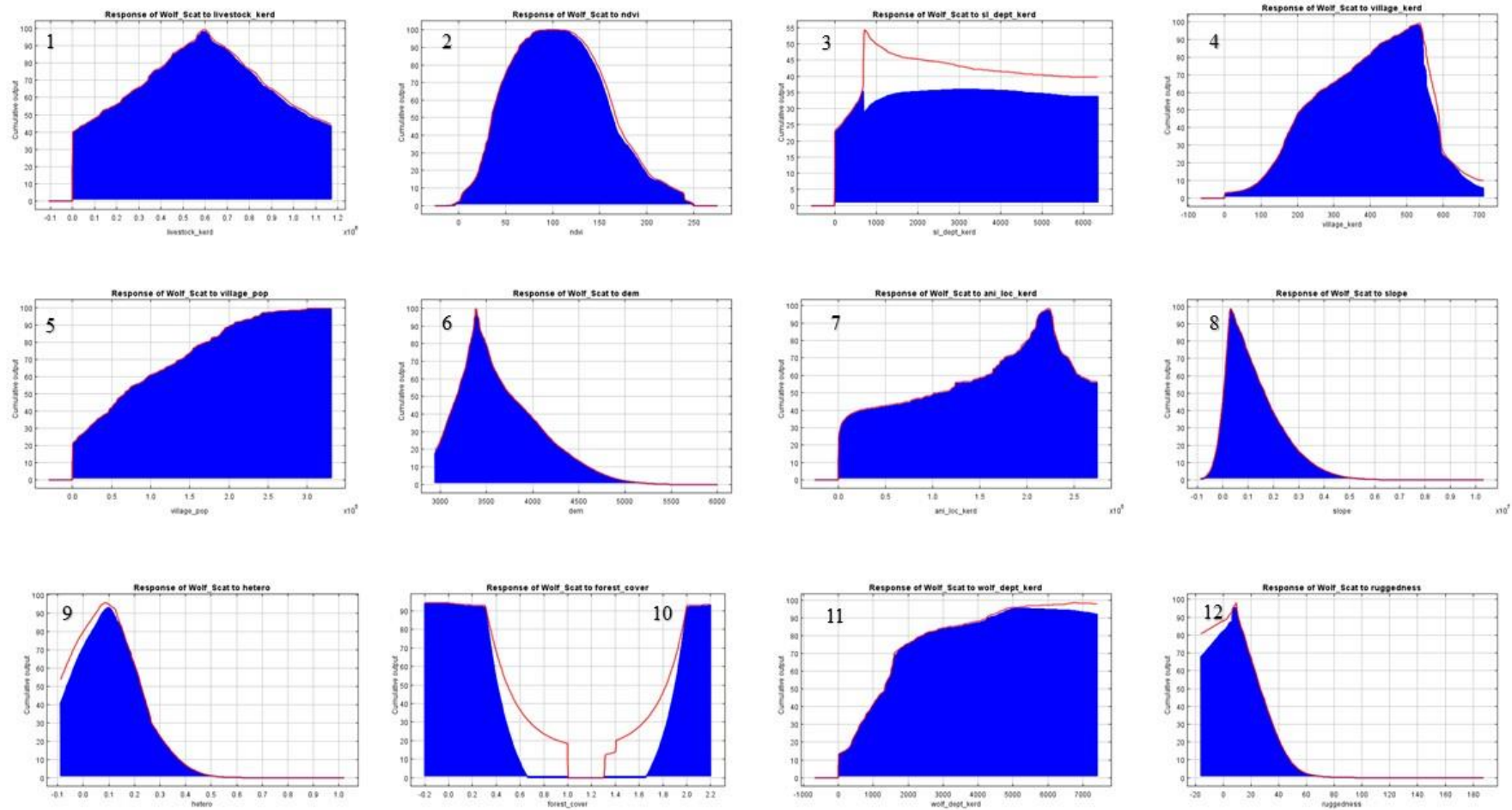
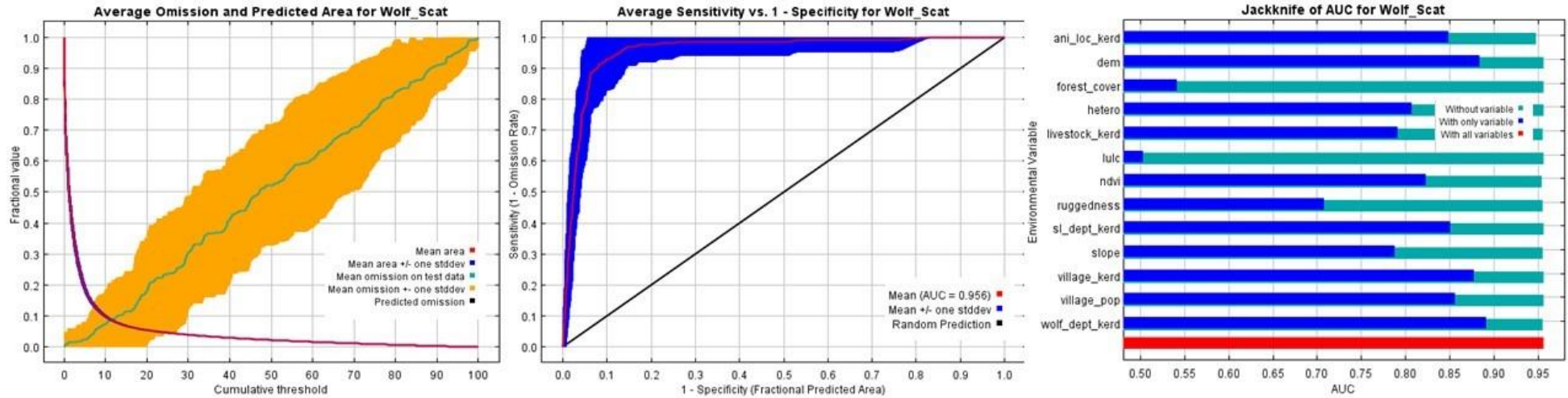


Fig. 4.7 a) Average omission and predicted are of wolf conflict. b) Sensitivity and specificity along with c) jackknife of AUC shown for each variable.



4.8 References

4.8 References

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5. Chapter 5

Movement, Ranging behavior and Habitat selection by individual wolves in the Spiti Landscape

5.1 Abstract

Wolves constitute an essential part of the mega-fauna in the Himalayan region as an umbrella species. The present chapter thus deals with the description of movement, home range, and the patterns of habitat selection in the context of Himalayan wolves, an apex predator in the Spiti region of the Cold Western desert of Himalaya. The study hypothesized that wolves' habitat selection would be strongly driven not only by the quantity of refuge (habitat type) available but also by its quality (intra habitat factors) and by the level of human activity in the surrounding areas.

To undertake the study, three individuals were GPS-tagged between 2015-2017. It was observed that the 50% MCP home ranges of wolves were $338.59 \pm 122.80 \text{ km}^2$. The 50 % Kernel Utilisation Distribution (KUD) Home Ranges was $86.38 \pm 81.50 \text{ km}^2$. The 95% of home ranges were $1044.26 \pm 56.27 \text{ km}^2$ and $449.53 \pm 407.99 \text{ km}^2$ for MCP and KUD, respectively. The 95 % Biased Random Bridge Utilisation (BRB), intensity, and recursion utilization distributions were computed for Leica as 433.9 km^2 , 765.5 km^2 , and 823.1 km^2 respectively. Similarly, for Kunzum is was calculated as 229.7 km^2 , 342.4 km^2 , and 353.8 km^2 . For Dhankar, it was computed as 180.4 km^2 , 358.2 km^2 , and 326.4 km^2 . The home ranges were also tabulated for 30 % and 50%, respectively, for all the individuals. The AKDE movement models generated a home range of Leica, Kunzum and Dhankar were 2938.14 km^2 , 3045.82 km^2 , and 978.34 km^2 , respectively. It was found that wolves used much of the landscape in juxtaposition with human dominance. BRB movement models depicted better utilization of space by wolves. The study shows that wolves avoided highly urbanized areas and were mostly in areas with lower road densities. The

movement trajectories of wolves showed by FPT analysis showed peaks and valleys of intensive space use as well as transience. The highlights of space use and choices made by individual wolves in the region are described in the study.

5.2 Keywords

MCP, Kernel, BRB, Autocorrelation, resource selection, Himalayan wolf

5.3 Introduction

Habitat preference was first described by Johnson (1980) as a component being chosen over others on equal availability. This definition has been challenged many times by several authors (Basille 2008). Habitat selection is a process that will govern individual fitness and differential habitat selection is a mechanism that allows species to co-exist (Rosenzweig 1981). The mechanism in which this process operates is often defined by optimal or intra-specific (Rosenzweig 1981, Morris 2003) causes while others have mentioned to be a function of density of resources (Lawlor and Smith 1976)). The nature of habitat selection is hierarchical, which means it will differ with respect to scale, and the limiting factors that operate the different scales are different. Strategies to cope with such limiting factors are first dealt with before proceeding to the next (Johnson 1980, Basille 2008). The difference between habitat and niche lies on the distributional and functionality aspects relating to environment in a landscape and community (Whittaker *et al.* 1973). With respect to wolves in general, studies have shown that they may survive in areas where human tolerance and adequate populations of prey may exist (Mladenoff *et al.* 1995, Wydeven *et al.* 2001, Mech and Boitani 2003, Llaneza *et al.* 2012). There also exist hierarchical nature of habitat selection in wolves thus underlining the importance of scale in habitat studies (McLoughlin *et al.* 2004).

In the North America wolves have been extensively tracked. In Northern Minnesota, 29 wolves were monitored and average home range of 230 km² was reported (Berg and Kuehn 1982).

Winter home range of a Pack in Mackenzie Lowlands of Wood Buffalo National Park was 1,280 Km² of which they extensively used 490 Km² (Oosenbrug and Carbyn 1982). In Superior National Forests, (Mech and Frenzel 1971), Peters and Mech (1975) observed wolves to have a home range between 125 – 310 km². In northern most latitudes above 75 degrees wolves were tracked with GPS collars and the largest home range reported was 6,640 km² during winter months of total darkness (Mech and Cluff 2011). In another study at the same area, five wolf packs were tracked, adult wolves had home ranges between 135 – 192 km² while yearlings ranged less than 100 km² (Ballenberghe *et al.* 1975).

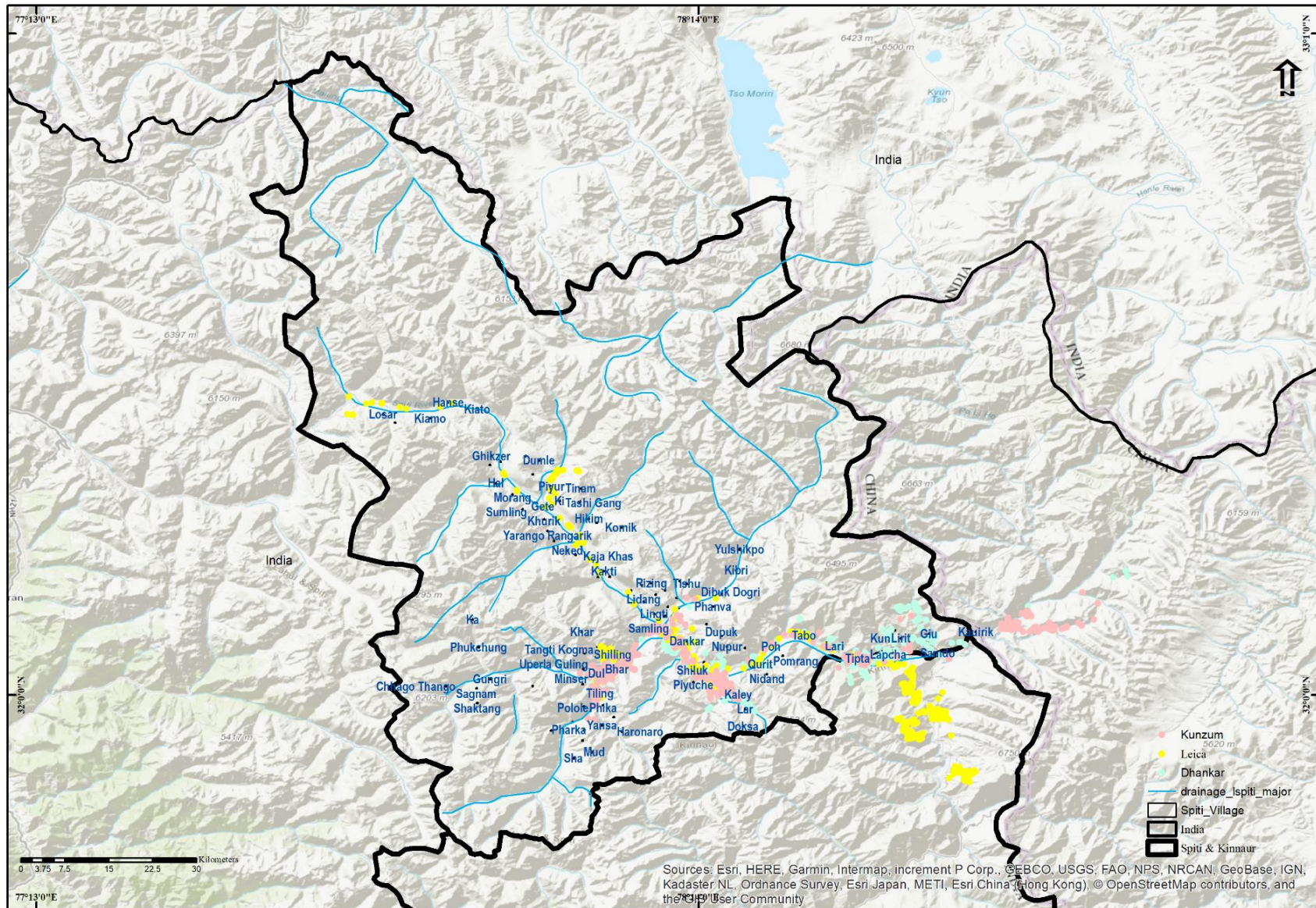
Wolves constitute a vital part of the mega-fauna in the Himalayan region as an umbrella species. The average home range reported so far for three packs of Indian wolf is 113.4 ± 24 km² (range=65.2-138.7) and 181 and 227.6 km² for lone male wolves (Jethva 2002). In another study in Maharashtra, India The average home range of the four packs was 183.58 ± 22.9 km². Individual home range of alpha males varied from 128 to 216 km² while alpha females ranged between 163 to 213 km² (Habib 2007). Mongolian wolves, which are the closest relative of the Himalayan/ Tibetan wolf were satellite-tracked by Kaczensky *et al.* (2008). A female wolf had a 20-month 'resident' period in which it lived in an area of 1,275 km² and a 9-month 'extension' period where it enlarged its range to 6,634 km². Similarly, another male from the same locality, had an 8-month 'resident' period during which it lived on an area of 8,959 km², followed by a 6-month 'roaming' period during which it covered 23,920 km², and followed by another 'resident' period during which it again returned and lived on an area of 3,558 km². To date that there is no concrete information on the ranging pattern or territoriality of the Himalayan wolf in the Indian Trans - Himalayas.

Conserving large carnivores in multiple use landscape and human-dominated landscapes is becoming a challenge in the present century (Chapron *et al.*, 2014). Human-dominated landscapes, are continually being secluded amongst a mosaic varied human land uses. More

often such areas are visibly limited in size so as to sustain a demographically or functionally a viable population of large carnivores (Wikramanayake *et al.*, 1998; Santini *et al.*, 2014). However, large carnivores have been known to be resilient and the consequences of this persistence have also been of much interest amongst various researchers and managers alike. It is well known that the behavior of large carnivores in landscapes with predominant human influence can be significantly co-adapted to the legacy of human persecution of such species. Such is the case with wolves (*Canis lupus*) that have persisted in these systems of scarcity. Wolves may have as a consequence of a prolonged association with persecution adopted cautious behavioral traits to reduce mortality and increase foraging efficiency in the presence of humans. These manifestations may be in the selection of breeding sites (homesites) in areas that minimize pack members' risk of mortality or to foraging in vulnerable prey through optimal strategies. Similarly, these factors will be driven by habitat characteristics that may shape the usage of space and determine the movement ecology of these wolves in the Spiti landscape of Himachal Pradesh. In this chapter, the study hypothesized that wolves habitat selection would be strongly driven not only by the quantity of refuge (habitat type) available but also by its quality (intra habitat factors) and by the level of human activity in the surrounding areas. The present chapter thus deals with the description of movement, home range, and the patterns of habitat selection in the context of Himalayan wolves in the Spiti region of the Cold Western desert of Himalaya. The current chapter will examine the following questions

- i) What is the ranging pattern or movement of Himalayan Wolves?
- ii) What is the Home Range of wolves?
- iii) What factors determine habitat use and selection by Himalayan wolves
- iv) How do the diet, predation, and habitat use converge in explaining the ecology of Himalayan wolves?

Fig. 5.1 Study Area with wolf location and Villages in the Spiti Landscape



5.4 Study Area

The Spiti catchment area (Fig. 1) which is divided by the Spiti River is a cold semi-arid region of the state of Himachal Pradesh. The greater Himalayas are to the south east of the valley while on the north of it lays Ladakh and east lays Tibet. The study area comprises two protected areas of Kibber Wildlife Sanctuary (WLS) (32°5 to 32°30 N and 78°1 to 78°32E) and Pin Valley National Park (NP) in the south west corner of the Spiti Catchment area. Kibber WLS was established in the Spiti Region (Lahaul and Spiti District) of the Indian state of in 1992 for conservation of trans-Himalayan wildlife. It is a mountainous cold desert, where altitudes range between 3600 m and 6700 m above mean sea level. Temperatures range between 23°C and 3°C in winter and between 1°C and 28°C in summer. The vegetation of this area has been broadly classified as dry alpine steppe (Champion & Seth, 1968).

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

The local agro-pastoral community, largely Buddhist, are concentrated in village clusters largely along the main Spiti River. There are approximately 60 villages through the length and breadth of the valley. Most agriculture- related activities are restricted to the short growing season (from May to September). The main crops cultivated are barley (*Hordeum vulgare*) and green peas (*Pisum sativum*). Livestock includes goats and sheep, cattle, 'dzomo' (a female hybrid of cattle and yak), and yaks. Donkeys are the beasts of burden, while horses, apart from being used for religious ceremonies, are mainly raised for trade. The region has traditionally practiced systems of grazing whereby nomadic as well as resident herders frequent this landscape. In this vast

landscape (~ 4000, (Sharma *et al.*, 2015) the study was concentrated much towards higher elevation regions of the area (> 3000 m) from villages surrounding Pin valley NP and Kibber WLS.

5.5 Methods

In order to determine livestock depredation and large carnivore presence I sampled the landscape by conducting questionnaire surveys (Fig.5.1) using a semi structured questionnaire (Lyngdoh *et al.*, 2014) among the locals across 35 villages. The surveys were distributed systematically to represent most of the landscape. A sighting of wolf was confirmed by showing them photographs of different canids and asking details of the sighting incident and place. Any ambiguity in the confirmation was not recorded. In total 200 households were surveyed with questions mainly focussed on household characteristics such as demography, income, grazing distance, livestock holding, depredation and carnivore presence.

5.5.1 GPS telemetry and data preparation

Wolf relocations records were obtained from data of three individuals that were GPS collared from a period of 2015-2017. Regular fixes were obtained and presence points were thus used from 2,602 locational fixes that were recorded. A total of 9 environmental layers were used to model wolf habitat use. I generated layers from Digital Elevation Model (30 m), aspect, slope. Livestock animal kernel density map were derived from village surveys and animal census data for Large, medium and small livestock. Following layers were then used to create various species distribution models (Fig. 5.1)

- 1) DEM (30 m) from SRTM data
- 2) Aspect layer
- 3) Slope
- 4) Cattle population layer

- 5) Ungulate density layer – generated from Suryawanshi *et al* 2017
- 6) Sheep and Goat population
- 7) Equid Population Layer
- 8) Drainage – generated from kernel density
- 9) Road – generated through kernel density

5.5.2 *Home range estimation and movement*

The area was extensively searched for wolf dens, signs and scat to determine probable areas of wolf activity. Before initiating the trapping procedures, the entire area was pre-monitored for presence of wolves. On confirmation, camera traps were laid in the area to ascertain possible movement pattern and probable movement path. Based on results, 15 to 20 padded leg-hold traps (Duke 3 coil spring rubber jaw trap, 3OS – RJ, Duke Company, West Point, MS 39773, USA) were set concealed in a circular manner along the sites the wolves frequent; around a live bait or partially consumed kill (whenever available). The trap sites were also laced with coyote & wolf gland lure and food lure (Hawbaker & Sons coyote & wolf gland lure 100 and Hawbaker & Sons, coyote food lure no. 10 Stanley Hawbaker and Sons, Fort Loudon, Pennsylvania, USA), in order to increase the possibility of wolf encountering the trap. Once set, traps were kept undisturbed and were manually checked at every 1 hr interval from a distance of 500 m with help of a binocular. The core capture team, which included an experienced biologist, a wildlife health professional and two assistants camped at a distance of 1 to 1.5 km from the trap site, so as to minimize the response time, thereby minimizing the possibility of trap-related injuries. Wolves will be trapped using soft padded leg hold- Minnesota Double coiled traps (Nellis 1968, Boitani and Powell 2012). Traps were concealed and lured using a wolf gland lure (Stanley Hawbaker and Sons, Fort London, Pennsylvania) and live baits. Animals captured were held by a snare pole and a nylon net. Animals were sedated in the hind quarters using cyclohexane (Ketamine) and a tranquilizer (Xylazine) by injection (Kreeger *et al.* 1988, Mech

and Boitani 2003, Boitani and Powell 2012). Animals were fastened with GPS collars (Globalstar Satellite System/Iridium) once trapped, principally to locate their movements. Regular fixes at 5 hour intervals were made to provide information on a cyclic basis. The wolves once captured before collaring were sexed, weighed, aged based on tooth wear (Gipson *et al.* 2000). In order to understand movement and related parameters of individual wolves, various trajectory analysis were performed (table. 5.1). Average movement distance with seasons, angular autocorrelation, minimum number of segments were also determined to understand any patterns in the movement of wolves. Package ‘Adehabitat LT’ was used for all trajectory analysis. The First Passage Time (FPT) was used as a measure of the time for an individual to enter and leave a circle of fixed radius r drawn around each location in quantifying intensity of space use (Pinaud, 2008; Gurarie *et al.*, 2016). The FPT is much higher within the restricted area and low when the animal is moving. In more advanced applications, the FPT is used to quantify characteristic spatial scales of area restricted behaviour by computing the radius at which the variance of the FPT is maximized (Fauchald & Tveraa, 2003). Package ‘Adehabitat LT’ was used for all trajectory analysis (Calenge, 2006, 2011; Basille *et al.*, 2008)

Home range was calculated using various methods and seasons for comparative purposes. I also used the behavioural change process analysis (BCPA) to investigate states of behaviour in the wolf movement through package ‘*bcpa*’ (Gurarie *et al.*, 2016). The minimum convex polygon method (MCP) calculation of the smallest convex polygon enclosing all the relocations of the animal was generated firstly. This polygon is considered to be the home range of the animal. Because the home range has been defined as the area traversed by the animal during its normal activities of foraging, mating and caring for young (Burt, 1943), a common operation consists to first remove a small percentage of the relocations farthest from the centroid of the cloud of relocations before the estimation.

The utilization distribution (UD, van Winkle, 1975) considers that the animals use of space can be described by a bivariate probability density function, the UD, which gives the probability density to relocate the animal at any place according to the coordinates (x, y) of this place. The study of the space use by an animal could consist in the study of the properties of the utilization distribution. The basic principle of the method is the following: a bivariate kernel function is placed over each relocation, and the values of these functions are averaged together. According to Benhamou and Riote-Lambert (2012), the time spent at a given location by the animal can be seen as the product between the mean residence time per visit times the number of visits of the location. To make biologically relevant distinctions between such components the estimation of an intensity distribution (ID) reflecting this average residence time and of a recursion distribution (RD) reflecting the number of visits were made using the movement generated by a biased random walk given the start and end relocation called a biased random bridge (BRB). All calculations were carried in R using Adehabitat package (Calenge *et al* 2011). Continuous-time stochastic process models, which overcome many of the limitations suffered by their discrete-time counterparts, provide a robust foundation for the future of movement ecology. Conventional home range estimation methods systematically, and sometimes grossly, underestimate home range areas for auto correlated relocation data. The data was analysed in ‘ctmm’ 0.3.0 package (Calabrese, Fleming & Gurarie, 2016) in R. ‘ctmm’ supports auto correlated kernel density estimation (AKDE) of home ranges as well as estimation of occurrence distributions and trajectories via time-series kriging. The AKDE predicts substantial additional space use relative to the conventional KDE.

5.5.3 *Habitat use and selection*

Habitat use was analyzed using ‘Adehabitat HS’ package (Calenge, 2007) which provides classes and methods for dealing with habitat selection analysis in R. Habitat corresponds to the resources and conditions present in an area that produce occupancy – including survival and

reproduction – by a given organism (Hall *et al.*, 1997). To understand habitat use I examined the distribution of the environmental variables on the area, as well as the distribution of the animals. Thomas & Taylor, 2006 distinguished three types of design used in the study of habitat selection. Design I studies can be used when animals are known but individuals are unidentified. These are examined at the scale of the population. Design II studies are adopted when animals are identified. In the current study animals were monitored using a GPS enabled collar. However, I measured availability at the scale of the population. We performed design II analysis to correspond to studies for which animals are identified (e.g. using radio-tracking) and habitat use is measured for each one, but availability is considered to be the same for all animals of the population. Lastly, in Design III approach, identified animals were measured for their habitat use as per their individual availabilities of Resource Units (RUs).

For Design II, an Outlying Mean Index (OMI) analysis was used to identify the directions in the ecological space on which the niches are the most different from the distribution of available points, also these differences between which the distribution of available points and the niches are the most similar. First the table X is centered for the availability weights, so that the origin of the space corresponds to what is available in average to the animals. Then, one performs a non-centered principal component analysis of the coordinates of the marginality vectors in this space. This allows to find the directions where the marginality is in average the largest. More formally, this analysis finds the vector $\mathbf{b} = (b_1, b_2, \dots, b_p)$ such that:

$$y = b_1x_1 + \dots + b_px_p$$

$P\sum_{i=1}^K \bar{y}_{ui}^2 = \sum_{i=1}^K (\bar{y}_{ui} - \bar{y}_{ai})^2$ is maximum on the first axis (where \bar{y}_{ui} is the mean of the utilization distribution of the i^{th} animal and \bar{y}_{ai} is the mean of the availability distribution for this animal).

The eigenvalues show the amount of marginality accounted for by each axis.

A canonical OMI analysis was also use to determine habitat selection. This analysis first distorts the ecological space so that the distribution of availability weights takes a standard spherical

shape. The direction where the marginality is the largest in this distorted space is the direction where habitat selection will be the clearest. However, there is a counterpart: the canonical OMI analysis places mathematical constraint on (i) the number of RUs (it should be larger than the number of environmental variables to allow the matrix inversion required by the analysis) and (ii) the environmental variables should be linearly independent (also to allow this inversion). For design III approach understanding habitat use by individual animals assuming availability will vary for each individual. Each animal is characterized by a niche defined in an “available space” particular to it. Marginality vectors that relate to what is available to the animal in average to what has been used in average by the animal. K-select analysis was used for this kind of approach (Calenge, 2007). In K select analysis marginality vectors are re-centered for a common origin. A non-centered principal analysis is performed on the table containing the co-ordinates of these re-cent red marginality vectors. Similar to the OMI analysis, the direction in ecological space where marginality is strongest is determined.

5.6 Results

Three individuals were GPS-tagged between 2015-2017. The details of the individuals are given below. It was observed that the 50% MCP home ranges of wolves were $338.59 \pm 122.80 \text{ km}^2$. The 50 % Kernel Utilisation Distribution (KUD) Home Ranges were $86.38 \pm 81.50 \text{ km}^2$. The 95% home ranges were $1044.26 \pm 56.27 \text{ km}^2$ and $449.53 \pm 407.99 \text{ km}^2$ for MCP and KUD respectively (Table 5.2).

The 95 % Biased Random Bridge Utilisation (BRB), intensity and recursion utilization distributions were computed for Leica as 433.9 km^2 , 765.5 km^2 and 823.1 km^2 respectively. Similarly, for Kunzum is was computed as 229.7 km^2 , 342.4 km^2 and 353.8 km^2 . For Dhankar it was computed as 180.4 km^2 , 358.2 km^2 and 326.4 km^2 . The home ranges were also tabulated for 30 % and 50% respectively for all the individuals. The AKDE movement models generated a

home range of Leica, Kunzum and Dhankar were 2938.14 km², 3045.82 km² and 978.34 km² respectively (Fig. 5.6-5.8).

A total of 760, 471 and 519 fixes were used for wolves, Dhankar, Kunzum and Leica in winter. While, 145, 271 and 436 fixes were used during the summer period respectively. The home ranges were calculated as MCP and Biased random bridge movement model kernels (Table 5.4). The estimated home ranges were determined at 95% and 50% respectively. Winter home ranges (MCP 95%) were 582.74 km², 767.81 km² and 914.63 km² for respectively. Summer home ranges were 4.82 km², 191.95 km² and 2078.15 km² respectively. Similarly, the BRB UD_s for three wolves in winter were 357.79 km², 618.65 km² and 150.63 km² respectively. Similarly, the BRB UD_s for the summer were estimated as 5.36 km², 359.30 km² and 759.15 km² respectively. There was no significant variation in home ranges of wolves between summer and winter between all the three wolves. (p value > 0.4 – 1, Mann-Whitney U test, MCP 50 & 95, BRB 50 UD, ID and RD)

Angular and auto correlation was found to be highly correlated in the x axis for all the three individuals (p < 0.01). Traversed paths were also correlated with respect to distance (p < 0.01). Wolf paths were auto correlated upto lag 4, however declined after subsequent relocations for all individuals. Similarly, angular movements showed high auto correlation with lag 2. The beginning of the trajectory is characterized by mean cosine close to 0.5 (tortuous trajectory) and cyclic patterns are observable in the angular shifts due to incremental steps taken (Fig 5.3 – 5.4). FPT analysis show wolf movements were highly restricted in the colder months i.e. Jan to March. High FPT values indicate intensive use of space and restricted used while lower values show transient movement. In the case of Dhankar, the individual showed more restricted movements in the early phase of autumn and later was mostly transient (Fig.5.5).

Outlying Mean Index (OMI, Fig. 5.10) analysis showed that axis 1 explained >90% (90.6%) of the marginality, while axis 2 explained 8.6 % of the marginality. The first two axes were

successful in explaining 99.2 % of the marginality. The species and samples plot showed wolves utilized resources positively on the first axis and negatively on the second axis. All three wolves selected movement on the first axis corresponding to the cattle, sheep, goat and equid prey base. While in terms of the physical nature of the habitat the axis showed negative relations towards slope and elevation.

The Canonical Outlying Mean Index also showed similar results in terms of the first two axis (80.91% and 17.30 %) explaining 97.2% of the marginality (Fig. 5.11). Axis 1 was strongly correlated with the availability of livestock in terms of small, medium and large livestock i.e. sheep, goat, equid and cattle. While axis 2 was strongly correlated with elevation and slope. The Resource Utilization and animals plot showed the Leica and Kunzum selected strongly for positive values of the first and second axis. While Dhankar selected strongly for negative values of the first and positive for the second axis respectively.

The K-select analysis (Fig.5.12) suggests the available resource units in terms of the distribution of the available RUs on the first two axes. Both the axes showed positive correlation to slope, ungulate, elevation, road and drainage. Axis 1 explained 89.35 % of the marginality while axis 2 explained 7.2% of the marginality. However, both axes were negatively correlated with livestock. The individual wolves showed preference towards resource units that were available with livestock. Leica and Kunzum showed affinities towards the selection of large domestic prey rich areas along with areas having equid availability while Dhankar selected areas that had more availability of medium sizes domestic ungulates such as sheep and goat.

5.7 Discussion

Ecology is fundamentally spatial, with ecological processes occurring on heterogeneous landscapes (Cagnacci *et al.* 2010, Morales *et al.* 2010). In the context of an animal's use of space, knowledge of such nature provide a 'live' point of contact between ecology and evolution

(Cagnacci *et al.* 2010). Thus, to begin to understand why animals move in space is to be able to answer as to why animals use a resource at a given time and scale. Unraveling such complex questions can lead us to answers on animal behavior and fitness (Urbano *et al.* 2010). Home range, movement, predation patterns and habitat selection are such key factors that are needed to understand the ecology of animals. In this study, I have described the home range, movement and habitat of individual wolves in the context of the landscape. I found that home ranges were different in terms of how they were calculated but core areas remain in valleys well in human-dominated spaces. Also, wolves preferred to utilize habitats with livestock presence, gentle slopes, and linear features such as roads or river valleys were utilized. In terms of elevation, Himalayan wolves preferred lower to mid-range elevations with respect to the landscape. Based on telemetry studies, the home ranges of gray wolves reported in Italy by Boitani (1982) and Ciucci *et al.* (1997) were between 100 - 200 km². Similar home ranges have been reported from other parts of Europe i.e. 173-294 km² (Okarma *et al.* 1998) in Poland, Finiio and Chovancová (2004) reported home ranges of 146 km² and 197 km² for male and female wolf respectively in Slovak. In Croatia, two packs recorded home ranges (MCP), 151 km², 92 km², 160 km² and 141 km² (Kusak and Huber 2000, Kusak *et al.* 2005). Home ranges on the closest conspecific i.e. Mongolian wolves which are the closest relative of the Himalayan/ Tibetan wolf were satellite-tracked by Kaczensky *et al.* (2008). A female wolf had a 20-month 'resident' period in which it lived in an area of 1,275 km² and a 9-month 'extension' period where it enlarged its range to 6,634 km². Similarly, another male from the same locality had an 8-month 'resident' period during which it lived on an area of 8,959 km², followed by a 6-month 'roaming' period during which it covered 23,920 km², and followed by another 'resident' period during which it again returned and lived on an area of 3,558 km². The home ranges of wolves in the current study showed wolves ranges were greater than most wolf home ranges and may be comparable to their Tibetan or Mongolian conspecifics. In terms of the most suitable home range

estimator, the study found that MCP provided comparable information in relation to the home range estimates with other studies. However, BRB estimates offer a more realistic approach in terms of space use and depict the model movement more closely to help identify wolf intensity, recursion and, utilization. The latest estimates by the AKDE estimators show home ranges which probably are encountered due to a two-dimension approach and lack of a proper barrier effect to be built in (Stark *et al.*, 2017; Péron, 2019) .

Wolves are reclusive creatures and tend to stay away from high concentrations of human population. Studies have shown that wolf occurrence depends mostly on human pressure, followed by prey availability, and lastly, landscape integrity (Fuller and Keith 1980, Fuller 1989, Mladenoff *et al.* 1995, Mladenoff *et al.* 2009, Llana *et al.* 2012). The current study also found that wolves used much of the landscape in juxtaposition with human dominance. Threshold limits are difficult to determine, however the study shows that wolves avoided highly urbanized areas and were mostly in areas with lower road densities. Land cover in the form of contiguous forest and prey density as well as low road density influence wolf Habitat suitability (Belongie 2008). Himalayan wolves selected very similar features in the use of habitat to Eurasian wolves. Wolves tend to avoid high density roads, steep slopes as in studies by Kunkel *et al.* (2004). Similarly, Whittington *et al.* (2005) found that wolves selected low elevations, flatter slopes, and southwest aspects probably due to low snow depth and prey availability. Similarly, wolves chose linear features as easy travel routes opportunistically which is demonstrated by a largely linear home range and travel paths.

The movement trajectories of wolves showed by FPT analysis showed peaks and valleys of intensive space use as well as transience. The wolves were more intensively using space toward the colder months. Larger FPTs are associated with slower and more sinuous movements, reflective of rest and foraging behaviors, while moderate and small FPTs likely reflect movements between patches and movements to escape predators. Studies have found moose

moved faster when traversing areas with higher predicted likelihoods of wolf resource use, and during times of day when wolves were more active (Ditmer *et al.*, 2018). Similar peaks and valleys were evident in the angular movements of the wolves. A similar peak and valley oscillation was consistent in the BCPA analysis (Fig. 5.9). Wolves seem to have small bursts of intensive and transient use in the landscape (Gurarie *et al.*, 2016).

The Himalayan wolf is a long ranging species. Its home ranges were measured for the first time using GPS telemetry. The use of such technology enabled tracking such species in harsh terrain such as that of the high range Himalaya. The key factors that contribute to the home range of these wolves are terrain features, prey availability and seasonality. Conservation of such species therefore will require vast landscape with optimal prey are needed to sustain good populations.

Table 5.1. Details of individuals collared and fixes used

Name and Collar ID	Age class	Actual weight	Ketamine	Xylazine	Induction Time	Down Time	Recovery Time	Sex	Fixes
Kunzum	Adult	32 Kg	4.9 mg/kg	0.9 mg/kg	14 min	37 min	6 min	Female	742
Leica	Adult	35 kg	5.1 mg/kg	0.5 mg/kg	15 min	30 min	4 min	Male	956
Dhankar	Adult	33 kg	-	-	-	-	-	Female	904

Table 5.2. The Minimum convex polygon and Kernel density estimates of home range

Home Range	Leica (km ²)	Kunzum (km ²)	Dhankar (km ²)
MCP (100%)	2773.44	970.10	936.39
MCP (95%)	1689.06	827.27	616.45
MCP (50%)	476.87	296.66	242.24

KUD (100%)	256.29	186.65	952.78
KUD (95%)	250.43	179.32	918.85
KUD (50%)	39.80	38.85	180.49
AKDE (95%)	2938.14	3045.8	678.63
AKDE (50%)	651.64	812.14	238.484

Table 5.3. Biased Random Bridge (BRB) Movement Kernel Density estimates with Intensity, Recursion and Utilization distribution of wolf individuals

S.No	Leica (km ²)		Dhankar (km ²)		Kunzum (km ²)		BBM
	50 %	30 %	50 %	30 %	50 %	30 %	
1	50 %	30 %	50 %	30 %	50 %	30 %	Kernel
2	103.53	33.53	67.17	21.02	55.80	17.54	Intensity
3	156.46	55.86	44.70	12.99	52.33	17.95	Recursion
4	30.17	6.54	14.84	3.50	55.82	5.28	Utilization

Table 5.4. Seasonal BRB home ranges of individual wolves

S.No	Home Range (km ²)	Dhankar	Kunzum	Leica	Dhankar	Kunzum	Leica
		Summer			Winter		
1	MCP 95%	4.82	191.95	2078.15	582.74	767.81	914.63
2	MCP 50%	1.07	21.64	466.05	290.23	557.94	255.84
3	BRB UD 95%	5.36	359.30	759.15	357.79	618.65	150.63
4	BRB ID 95 %	6.53	478.66	952.29	542.09	755.76	320.92
5	BRB RD 95 %	6.16	466.79	1165.06	511.90	701.58	384.38

6	BRB UD 50 %	1.10	46.08	84.14	49.01	84.76	8.36
7	BRB ID 50 %	1.88	87.48	135.67	116.13	154.00	39.35
8	BRB RD 50 %	1.75	79.12	244.02	96.28	143.64	78.58

Fig. 5.2a Environmental layers used

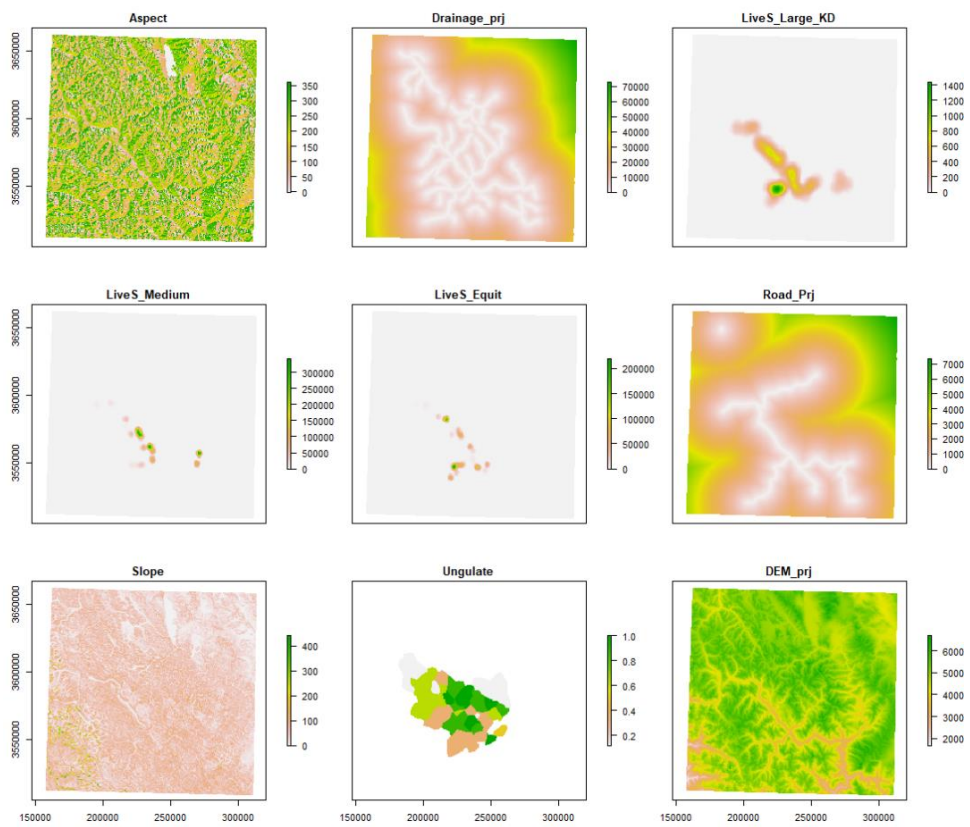


Fig.5.2b Histogram of layer versus wolf re-location

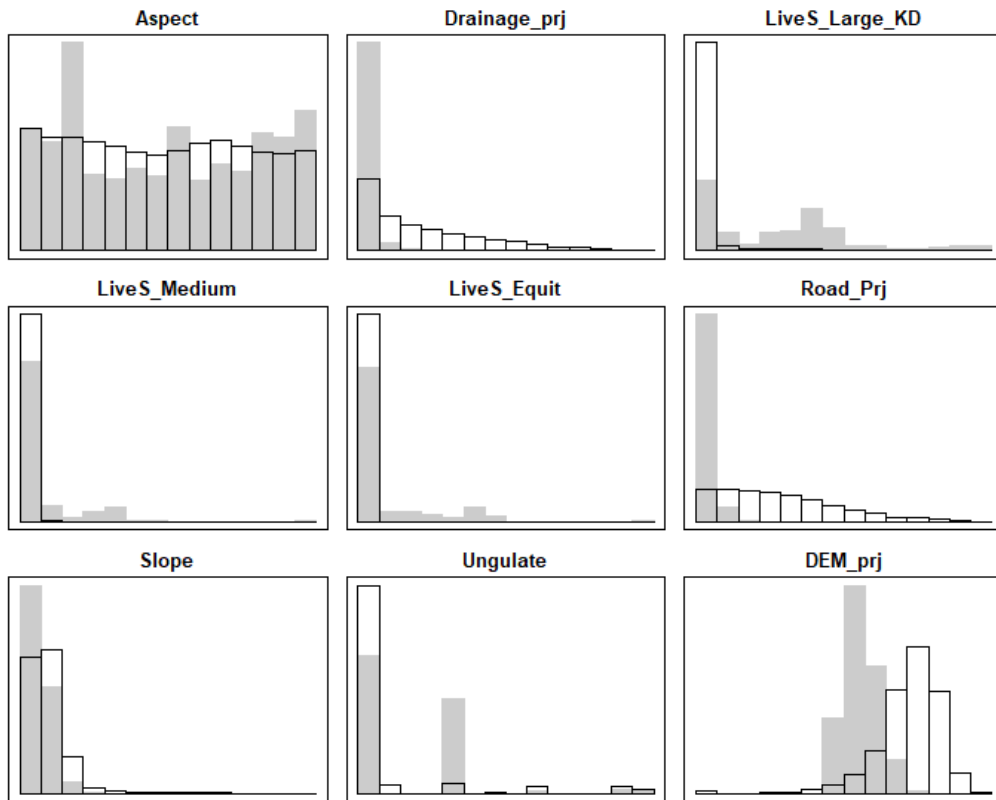


Fig 5.3. Angular auto-correlation of wolf trajectory for non-discretized data

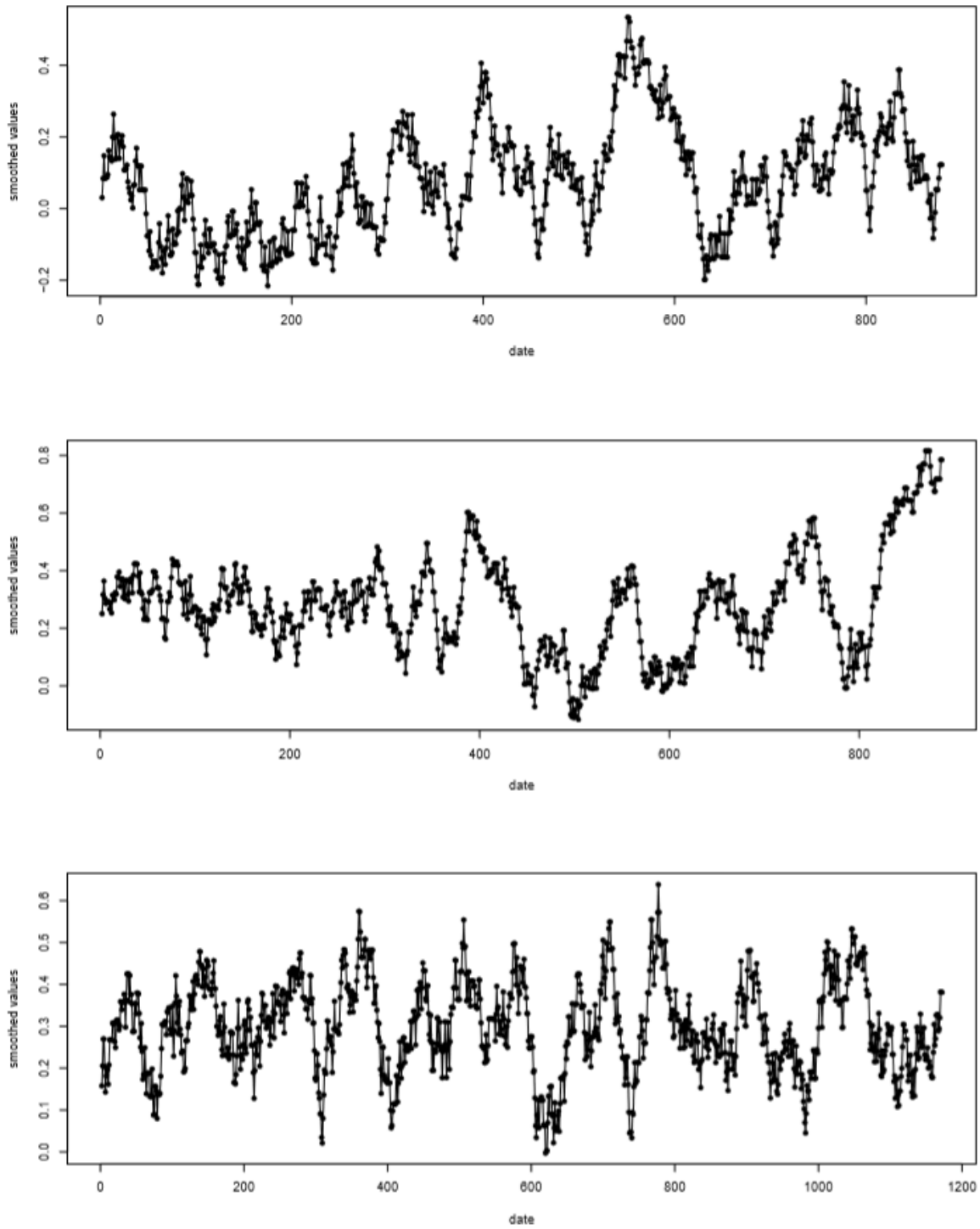


Fig 5.4 Distance traversed by collared wolves. Graphs show valleys and peaks in terms of wolf movements.

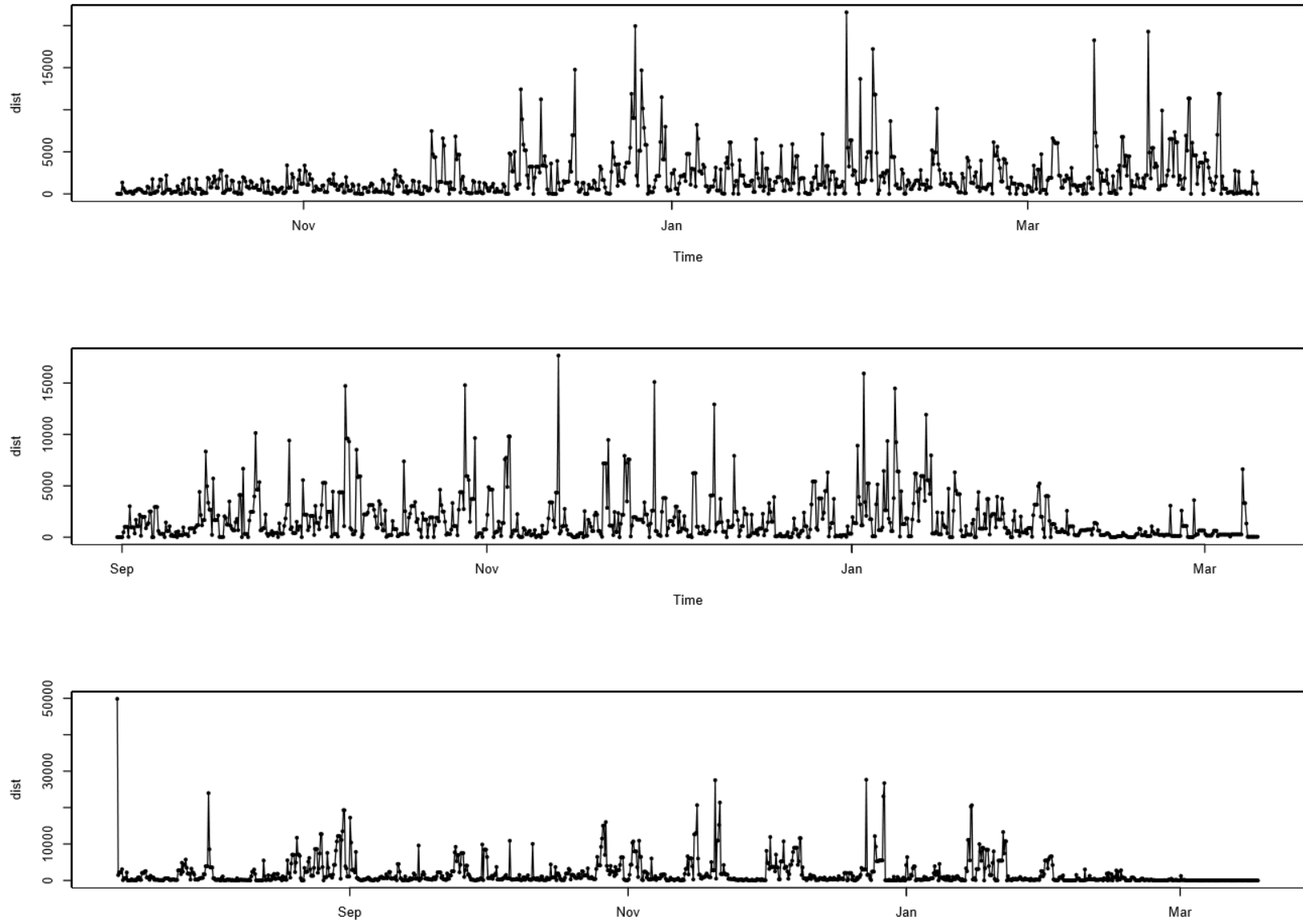


Fig. 5.5. FPT of individual wolves. Graph depicts intensity and tortuosity of movement within 10 km radius. Higher bars intensity.

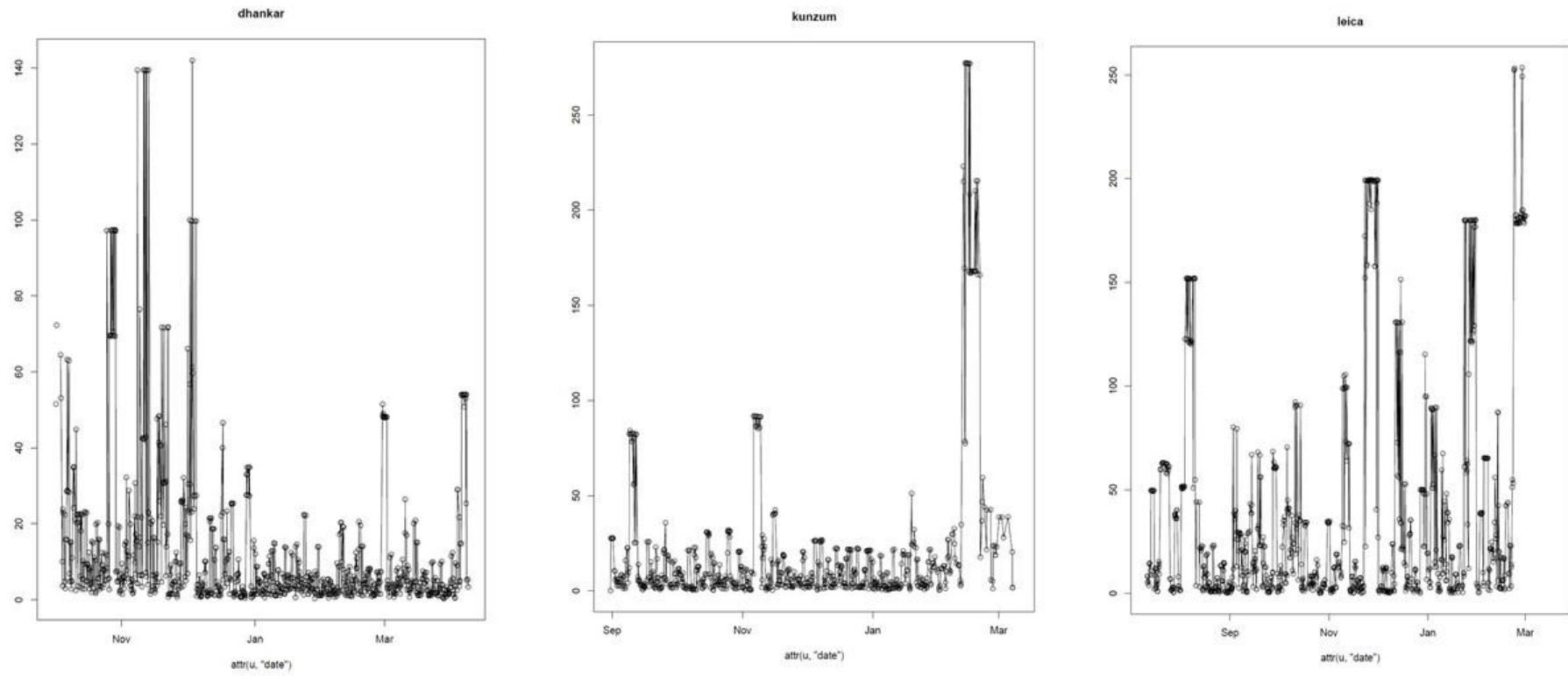


Fig.5.6. MCP bootstraps of individual wolves i.e Dhankar, Kunzum and Leica

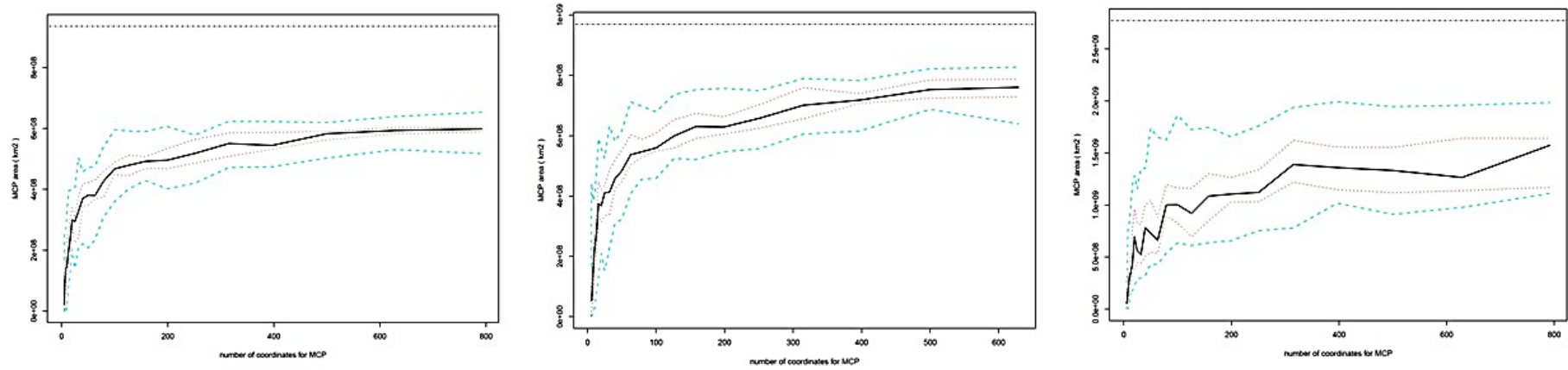


Fig 5.7. Kernel Home Range of Individual

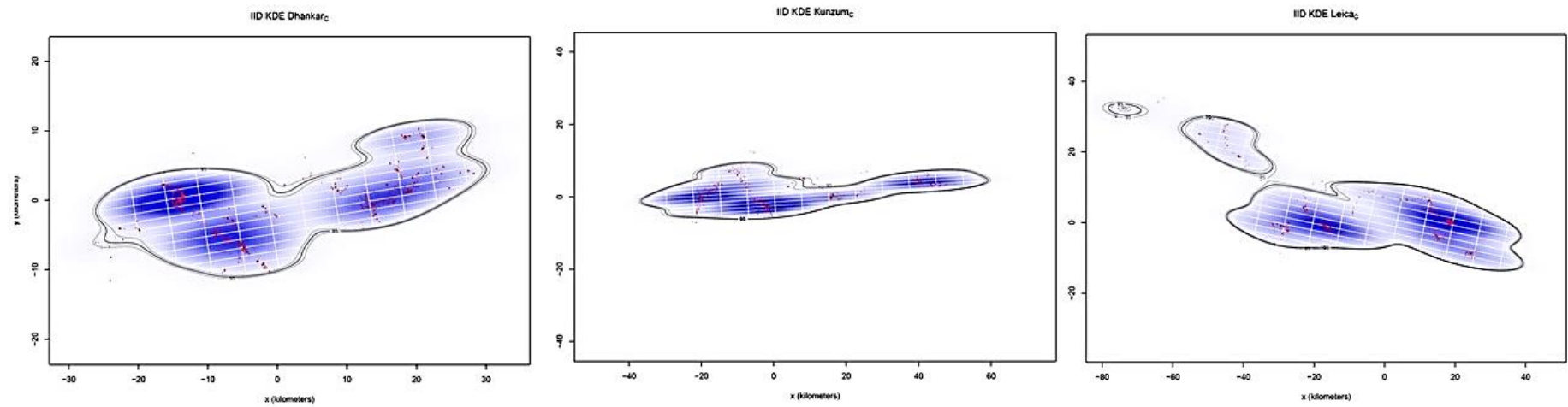


Fig.5.8. UD, RD and ID of three individual wolves

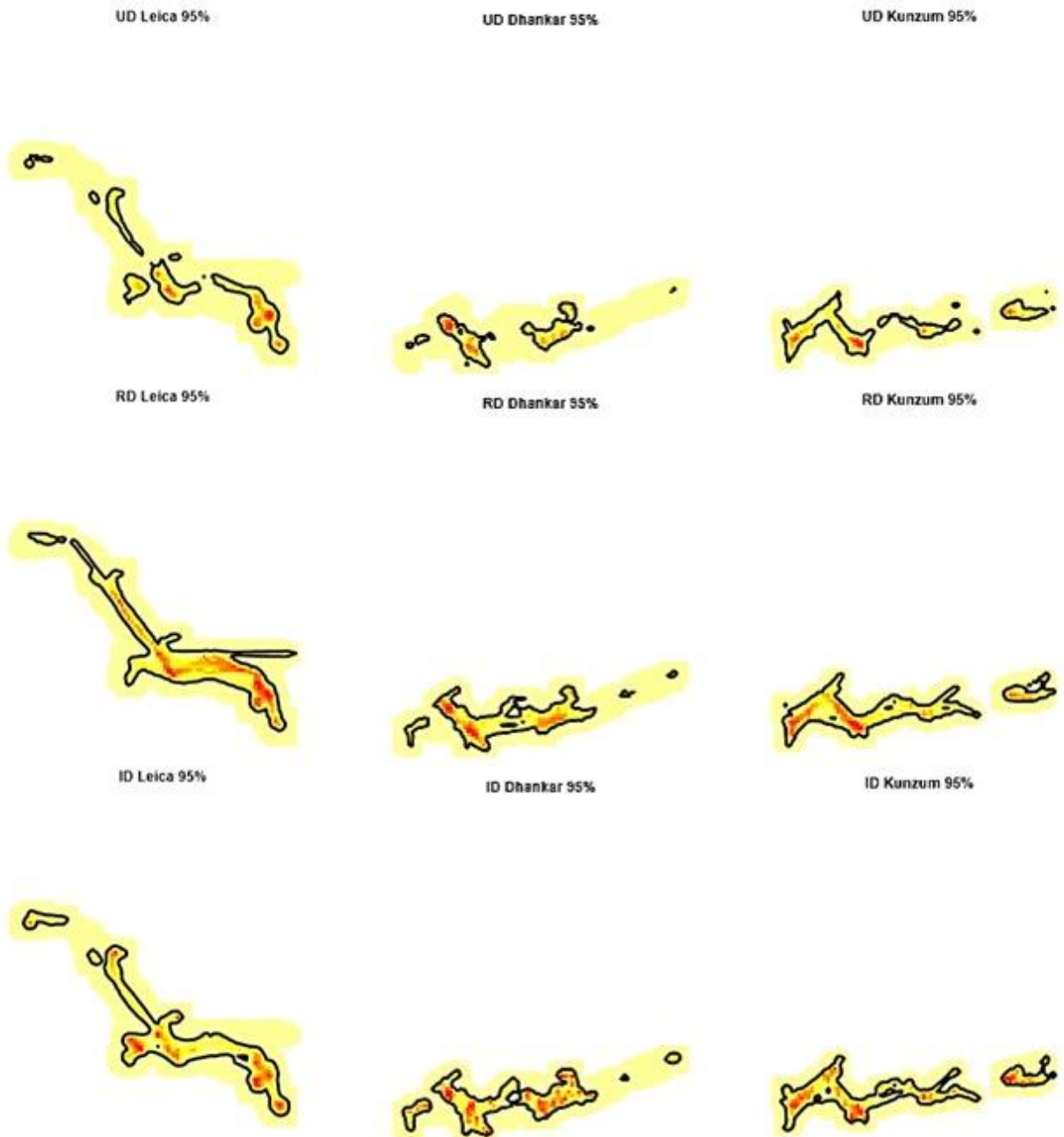


Fig 5.8a Comparative 50 % UD of wolves in the study area

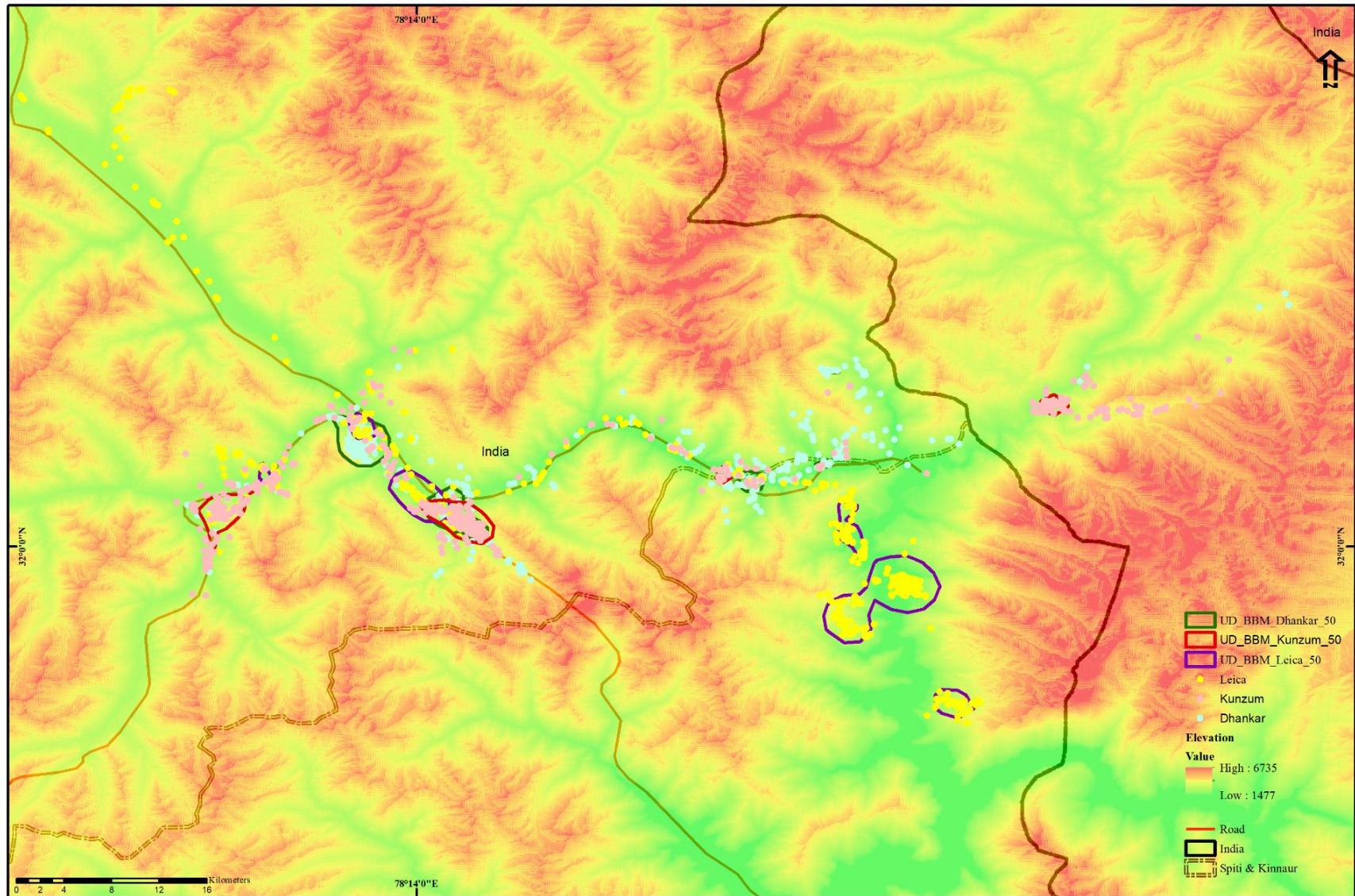


Fig 5.8b Comparative 50% IDs of wolves in the study area

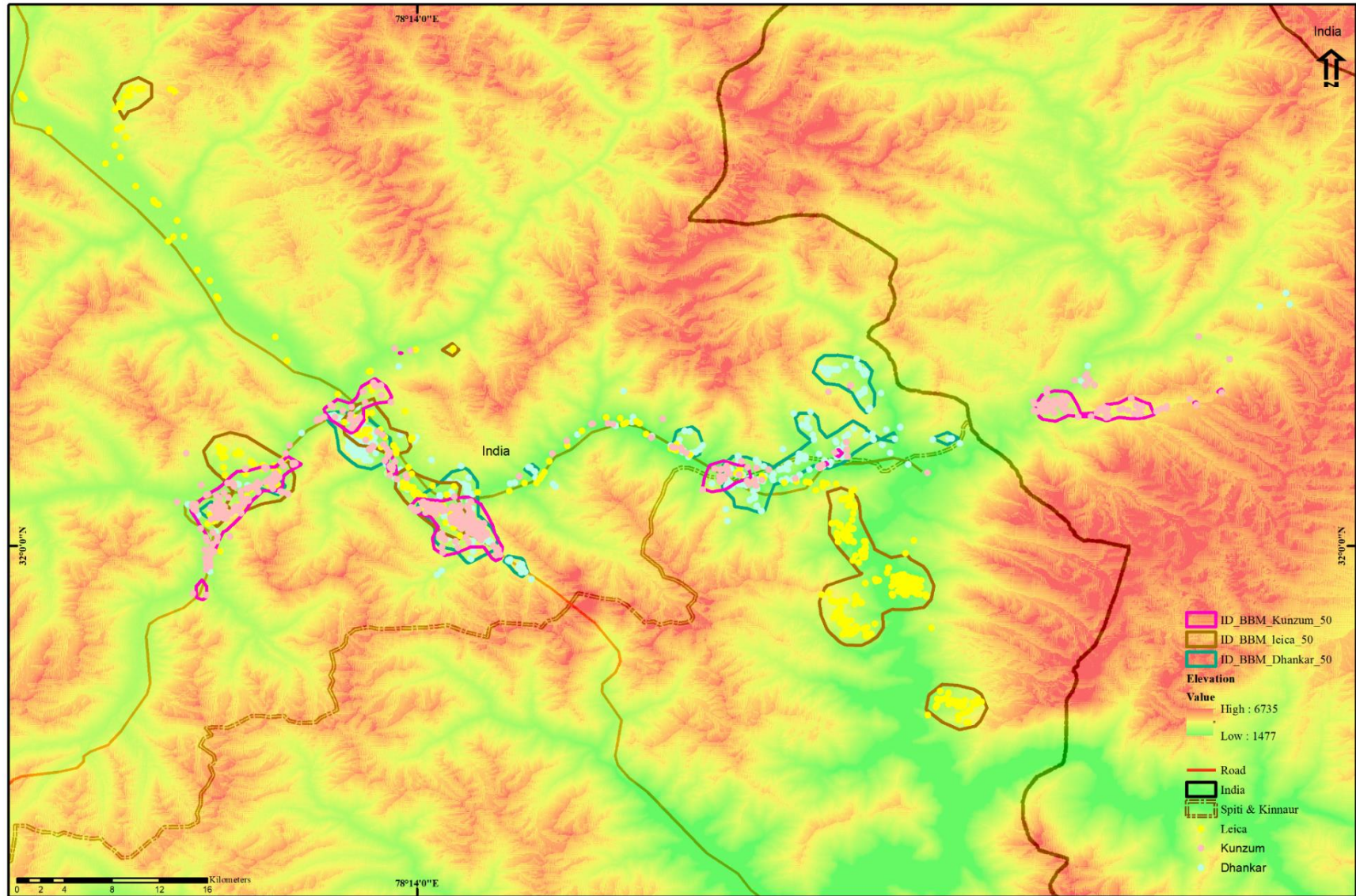


Fig 5.8c Comparative 50% RDs of wolves in the study area

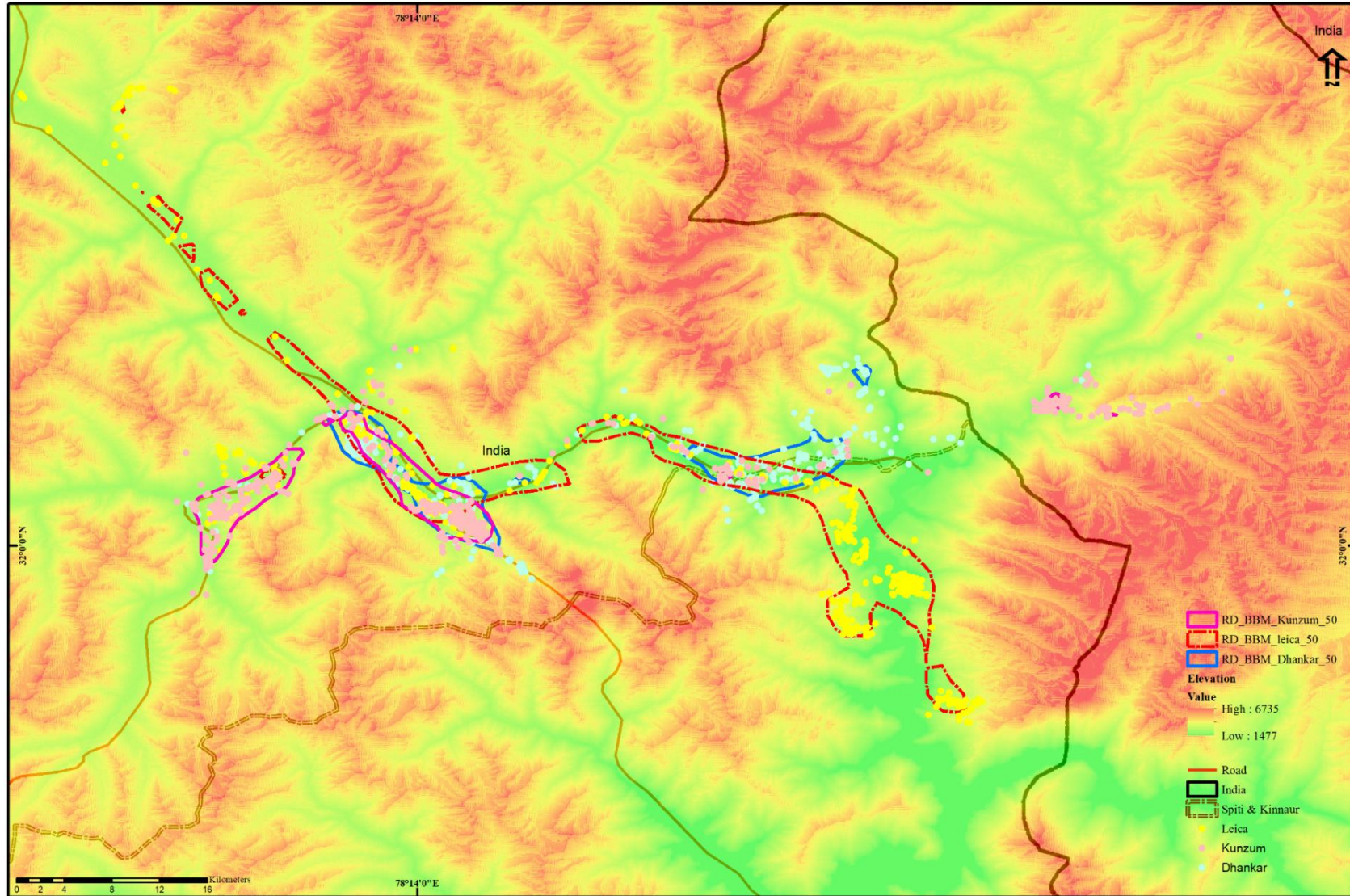


Fig.5.9. AKDE (weighted) of three individual wolves with time kriging of movement paths

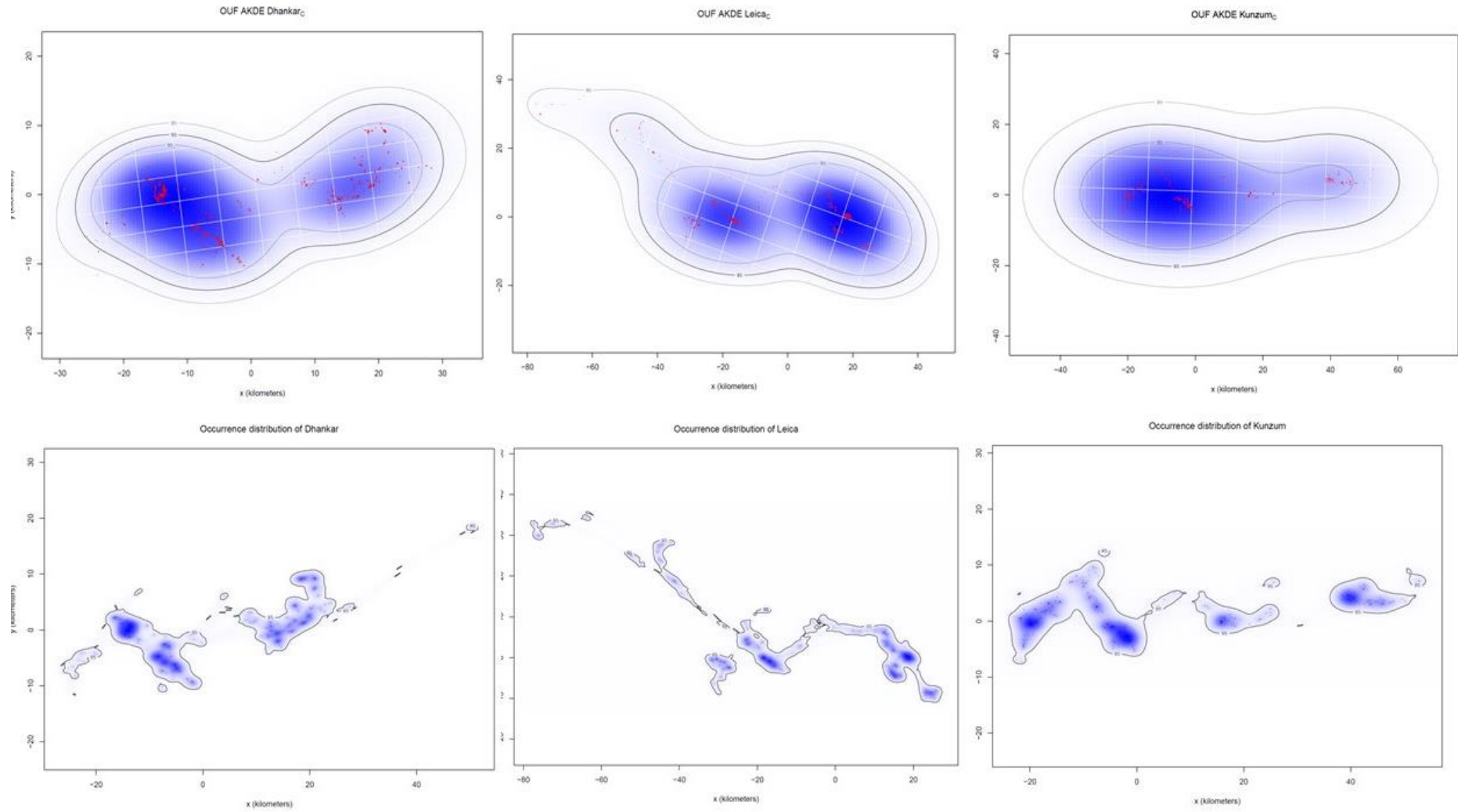


Fig.5.10a. Home Range of Dhankar with various Methods

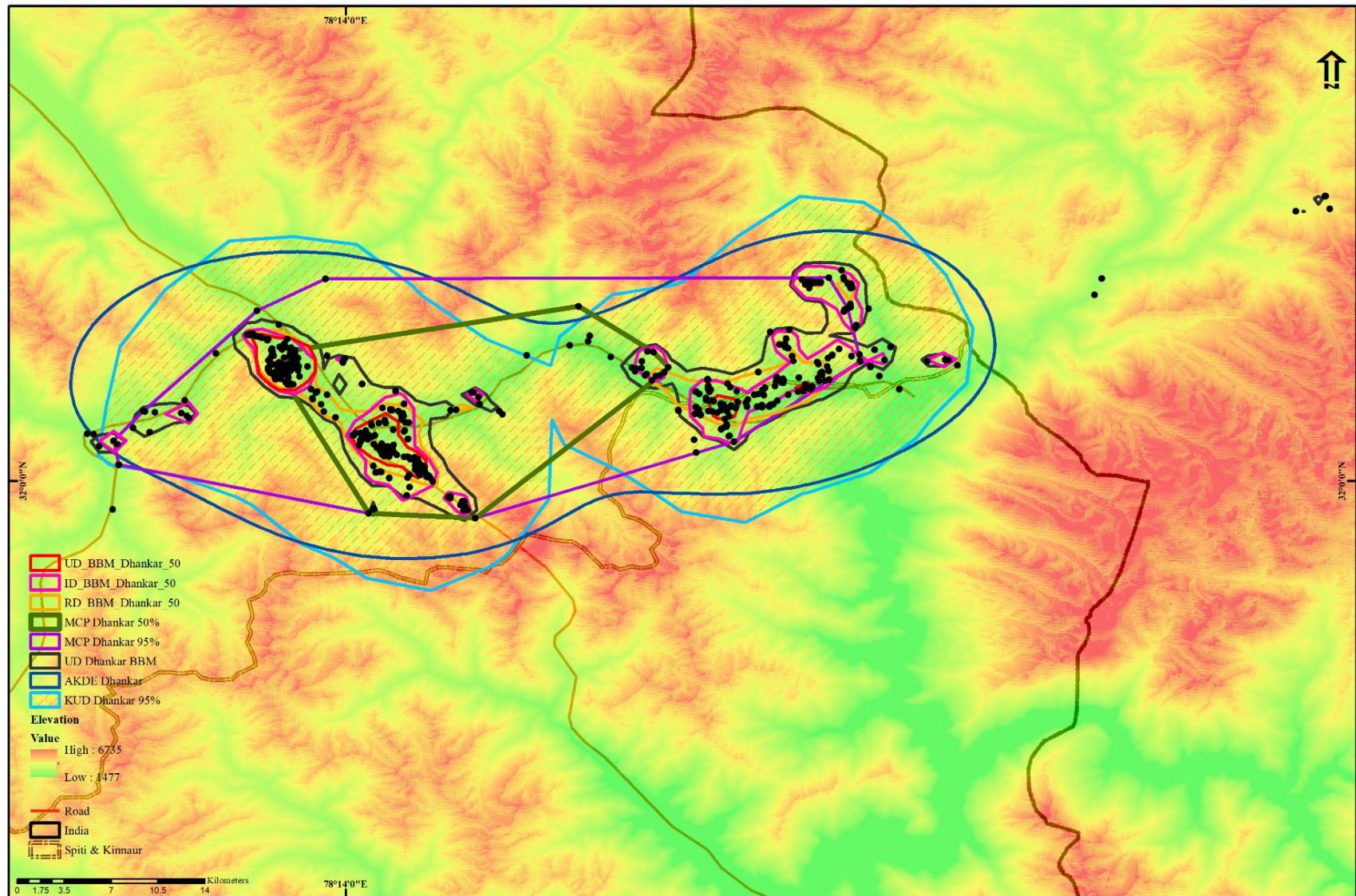


Fig.5.10b. Home Range of Kunzum with various Methods

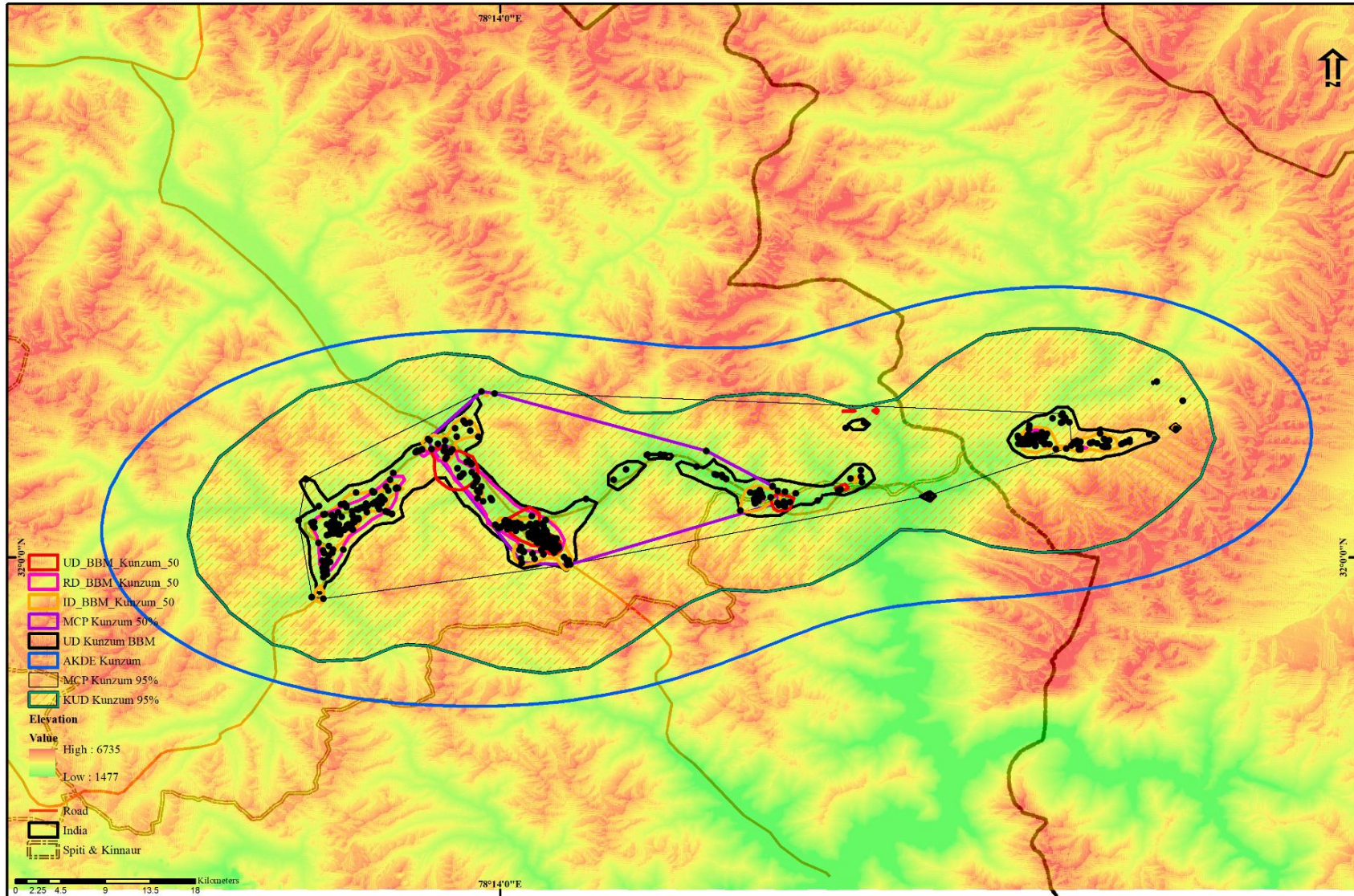


Fig.5.10c. Home Range of Leica with various Methods

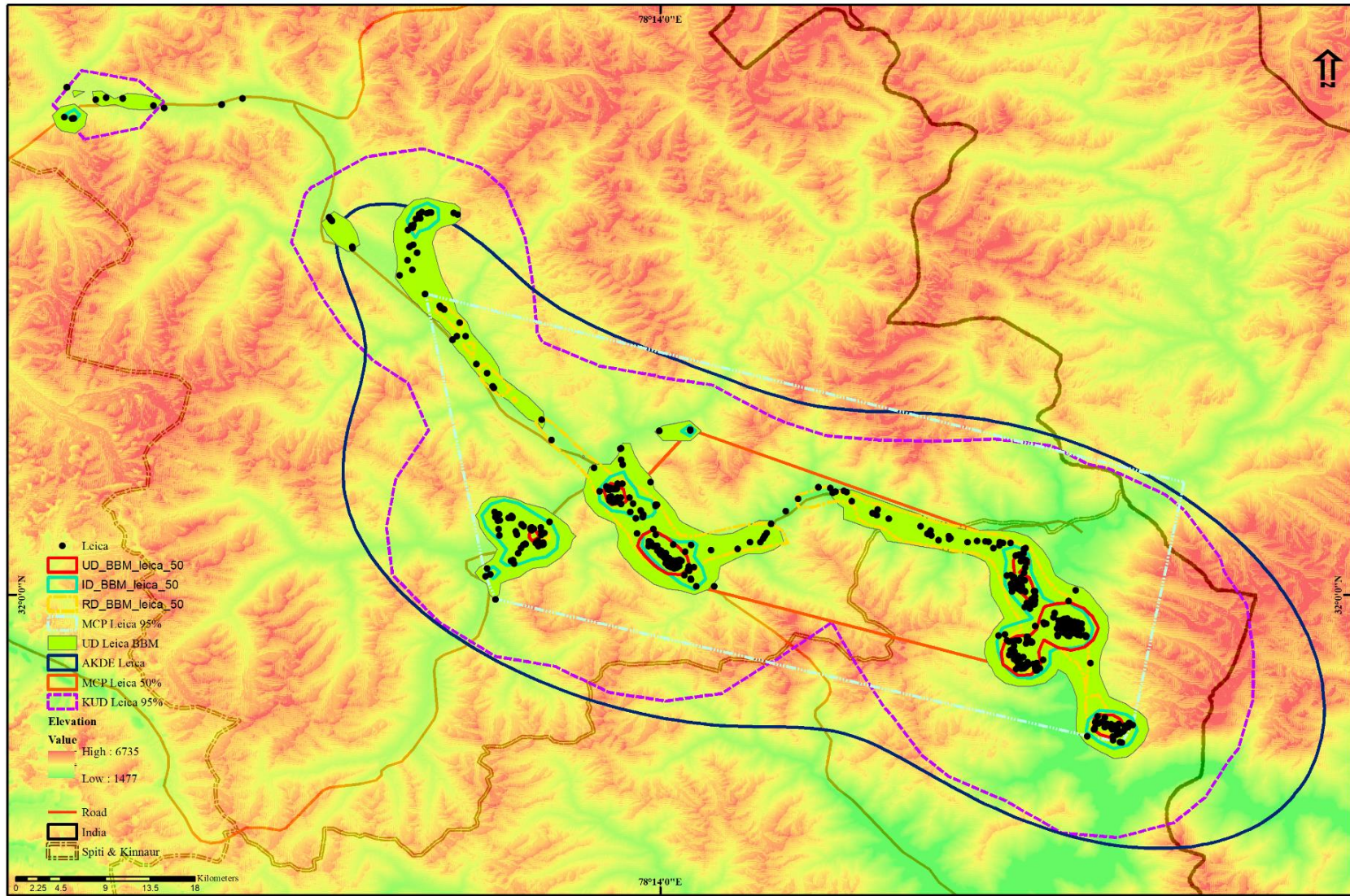


Fig.5.10d. Winter Home Range of Leica

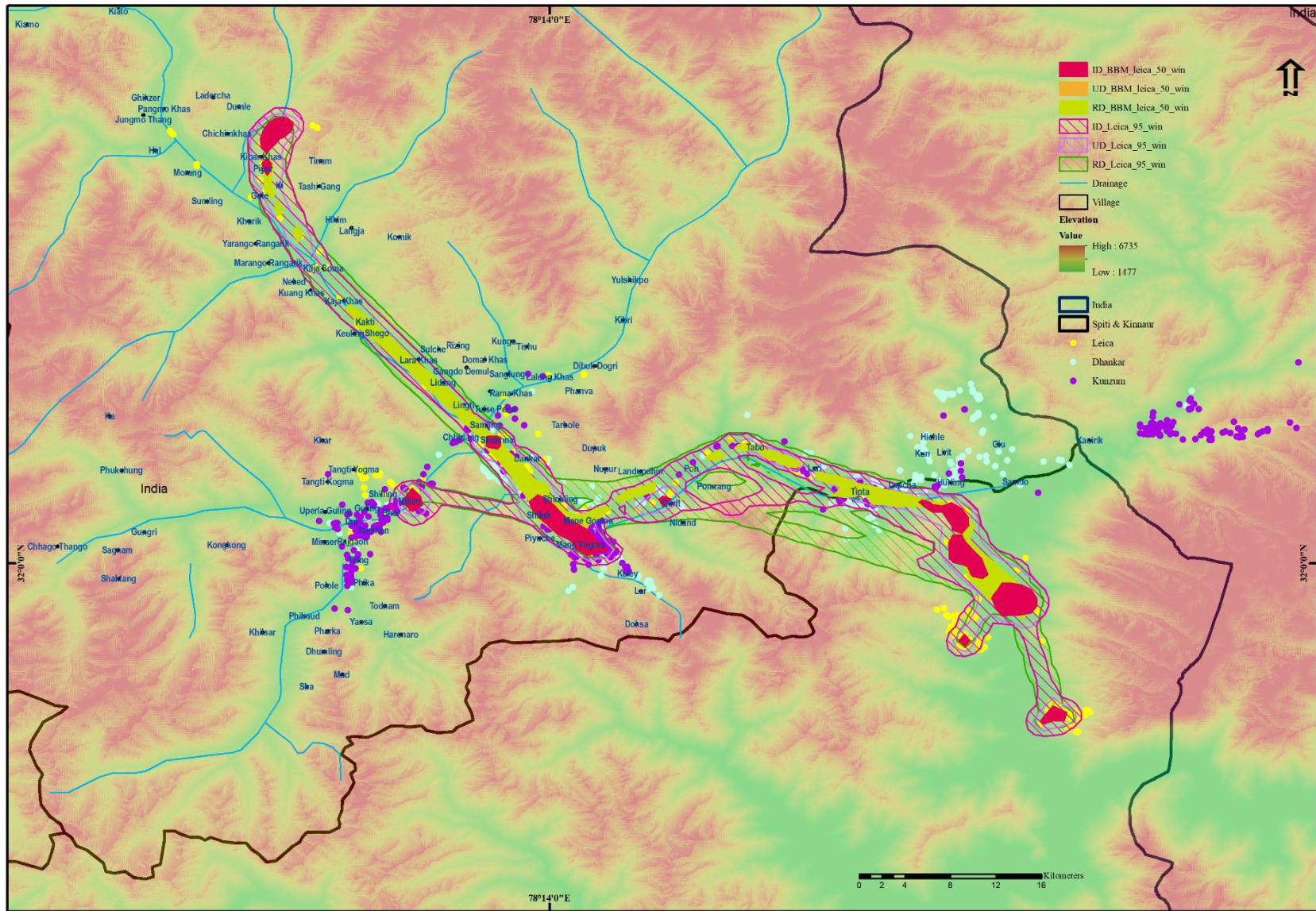


Fig.5.10e. Summer Home Range of Leica

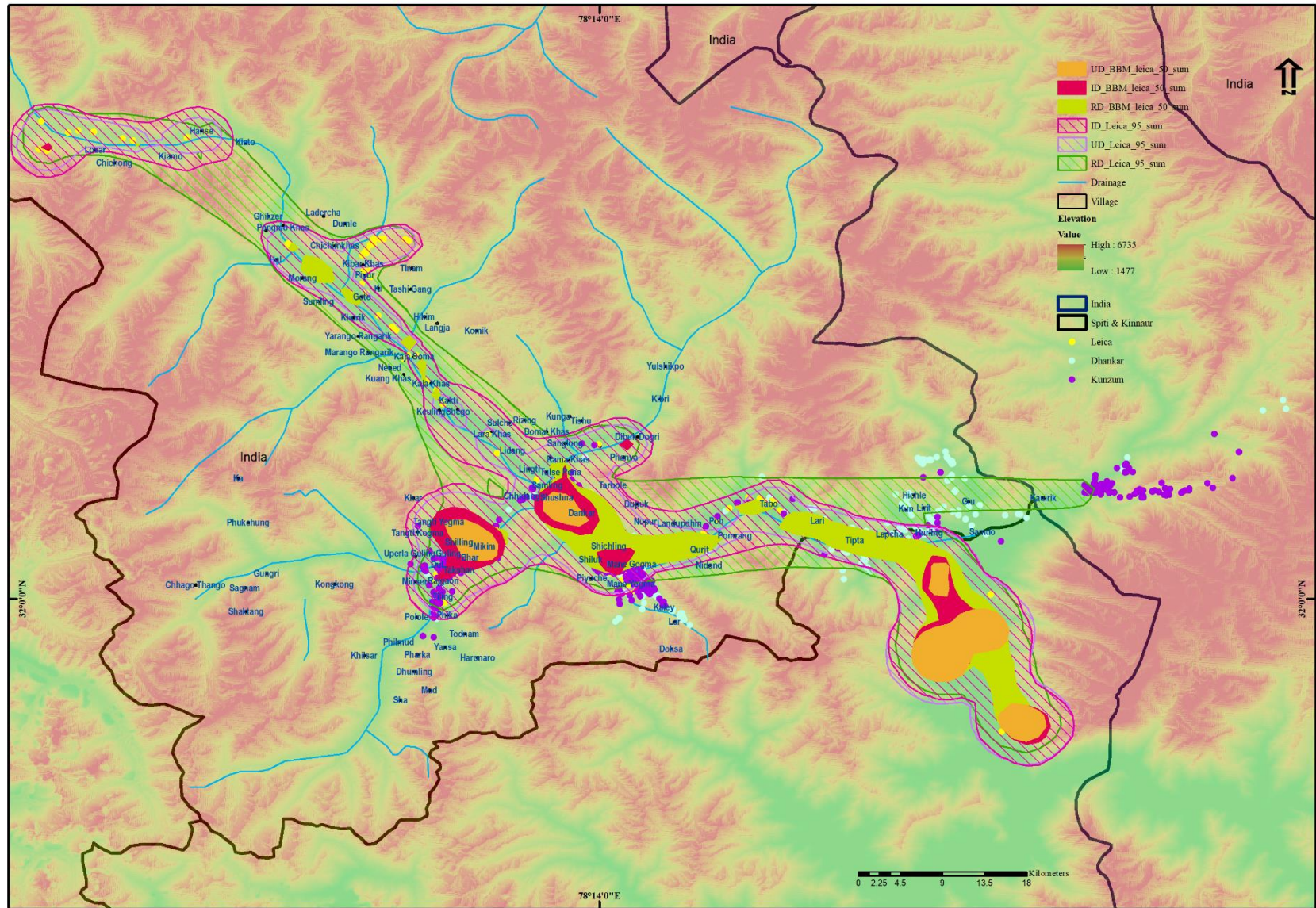


Fig.5.10f. Winter Home Range of Kunzum

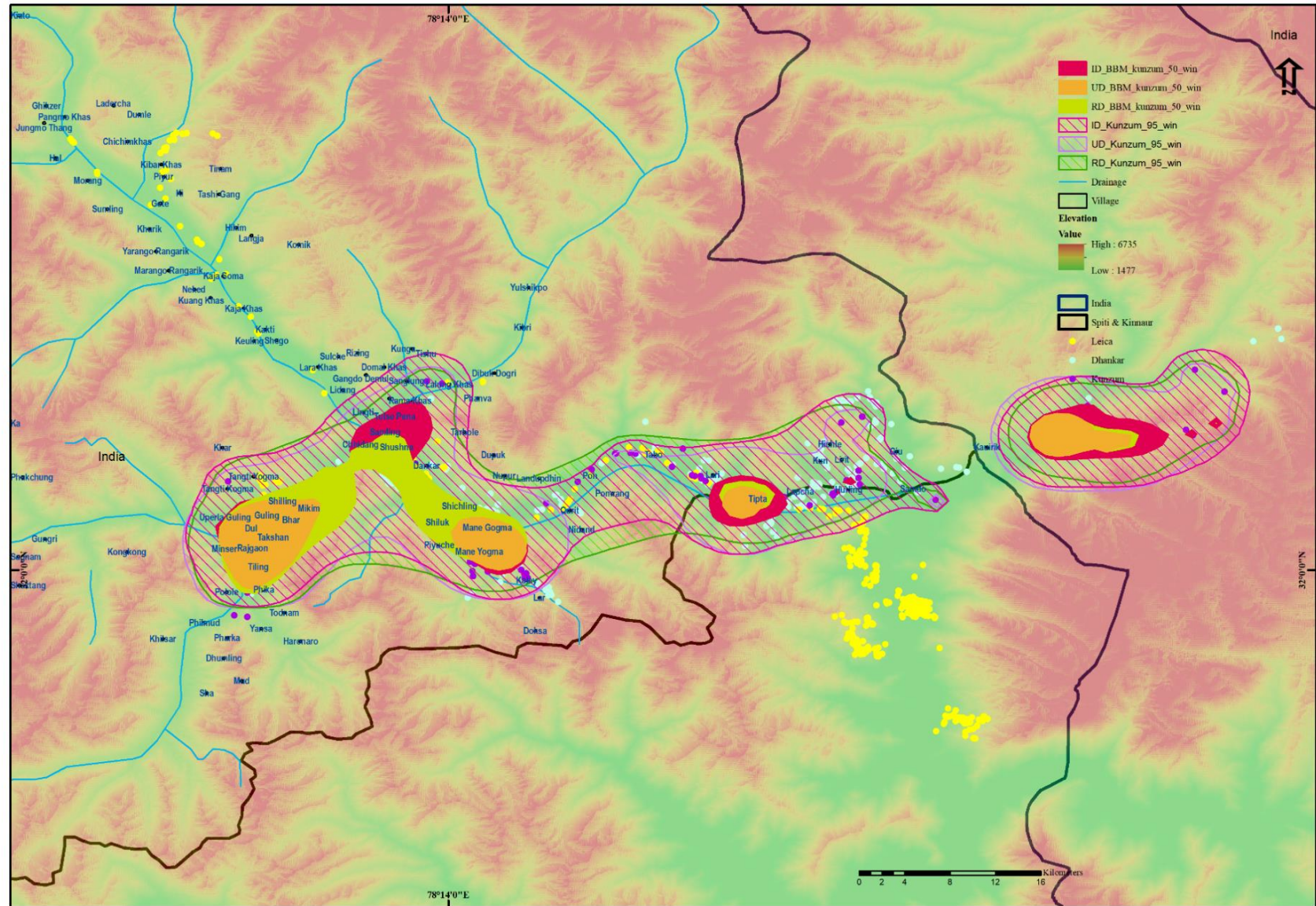


Fig.5.10g. Summer Home Range of Kunzum

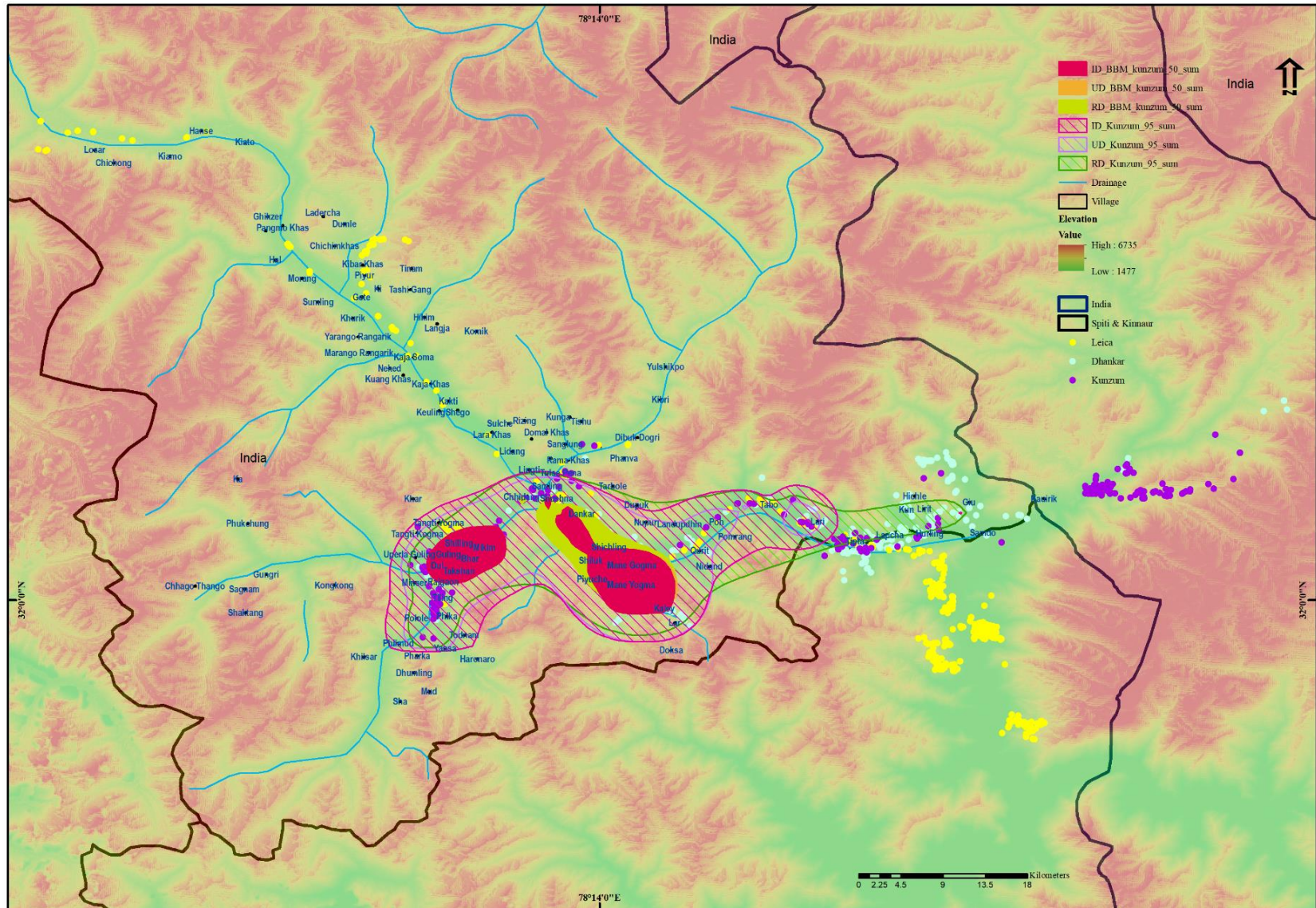


Fig.5.10i. Summer Home Range of Dhankar

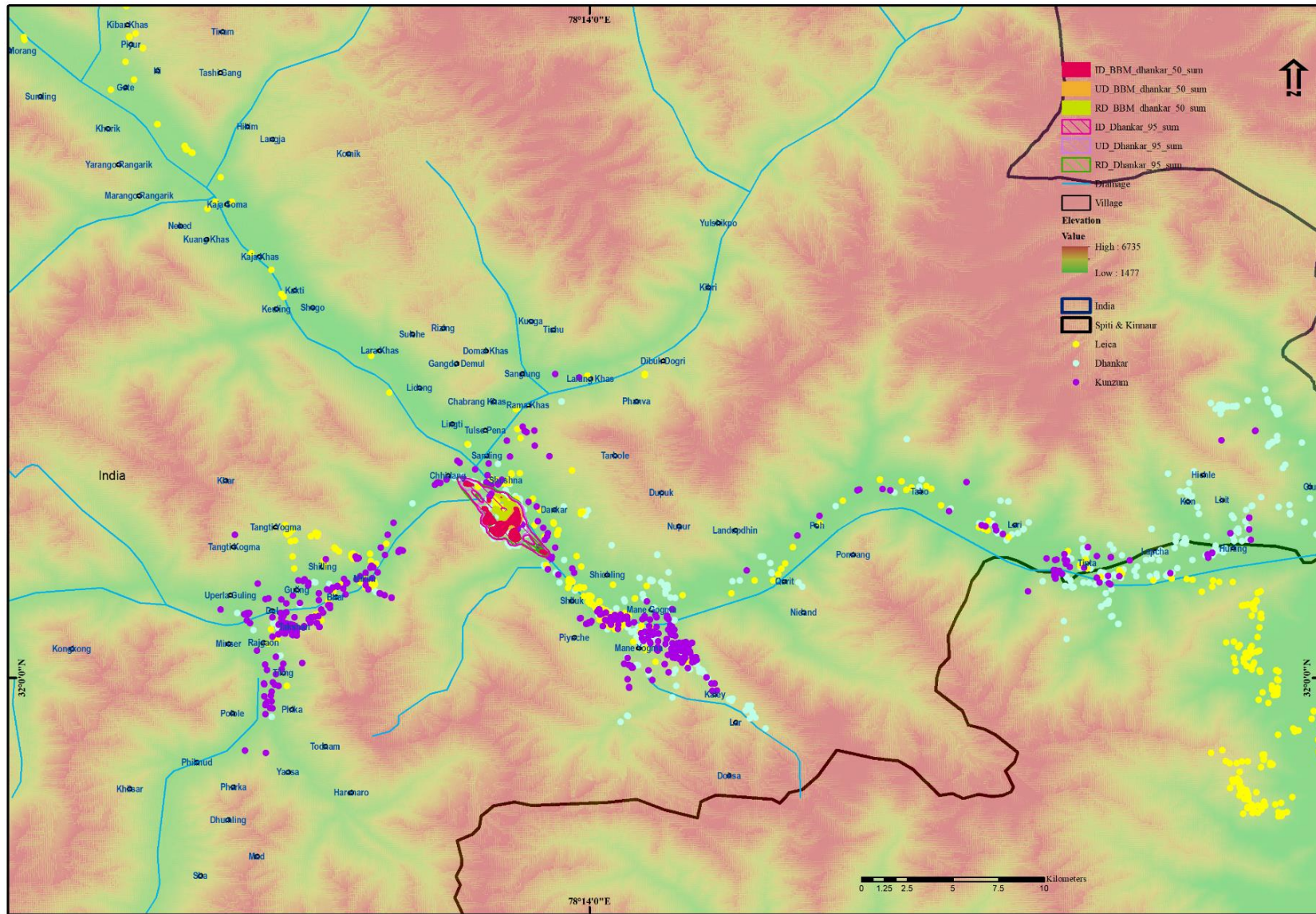


Fig.5.9. BCPA plots showing change in behavioral states of individual wolves over time. Last row indicates changes in movement speeds.

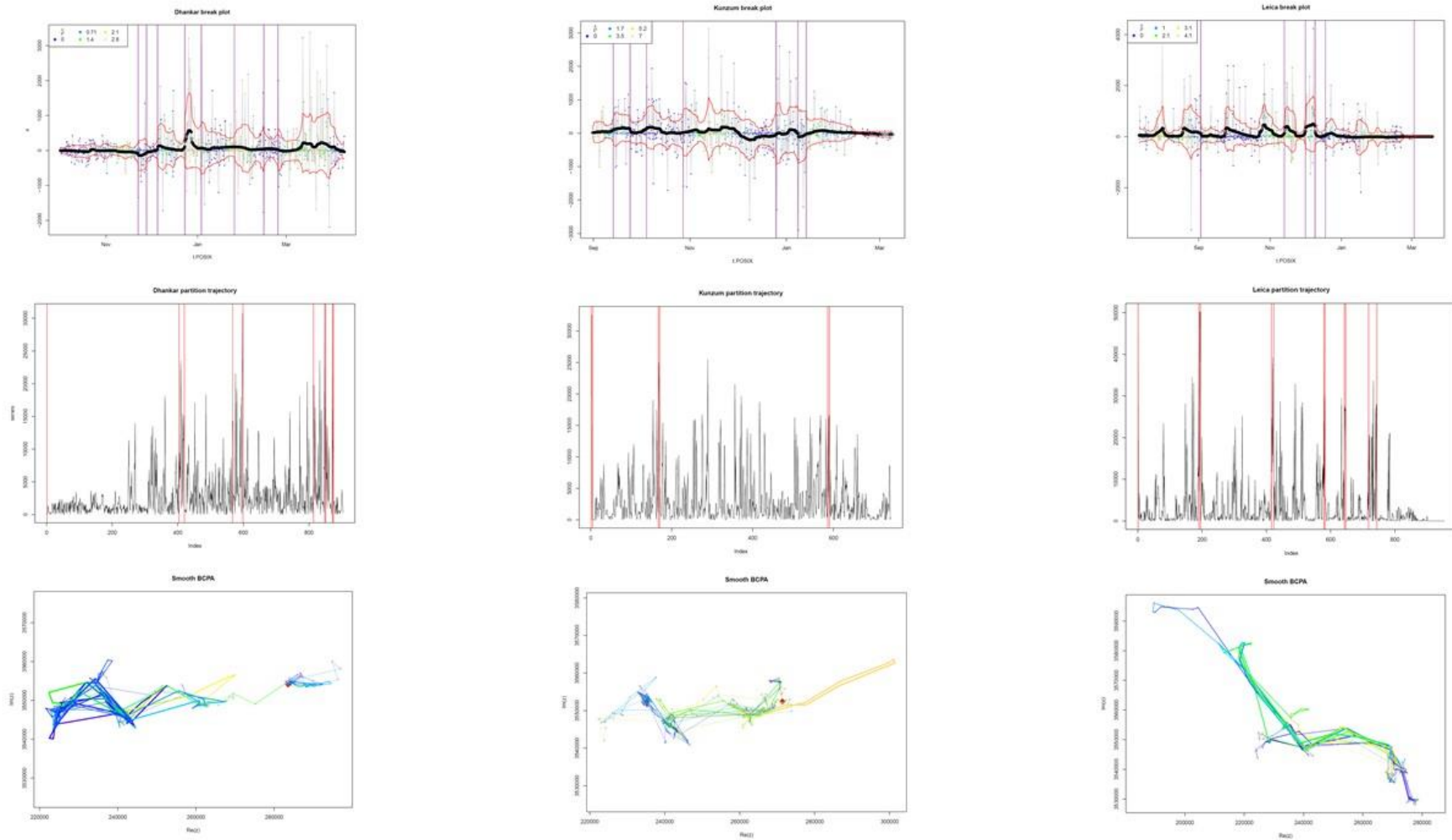


Fig.5.10. Outlying Mean Index (OMI) Analysis for individual wolves. Individuals show strong selection for areas with higher domestic ungulate presence

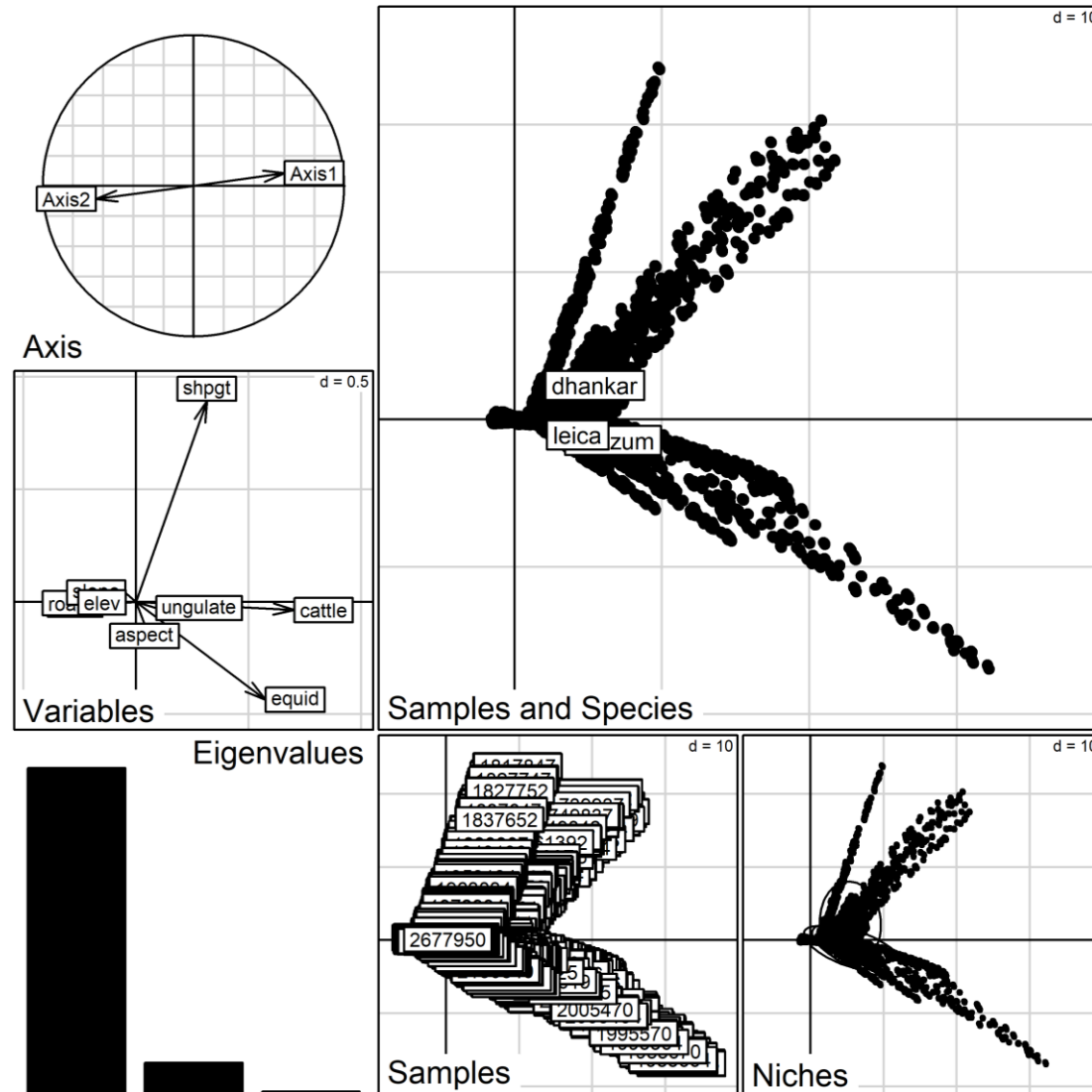


Fig .5.11 Canonical Outlying mean Index (CANOMI) analysis plot. Individual wolves show strong correlation with first axis and domestic ungulate availability

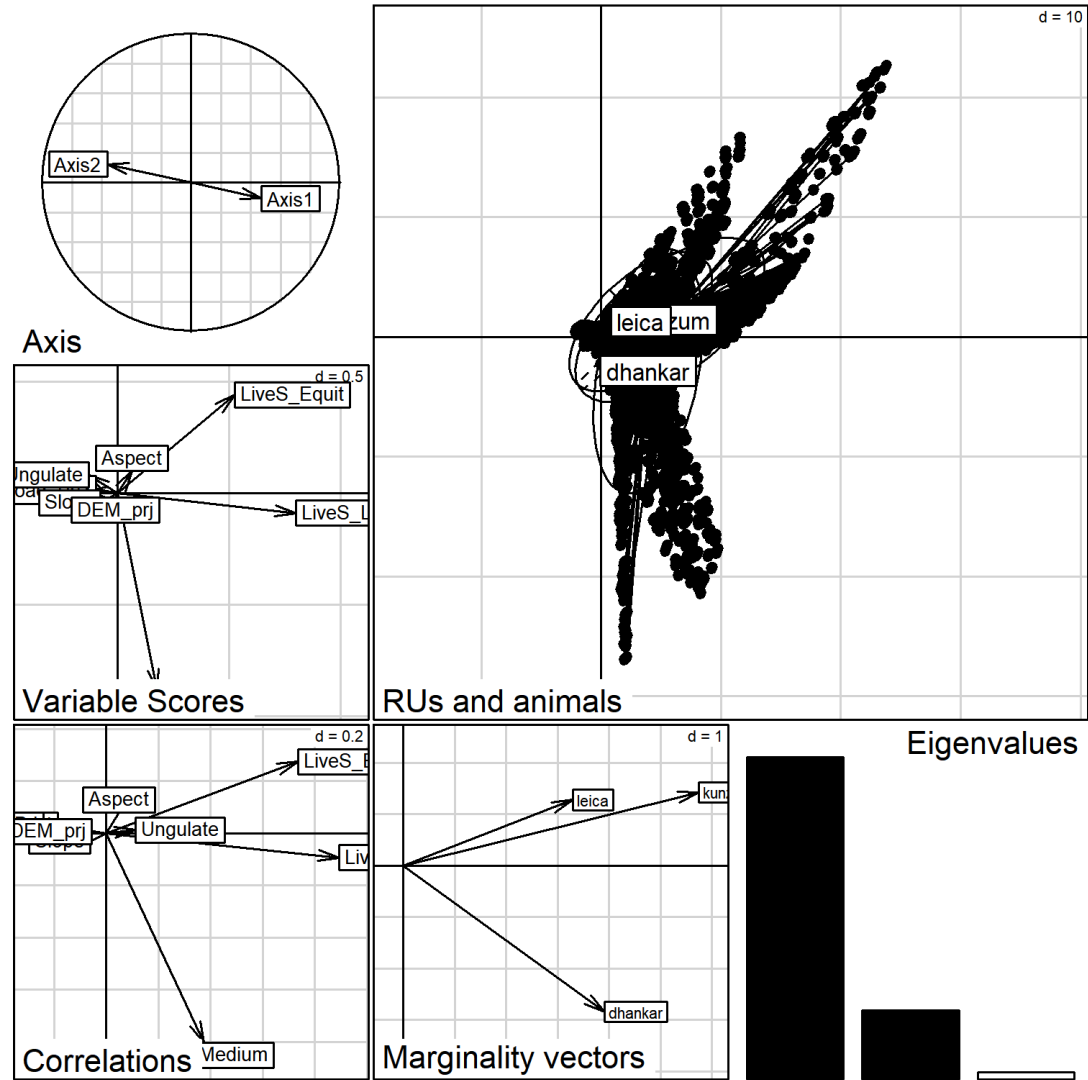
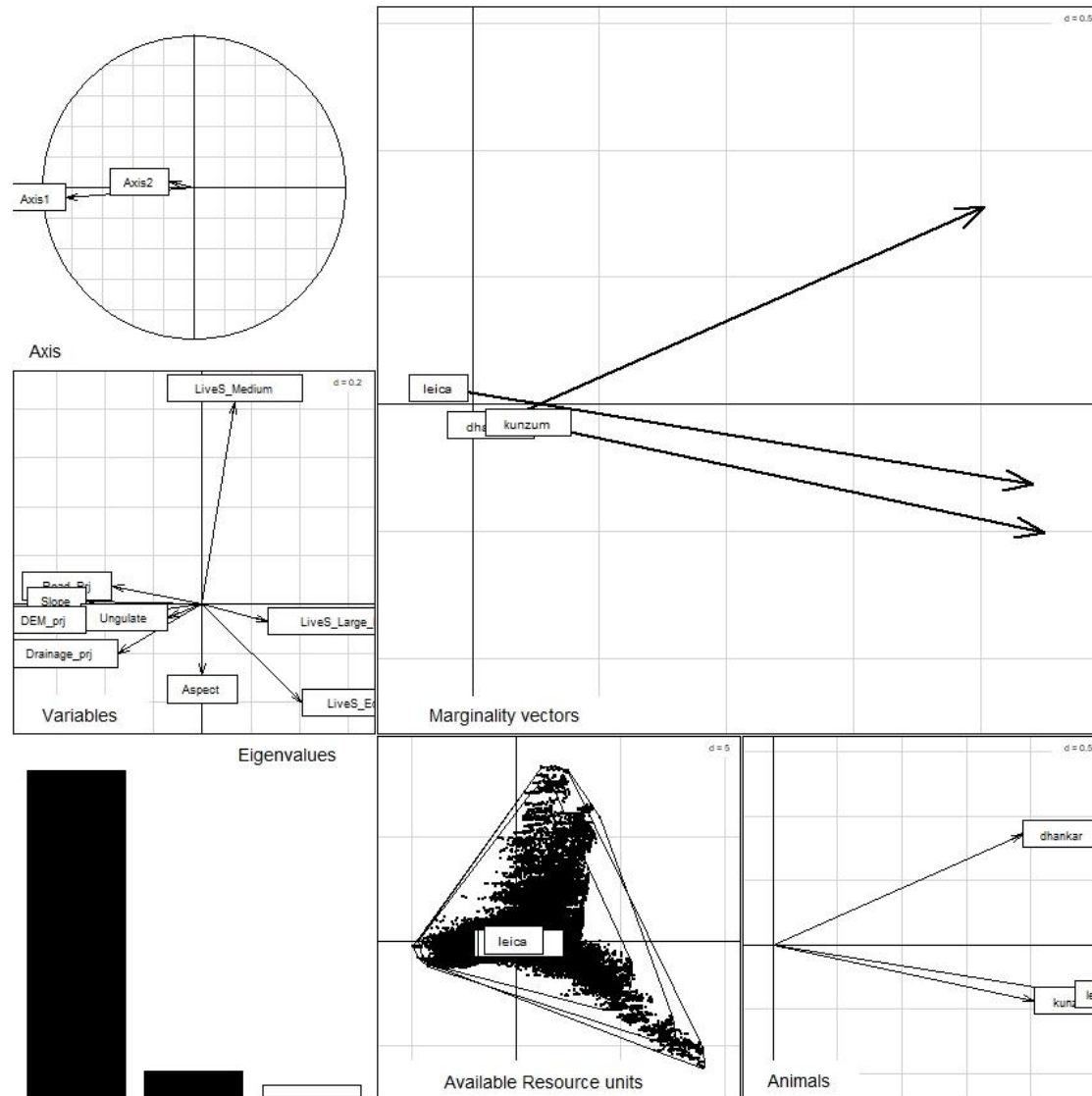


Fig.5.12. K-select analysis plot. Habitat selection by individual wolves shows Dhankar selected habitats with more sheep or goat presence strongly



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6. Chapter 6 - Conclusions and Management Implications

6.1 Abstract

The Trans-Himalayan region of the states of Himachal Pradesh, Uttarakhand, Ladakh, and Sikkim have been harsh areas where data generation of such umbrella species has been lacking. The current study aims to bridge this knowledge gap in terms of the ecology of the species, such as the Himalayan Wolf. Wolves are top predators and require vast landscapes. As a generalist species, wolves also have wide-ranging ecological roles in such systems. It is essential to recognize that in the long run, for the survival of such species, reduction of conflict with humans, habitat, and prey restoration is crucial. In the case of the Himalayan wolf, an authentic Asian wolf and most basal lineage amongst all wolves, a transboundary strategy for prey and its protection or management in some areas to increase acceptance and conserve the species within its exclusive range is needed. Higher number studies on wolves with respect to its food web ecology, prey-predator dynamics and encouraging community participation for human-wolf conflict mitigation in such sensitive landscapes is advocated at policy and managerial levels.

6.1.1 Significance of the study's outcomes

The major chapter one provided a comprehensive review, including field data validation of the diets of Himalayan wolves in comparison with its conspecifics. Thus the chapter adds to existing knowledge of the wolf diet in the world. It was found that wolves may be under considerable conflict in the Asian region. However, it is notable that wolves have been recorded to have a minimal domestic diet in cases where livestock pressures are low and where natural prey populations still subsist. As conflict levels are difficult to ascertain from scatological analysis alone, future investigations of such aspects may provide a more in-depth perspective on how wolves exist in conflict with humans.

The second major chapter deals with wolf conflict mapping in the region. It was found that wolves of Spiti largely preyed on large domestic prey. Similar studies from the adjoining

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landscape of the areas reflect comparable patterns. The results showed that perceived levels of livestock depredation did not emulate actual levels of depredation in concurrence with earlier studies. This study, therefore, provides a great understanding of species ecology for furthering conservation actions given the harsh context of the high elevation Himalayan rangelands. The applicability of such methods can be improved through repeated efforts that can aid in the policy framework for many Himalayan species. This approach may also assist in informing the management towards timely interventions in order to conserve such an elusive, large-ranging and ecologically unique Himalayan wolf.

The final chapter 3 on the movement ecology of the species provides a spatial model as a 'live' point of contact between ecology and evolution. The Himalayan wolf is a long-ranging species. Its home ranges were measured for the first time using GPS telemetry. The use of such technology-enabled tracking such species in harsh terrain such as that of the high range Himalaya. The key factors that contribute to the home range of these wolves are terrain features, prey availability, and seasonality. Conservation of such species, therefore, will require a vast landscape with optimal prey that is necessary to sustain good populations.

The synthesizing all three factors from these chapters, one can state that the diet of wolves is closely related to prey availability and landscape heterogeneity. On the one hand, it may be expected that wolves are marauders of livestock; however, on the availability of suitable wild prey, wolves would prefer such a game. This pattern coincides with the perceptions of the public, where it is often assumed far more loss is created than actualities. And thus, wolves are not voracious feeders; instead, they utilize the landscape in accordance with their ecological adaptability and resilience. Therefore, wolves prefer an undulating and lesser slope landscape with tolerable limits of human development.

Future research in terms of wolf food web ecology, taxonomic recognition, and hybridization will provide a much better understanding of wolf evolution and ecology in the region.

6.2 Management Implications

6.2.1 In the context of the wolf diet, the landscape of Spiti and Himalaya have the potential to harbor more wild prey. Therefore, if efforts are made on the front of identifying high conservation value areas in the landscape for such prey, wolves may persist and sustain themselves in the region

6.2.2 The Spiti and Ladakh region is an ecologically sensitive and vital landscape for the assemblage of Trans-Himalayan fauna. Therefore, efforts in reducing anthropogenic pressure in terms of overgrazing in the landscape are crucial during the summer months. A system of rotational grazing would be most relevant to sustain livelihoods and foraging habitats for wild prey.

6.2.3 During the study, wolves, were observed to engage and range with feral dogs sporadically. Current steps to curb feral dog menace in terms of possible threats to wolves, as well as other principal prey, will be needed. Kleptoparasites such as feral dogs and events where dogs were involved in removing carcasses brought down by wolves or snow leopards increase events of conflict as wild predators may be required to hunt more frequently or contact disease.

6.2.4 In the Spiti landscape, grazing regimes have drastically changed, and according to some notable studies from the landscape, these have indirect impacts on wolves. These landscapes show reduced productivity and increased pressure. Wild prey populations are depressed, and often conflict increases. Steps to regulate grazing through locals is essential. In the current scenario, migrant contractual grazing is often unappreciative of the landscape ethos.

6.2.5 The Spiti region's biodiversity is intricately linked with its ethos that flows from Tibeto-Buddhist culture. The culture is of generating compassion towards others being and that all beings are sentient. It is this ethos that has allowed wolves to persist. Efforts to connect the socio-religious organization and their leaders

6.2.6 Encouraging eco-friendly wolf tourism could be of great advantage to local residents of the area in tangent with snow leopard tourism