Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

QUAID-I-AZAM UNIVERSITY

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Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

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BY

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LIST OF ABBREVIATIONS

Abbreviation	
%	Percent
°C	Degree Centigrade
AJK	Azad Jammu And Kashmir
alt	Altitude
AUC	Area Under the Curve
BNP	Broghil National Park
c	Recapture Probability
CCL	Carnivore Conservation Lab
CGNP	Chitral Gol National Park
CI	Confidence Interval
CITES	The Convention on International Trade in Endangered Species of Wild Fauna and Flora
CKNP	Central Karakoram National Park
cm	Centimeter
CMR	Capture-Mark-Recapture
CSV	Comma-Separated Values
DEM	Digital Elevation Mode
df	Degree of Freedom
DNA	Deoxyribonucleic Acid
e.g	For example
ENMs	Ecological Niche Models
et al	And Others
etc	Et Cetera
FAO	Food and Agriculture Organization
fdr	False Discovery Rate
FN	False Negative
FP	False Positive
FPR	False Positive Rate
GA	Georgia
GB	Gilgit-Baltistan

GIS	Geographic Information System
glc2000	Global Landcover 2000
GLM	General Linear Model
GPS	Global Positioning System
GSLEP	Global Snow Leopard Ecosystem Protection Program
HEC	Higher Education Commission, Pakistan
HWF	Himalayan Wildlife Foundation
IBA	International Bear Association
IRSIP	International Research Support Initiative Program
IUCN	International Union for Conservation of Nature
kg	Kilogram
km	Kilometer
KNP	Khunjerab National Park
KP	Khyber Pakhtunkhwa
KVO	Khunjerab Villagers Organization
m	Meter
MaxEnt	Maximum Entropy
MDNP	Musk Deer National Park
MHNP	Margalla Hills National Park
MNP	Machiara National Park
MoU	Memorandum of Understating
MS	Microsoft
N	Population Size
NDVI	Normalized Difference Vegetation Index
NGS	Next-Generation Sequencings
npv	Negative Predictive Value
p	Capture Probability
PKR	Pakistan Rupees
PPV	Positive Predictive Value
QNP	Qurumber National Park
ROC	Receiver Operating Characteristic

SCR	Spatial Capture-Recapture (SCR)
SDMs	Species Distribution Models
SE	Standard Error
SECR	Spatially Explicit Capture-Recapture Models
Signif	Significance
SLF	Snow Leopard Foundation
SLIMS	Snow Leopard Information Management System
SLL	Snow Leopard Landscapes
SLT	Snow Leopard Trust
TN	True Negatives
TGR)	Tooshi Game Reserve
TP	True Positives
TPR	True Positive Rate
UK	United Kingdom
USA	United States of America
USD	United States Dollar
vrmint	Vector Ruggedness Measure
vs	Versus
WI	Wisconsin

Ecology and Conflicts Dynamics of Apex Predators in Northern Pakistan

ABSTRACT

Apex predators are usually associated with large body sizes, low densities, large home ranges, and wide distributions. They are frequently considered flagship species as conservation efforts for them benefit entire communities. Apex predators play a crucial role in maintaining healthy, balanced ecosystems, though the magnitude of their effects as ecosystem regulators has been immensely underestimated. The widespread decline in numbers and distribution of large carnivores due to human persecution has led to a loss and reconfiguration of biological diversity in many ecosystems, highlighting the ecological effect of carnivores and the broad-scale consequences of their loss.

Pakistan is home to 10 of 18 known mammalian orders which reflects significant diversity in the country. Unfortunately, the majority of large mammals in Pakistan are either threatened or endangered. Key large predators in northern Pakistan include the snow leopard, brown bear, grey wolf, and Himalayan lynx. I selected the snow leopard and brown bear as model predator species for this study because both are iconic species and represent distinct habitats and foraging while having overlapping ranges in Pakistan's high mountainous.

The long-term survival of these majestic species in Pakistan is uncertain due to intensifying threats, e.g., growing human populations, expanding infrastructure, increasing livestock, increasing dependency on natural resources, poaching, and growing and unmanaged tourism. For snow leopards, direct killing by farmers is the single most significant threat. Climate change is another emerging threat and is intensifying ongoing challenges for the survival of thin predator populations in human-dominated landscapes. Such a situation requires targeted conservation efforts. However, there are critical knowledge gaps in the ecology of large predators in Pakistan. For example, their distributions are dated and based on anecdotes and limited understanding of habitat requirements—reliable population estimates are unavailable, and the nature and magnitude

of their conflicts with people are not well known. The overall goal of this study was to fill these knowledge gaps for the informed conservation of apex predators in Pakistan. The study relied on empirical data collected through modern techniques like camera trapping and molecular genetics, in combination with advanced analytical methods, to construct species distributions and assess populations and human-carnivore interactions.

I found that northern Pakistan still supports good habitats for large predators, including snow leopards and brown bears, though quality across the landscapes was not uniform. For snow leopards, a large portion of previously known range represented low-quality habitat, including areas in lower Chitral, Swat, Astore, and Kashmir. Conversely, Khunjerab National Park (KNP), Misgar, Chapursan, Qurumber National Park (QNP), Broghil National Park (BNP), and Central Karakoram represented high-quality habitats. Variables with higher contributions in the habitat model were precipitation during the driest month (34%) and annual mean temperature (19.5%). The connectivity analysis for snow leopards revealed that the population in the Hindu Kush landscape was more connected with the population in Afghanistan as compared to other populations in Pakistan. Similarly, the Pamir-Karakoram population was better connected with China and Tajikistan, while the Himalayan population was connected with the population in India.

Similarly, for brown bears, a large portion of the historic range represented low-quality habitat, including areas in Swat, Lower Chitral, Neelum Valley, Naran-Kaghan, Khanbari, parts of Central Karakoram National Park (CKNP), and the surrounding areas of Gilgit. On the other hand, Deosai National Park (DNP) and its surrounding areas, KNP, QNP, BNP, Musk Deer National Park (MDNP), Misgar, Chapursan, parts of Astore Valley, Yarkhun Valley, Laspur Valley, Phandar Valley, and Kharmang Valley represented high-quality habitats. The connectivity model for brown bears showed that the population in the Hindukush range was isolated. The population in BNP and QNP was connected with the population in Afghanistan, while the KNP population was connected with China. In the Himalayas, the brown bear population had a weak connection with the population in Indian Occupied Kashmir. Inside Pakistan, the brown bear population in KNP, BNP, QNP, Misgar, and Chapursan were connected. The CKNP population was either isolated or weakly connected with KNP. The brown bear population in DNP and surrounding areas had a connection with that of MDNP.

Two best-quality habitats for both species were selected to estimate populations. KNP and its surroundings constitute prime habitat for snow leopards. Nineteen unique snow leopard individuals were identified in this area from photographic data of 122 camera stations active for 1,243 trap-days. The spatial capture-mark-recapture (SCR) model estimated a total of 55 individuals with 29.05-104.27 (95% CI) across 5,764 km^2. The base encounter rate was 0.008, and the spatial scale of movement was calculated at 6.726 ± 1.23 km. This yielded a density of 1 animal per 100 km^2, with an upper confidence limit of 1.8 individuals/100 km^2, and lower confidence limit of 0.5 individuals/100 km^2.

For brown bears, the population was estimated in DNP, an area known to be the main stronghold of the species, using double-observer visual counts in combination with capture-mark-recapture (CMR). Thirty bears were sighted in 19 sighting events, excluding double counts. The Huggins Closed Capture model estimated a capture probability (p) 0.48 ± 0.11SE with 0.28-0.69 (95% CI), and recapture probability (c) 0.48 ± 0.11SE with 0.29-0.68 (95% CI). The averaged population size (N) was 44.64 ± 12.66SE with 19.84-69.45 (95% CI).

During conflict surveys, 2,733 respondents reported 32,753 livestock (6,551 per year, with an average 2.39 per household, per year) losses to various carnivores and diseases, with a total economic loss of PKR 38,423,996 (PKR 7,684,799 per year with an average PKR 2811.855 per household, per year). Among these losses, diseases contributed 80%. The majority (53.80%) of losses related to small ruminants. Such a high level of property loss induced fear in local communities, influencing their tolerance towards large carnivores. Our analysis indicated that people were more tolerant of snow leopards in the north-eastern parts of the range. However, acceptance decreased in areas with frequent predator sightings. Depredation of livestock by snow leopards and the proportion of herding families in communities contributed significantly to negative attitudes towards predators.

In conclusion, northern Pakistan supports high-quality habitats for large predators like snow leopards and brown bears. The populations of these predators are patchy, but a few high-quality habitats support higher densities. Both species maintain regional connectivity, which must be protected for the species' long-term survival. Connectivity among some populations within the country is weak, which could be improved through targeted conservation work on movement corridors identified in this study. Human-predator conflicts pose a serious challenge to the future of these species. The co-existence of predators with human communities could be managed by addressing factors that determine human attitudes to carnivores, compensation for livestock predation, and education.

In conclusion, northern Pakistan supports high-quality habitats for large predators like snow leopards and brown bears. The populations of these predators are patchy, but a few high-quality habitats support higher densities. Both species maintain regional connectivity, which must be protected for the species' long-term survival. Connectivity among some populations within the country is weak, which could be improved through targeted conservation work on movement corridors identified in this study. Human-predator conflicts pose a serious challenge to the future of these species. The co-existence of predators with human communities could be managed by addressing factors that determine human attitudes to carnivores, compensation for livestock predation, and education.

ECOLOGY AND CONFLICT DYNAMICS OF APEX PREDATORS IN NORTHERN PAKISTAN

CHAPTER 1

General Introduction

1 General Introduction

1.1 SIGNIFICANCE OF APEX PREDATORS.

Apex predators, like large carnivores, are generally characterized by large body size, low densities, large home ranges, and wide-ranging movements. Factors like prey availability and habitat suitability determine their abundance in an area, while the presence of other predators has a lesser effect (Carbone and Gittleman, 2002). The dietary breadth of subordinate large carnivores appears to be limited, controlled by interspecific competition with dominant predators (Ferretti et al., 2020). Fierceness and intelligence are also attributed to apex predators. They draw the attention of the scientific community, as well as the public, because of their ecological roles (Allen et al., 2017; Bruskotter et al., 2017), like the functioning and structuring of ecosystems, disease control, and biodiversity conservation (O'Bryan et al., 2018; Ripple et al., 2014; Stier et al., 2016). These facts justify their significance for conservation (Hebblewhite et al., 2005).

Apex predators perform a crucial role in maintaining healthy and balanced ecosystems, but they have been immensely underestimated as ecosystem regulators (Ripple et al., 2014). Their role can be triggering cascading effects through lower trophic levels to maintain ecosystem integrity (Terborgh et al., 1999). Recent studies suggest that through suppressive effects on large and medium herbivores and smaller predators, apex predators can shape ecosystems (Ferretti et al. 2020; Colman et al., 2014; Ritchie and Johnson, 2009). The mesopredator release hypothesis foresees that the number and activity of smaller predators increases when the number of apex predators decreases, and this is due to lower direct killing and food competition by apex predators (Crooks and Soulé, 1999; Moseby et al., 2012). Consequently, mesopredator outbreaks are usually associated with high predation, which affects their prey numbers (Ritchie and Johnson, 2009). The influence of large predators on their prey and mesopredators can result in a redistribution of landscapes, and disturbs landscape features, habitat use, and the abundance of several species (Ripple and Beschta, 2006). The ecological release of mesopredators has drastic effects on rivers, oceans, forests and pastures, which places an additional burden on species already suffering.

The traits that place large carnivores at the apex of trophic systems also bring them into conflict with humans because competition for game and livestock are predominant sources of such conflict. Large carnivores have been persecuted by humans for ages. Fear is one of the oldest reasons behind this persecution (Gross, 2008). Contrary to other large mammals, carnivores have not been killed for consumption, but for removal as they are considered pests (Frank and Woodroffe, 2001). Humans must be ready and able to alter their own attitudes for co-existence with predators. Human persecution and habitat loss have resulted in catastrophic declines of apex predators throughout the world. Humans may have many reasons for trying to eliminate apex predators, but competition for food is perhaps the most important one. Real food webs are not particularly simple—there is a complex network of direct and indirect interactions. Such complexities sometimes bring out an unusual response to conservation efforts (Polis and Strong, 1996).

1.2 APEX PREDATORS IN NORTHERN PAKISTAN AND THREATS TO THEIR SURVIVAL

Among 18 known mammalian orders, members of 10 are present in Pakistan, which indicates considerable diversity and corresponding overall trends (Sheikh and Molur, 2005). Northern Pakistan hosts more large mammalian species as compared to other areas of the country. However, most of these species are either threatened or endangered (Rao and Marwat, 2003). The key large predators in the northern Pakistan include the snow leopard (*Panthera uncia*), common leopard (*Panthera pardus*), brown bear (*Ursus arctos*), grey wolf (*Canis lupus*), Asiatic black bear (*Ursus thibetanus*) and Himalayan lynx (*Lynx lynx*). I selected the snow leopard and brown bear as model predator species for this study, because both are iconic species for Pakistan, and represent distinct habitat and foraging, while having overlapping ranges in the high mountains of Pakistan.

On global level, snow leopard is categorized as Vulnerable, while the brown bear is categorized as Least Concern, according to The IUCN Red List of Threatened Species (2014.2). They are listed in Appendix-I and Appendix-II of CITES, which means that trade in these animals' species and their body parts is illegal. In Pakistan, both these predators are considered as Critically Endangered due to various threats, like habitat degradation, illegal hunting, and prey depletion (Sheikh and Molur, 2005). Both species are legally protected in Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and Azad Jammu and Kashmir (AJK) through various wildlife acts.

The Himalayan brown bear is predominantly herbivorous, as indicated by diet composition in Pakistan and India (Nawaz et al., 2019). In Pakistan, its diet consists of plant matter (64%) and animal matter (36%). It subsists on eight plant families, Apiaceae, Asteraceae, Caryophyllaceae, Cyperaceae, Lamiaceae, Poaceae, Polygonaceae, and Rubiaceae. Golden marmots are brown bears' main source of meat. Males are generally more carnivorous than females, probably because of their larger size and higher energy demand for hunting marmots (Nawaz et al., 2019). Snow leopards are capable of killing prey up to three times of their own weight. Their main prey consists of medium-sized mountain ungulates, especially Himalayan or Siberian ibex (*Capra sibirica*), bharal or blue sheep (*Pseudois nayaur*), markhor (*Capra falconeri*), and Himalayan tahr (*Hemitragus jemlahicus*). They also reportedly prey on other ungulates present in their range, including small mammals, rodents, and birds. In Pakistan, limited studies, confined to small areas, have been conducted which revealed that major portion i.e., up to 70% of their diet consist of domestic livestock, including sheep, goat, cattle, yak and hybrid of cattle-yak. Among wild prey, Siberian ibex, markhor, hare, marmot, pika, and birds were dominating (Anwar et al., 2011; Hacker et al., 2021; Khatoon et al., 2017).

The principal threat to large mammalian carnivores is deliberate or accidental killing by people (Woodroffe, 2001). The snow leopard is facing many threats (McCarthy et al., 2017; McCarthy and Chapron, 2003), and its survival is challenged mainly due to illegal killings: either due to retaliatory killings by herders/farmers or poaching for pelts and other body parts. Recently some more threats have indicated including climate change, large scale infrastructure, mining, and barriers such as fences or roads (Wingard et al., 2015; Zahler 2016). Habitat loss and prey depletion are also growing threats to the abundance and distribution of snow leopards in Pakistan. Another emerging threat is species-focused conservation policies, like trophy hunting, which targets ungulates for promotion and conservation, but ignores other sympatric species (Hussain, 2003). People sometimes consider the snow leopard dangerous because it may kill large ungulates to the size of a domestic yak. The brown bear in northern Pakistan is facing several threats, for instance, growing human population, expanding infrastructure, increasing livestock, increasing dependency on natural resources, poaching, and growing and unmanaged tourism (Nawaz, 2007). Sometimes it is killed due to culture and beliefs, because many bear body parts are believed to have magical medicinal power. Infrastructure and resource use by humans have adversely affected the natural resource in Pakistan. Also, climate change is another serious issue. These factors are shrinking the main habitat of brown bear resulting its shrinking populations. As brown bears in Pakistan mainly feed on plant matters and grown livestock number in its habitat is creating a serious competition for resource use which represent major threat to its habitat (Hameed et al., 2013; Nawaz, 2007).

1.3 BARRIERS TO THE CONSERVATION PLANNING OF APEX PREDATORS

A sound knowledge base of species ecology is vital for conservation planning. The following knowledge gaps limit the management of apex predators in the northern Pakistan.

1.3.1 Species distributions are dated and based on anecdotes

Assessment of available suitable habitat and identification of possible movement corridors are of prime importance for developing conservation strategies for threatened species. Accurate modelling of the geographic distribution of species is essential to different applications in ecology and conservation (Fourcade et al., 2014; Phillips and Dudík, 2008; Renner and Warton, 2013). The spatial and temporal distribution of species is a fundamental subject of ecology. It is important to be aware of the variables constraining or facilitating species' occurrence to avoid the under-prediction or over-prediction of its distribution or habitat suitability (Baldwin, 2009). Much of this data are readily available, for example, in the form of digital elevation models (https://www.usgs.gov) and global databases of climate (https://www.worldclim.org), productivity, and human impacts/infrastructure (http://www.fao.org).

Connectivity among habitats and populations is another important factor that influences a variety of ecological processes, like metapopulation dynamics, gene flow, seed dispersal, demographic rescue, infectious disease spread, population persistence, exotic invasion, range expansion, and biodiversity conservation (Calabrese and Fagan, 2004; Damschen et al., 2006; Fagan and Calabrese, 2010; Kareiva and Wennergren, 1995; Moilanen et al., 2005; Moilanen and Nieminen, 2002; Ricketts, 2001). Preserving and restoring connectivity is a top conservation priority, and conservation organizations are devoting substantial resources to accomplish such targets (Beier et al., 2006; Kareiva, 2006). A reliable, efficient and process-based approached is required to achieve this objective in complex landscapes. A new category of ecological connectivity models, based on electrical circuit theory was introduced by McRae et al. (2008). Resistance, current and voltage determined through graphs or raster grids can be associated with ecological procedures, like gene flow and individual movement that take place across landscapes or large population networks. Circuitscape is not the right modeling method for every connectivity application, but it is strongly complementary to others, and often works well in conjunction with other methods. Other widely used approaches include individual-based movement simulations (Hargrove et al., 2005), the derivation of landscape pattern indices (Schumaker, 1996), least-cost path models, graph theory (Adriaensen et al., 2003; Keitt et al., 1997; Minor and Urban, 2007; Urban and Keitt, 2001) and Brownian bridge movement model (Horne et al., 2007). In present study, Circuitscape was selected due to its convenient use with habitat model, developed by Maxent.

1.3.2 Limited knowledge of habitat requirements

The snow leopard has obtained an iconic status worldwide and is treated as a flagship species of the Greater Himalayan ecosystem (Alexander et al., 2016). The species is native to the mountain ranges of Central and southern Asia—some of the world's most rugged landscapes (Bhatnagar et al., 2001; Jackson et al., 2008; Network, 2014). It occurs in the Hindu Kush, Karakoram, Altai, Sayan, Tien Shan, Kunlun, Pamir, and outer Himalayan ranges, and smaller isolated mountains in the Gobi region (Hussain, 2003; Nowell and Jackson, 1996; Schaller, 1976). Estimates of global distribution range vary from 1.2 million to over 3 million km^2 (Network, 2014) and the species is highly threatened throughout its range. A recent study estimated its occupied range to be about 2.8 million km^2 (McCarthy et al., 2017) spreading across 12 countries—Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan and Uzbekistan (Fox, 1994; Jackson and Hunter, 1996; Maheshwari, 2013). The potential range of snow leopards may also extend to northern Myanmar, but recent snow leopard presence in this area has not been confirmed (Network, 2014).

In Pakistan, the snow leopard is found throughout the mountain ranges of the northern part—Hindu Kush, Karakoram, and Himalayas— in Chitral, Dir, Swat, and Kohistan districts of KP, in all districts of GB, and in the northern part of Neelum Valley of AJK (Ahmad et al., 2016; Hussain, 2003; Nowell and Jackson, 1996; Schaller, 1976). Pakistan's total estimated snow leopard habitat, according to Roberts' (1977) range maps, is about 80,000 km^2, of which about half is considered as the prime habitat (Fox, 1989). However, this preliminary evaluation of the snow leopard's distribution is based on general expert judgments, anecdotal information and topography. Consequently, these coarse distribution maps are not always in close agreement with the actual distribution—the discrepancy may be huge at the regional and global level (Fox, 1994). Accurate modelling of the geographic distribution of species is crucial for conservation planning (Fourcade et al., 2014; Phillips and Dudík, 2008; Renner and Warton, 2013). No study on the habitat suitability of snow leopards has been conducted before this study.

The historical distribution range of the Himalayan brown bear extends from the Pamir, Hindu Kush, western Himalayan, western Kunlun, Karakoram, Shan, and Tian Shan ranges in southern Asia (Nawaz, 2007; Roberts, 1977). Its global population throughout the entire distribution range has not been estimated. Brown bear distribution is mostly limited to the higher elevations of Central Asia and the Asian Highlands, where the effects of climate change have been reported more evidently (Aryal et al., 2014).

In Pakistan, the presence of brown bears in the western Himalayas has been confirmed in several localities—Neelum Valley, Kaghan Valley, Nanga Parbat, Astore Valley, and the Deosai Plateau (Ahmad et al., 2016; Nawaz, 2007; Roberts, 1977). Their presence has also been recorded in different valleys, glaciers, and high meadows in the

Pamirs, Karakorams, and Hindu Kush (Roberts, 1977; Schaller, 1976). The species is also found in Chitral, Kalam (Kohistan) and Pallas Valley (Indus Kohistan) (Nawaz, 2007; Roberts, 1977). In Southern Asia, the species exists in small and isolated populations in remote and rugged mountainous areas, and has been declared endangered (Servheen et al., 1999).

In Pakistan, the brown bear is distributed over an area of about 150,000 km^2 in the country's northern parts (Haq and Rahatullah, 2012; Nawaz, 2007). Total suitable brown bear habitat is approximately 68,503 km^2 which is about two percent of the total suitable habitat in Central Asia and the Asian Highlands (Su et al., 2018). It is predicted that brown bear habitat in Pakistan is most vulnerable to climate change after India, and suitable habitat will shrink to 56,501.30 km^2 (17.52% loss) by 2050 (Su et al., 2018). However, this assessment of brown bear habitat is based on secondary information and did not include proper field efforts. Very limited information is available on brown bear habitat suitability in Asia and Central Asia (Dai et al., 2019; Ghoddousi et al., 2020; Nawaz et al., 2014; Su et al., 2018). The Himalayan brown bear is a threatened species in Pakistan, and only a single study has been conducted so far on its habitat assessment in Deosai National Park (Nawaz et al., 2014). Our goal was to identify available suitable habitat, the extent of connectivity existing between populations, and the climatic and topographic factors that limit the distribution of brown bears across their distribution range in Pakistan.

1.3.3 Lack of reliable population estimates

Population monitoring is a key tool for the conservation of a species. Without an appropriate monitoring of the population and habitat of a target species, it is not possible to judge the usefulness of conservation actions. So far, reliable baseline information is lacking to make informed decisions (Jackson et al., 2005). To ensure that the populations of large predators persist, conservationists need to understand the population trends and distributional patterns of each species (McCarthy and Chapron, 2003).

There are no robust estimates of snow leopard population across the world. Total snow leopard population is estimated from various figures as guesses to be 4,000–7,500

(Jackson et al., 2010; McCarthy and Chapron, 2003; Sharma et al., 2019; Snow Leopard Working Secretariat, 2013). The lack of reliable overall population estimates and standardized methodologies are key hurdles that are yet to be overcome before we can be sure about snow leopard population trends. Schaller (1979) estimated Pakistan's snow leopard population to be 104–130 individuals. Malik (1995) reported that around 400 snow leopards could be present in Pakistan. Surveys undertaken in the Skardu and Ghanche districts of GB resulted in an estimate of 90–120 animals in that area and the estimated population was placed at 300–420 animals throughout Pakistan (Hussain, 2003). However, these figures are not based on standardized approaches, nor did they consider statistical assumptions, the ecology of snow leopards, or the risks of extrapolating results over large spatial landscapes (Sharma et al., 2019).

Many populations of brown bear are isolated and are of conservation concern, particularly in the southern parts of their distribution range (McLellan et al., 2017). The brown bear's phylogeography has been studied comprehensively in many parts of its distribution range (Hirata et al., 2013), but information about its population status in the Central Asia is minimal—many populations are further fragmented into several smaller populations (McLellan et al., 2017). Two subspecies of brown bear, the Tibetan brown bear (*Ursus arctos pruinosus*) and Himalayan brown bear (*Ursus arctos isabellinus*), occupy the southern Tibetan Plateau and the north-western Himalayas, respectively (Aryal et al., 2012; Nawaz, 2007). Habitat fragmentation, the main factor leading to the isolation of populations and individuals, has negative genetic and demographic effects (Boitani, 2012). Once abundant in northern Pakistan, the Himalayan brown bear has been eliminated from most of its former distribution range. This decline may imply a reduction in genetic diversity, compromising population survival. There has been an estimated 200–300-fold decrease in brown bear population in northern Pakistan during the last 1,000 years, possibly due to growing human populations and glaciations. However, despite the presence of a bottleneck genetic signature, the population in northern Pakistan has a moderate level of genetic diversity and is not at immediate risk of inbreeding depression. Gene flow may exist with adjacent populations (Bellemain et al., 2007).

The overall population status of the brown bear throughout its distribution range has not yet been determined, although estimates do exist for certain populations. For example, in China, brown bears exist as poorly defined populations in the west and northeast, with population estimates of 6,000 and 1,000, respectively. In India, the estimated population range is 500–750 individuals (Japan Bear Network, 2006), while in Pakistan, information about brown bear distribution and population status is patchy, but approximately 150–200 bears may exist in seven populations in three major mountain ranges— Himalayas, Karakorams, and Hindu Kush. Connectivity among these seven populations is limited, and some are completely isolated (Nawaz, 2007). All these populations are small and decreasing, except for the Deosai population, which is growing (Nawaz et al., 2008).

1.3.4 Limited knowledge of human-carnivore interactions

The human population has increased globally, which has resulted in an increased human caused variation of natural landscapes and resource use, which pushes wildlife to stay in close vicinity of humans (Inskip and Zimmermann, 2009). Such circumstances often lead to human-wildlife conflict because the actions of humans and their livestock come across with those of wild animals (Inskip and Zimmermann, 2009). Human-carnivore conflict is a situation associated with the persecution of carnivores, livestock depredation and efforts to conserve carnivores (Woodroffe et al., 2005). Due to their large spatial requirements and sizeable food requirements, large carnivores are especially prone to interacting with humans (Linnell et al., 2001; Treves and Karanth, 2003). In addition to threats, like prey depletion, habitat loss, poaching and fragmentation, which stand to reduce the populations of large carnivores, (Cardillo et al., 2004; Chapron et al., 2008; Wolf and Ripple, 2016), retaliatory killings for depredation on livestock are perhaps the most direct and widespread threat to their survival (Inskip et al., 2014).

The mitigation of human-predator conflict is challenging. Reliable knowledge of the factors involved in livestock depredation is crucial to devising strategies to mitigate this conflict (Khanal et al., 2020). Recently strategies for livestock management to reduce killing by predators drew the attention of wildlife managers and herders. However, still lesser importance was given to the various environmental factors affecting such predations (Ugarte et al., 2019). Livestock depredation is the sparking factor of human-carnivore conflicts in landscapes used for livelihood production (Loveridge et al., 2010). Domestic animals lose their anti-predator abilities because of living in low-risk areas/human-arbitrated environments, which makes them more vulnerable to predators (Madhusudan and Mishra, 2003).

Large carnivores often do not stay confined to spaces like nature reserves. Instead, they move out to search for easy prey like livestock, and sometimes even humans within shared spaces—their traits, like low population density, solitary or social hunting, and large ranges, facilitate them (Ugarte et al., 2019). Many species of predators are involved in livestock depredation, including pumas (*Puma concolor*), jaguars (*Panthera onca*), and foxes (Lycalopex spp.) in Central and South America (González et al., 2012; Palmeira et al., 2008; Soto-Shoender and Main, 2013); bears (*Ursus* spp.), lynx (*Lynx* spp.), and wolves (*Canis lupus*) in North America and Europe (Musiani et al., 2003; Smith et al., 2014; Thorn et al., 2013), lions (*Panthera leo*), cheetahs (*Acinonyx jubatus*), black-backed jackals (*Canis mesomelas*), and caracals (*Caracal caracal*) in Africa (Thorn et al., 2013; Woodroffe and Frank, 2005), and snow leopards (*Panthera uncia*), common leopards (*Panthera pardus*), and tigers (*Panthra tigris*) in Asia (Bagchi and Mishra, 2006; Miller et al., 2015).

Multiple factors affect the magnitude of livestock depredation by large carnivores, including livestock husbandry practices (Kuiper et al., 2015; Woodroffe et al., 2007), wild prey availability (Odden et al., 2008), seasonal patterns (Farhadinia et al., 2017; Johansson et al., 2015), predators' behavioural characteristics (Lucherini et al., 2018), habitat type and structure (Miller et al., 2015), and predator abundance (Weise et al., 2018). One of the major reasons of prey population decline is livestock grazing, which decreases available forage (Madhusudan and Mishra, 2003) and increases the risk of disease transmission to wild animals (Kaul, 2003), resulting in large carnivores switching their dietary preferences from wild prey to domestic prey. However, the role of wild herbivore density in determining the extent of livestock predation by carnivores is dubious (Khorozyan et al., 2015; Soofi et al., 2019). Poor livestock management is another important reason for livestock killings by predators (Woodroffe et al., 2007).

Human-predator conflict is poorly studied in Pakistan, and only a few studies have described it (Ahmad et al., 2016; Bibi et al., 2013; Dar et al., 2009; Din et al., 2017; Kabir et al., 2014) despite the wide prevalence of the issue, particularly in northern Pakistan where various large carnivores—snow leopards, common leopards, brown bears, Asiatic black bears (*Ursus thibetanus*), and grey wolves—often come in contact with humans and contribute to significant economic losses (Ahmad et al., 2016). All these studies were also limited to specific areas, and therefore, do not reflect the overall trends of human-bear conflict. The present study is the first-ever covering the whole of northern Pakistan to assess human-predator conflicts and factors that shape human attitudes to large predators.

1.3.5 Emerging technologies to address knowledge gaps about elusive species

1.3.5.1 Technology

Different methods have been used for population estimation of large carnivores. These include questionnaires, interviews, and sighting reports from local informants (Gittleman et al., 2001; Henke and Knowlton, 2005; Mishra et al., 2006). Signs survey is another technique for elusive animals but are subject to observer bias (Long et al., 2007; McCarthy et al., 2008). Track counts can also be used for population estimation of large carnivores (Siira et al., 2009). Vocalizations ((Bauer, 2007; DeMatteo et al., 2004) and spotlight counts can be used to record animals' presence and to estimate population size sometime (Henke and Knowlton, 2005). Prey biomass method (Karanth et al., 2004; McCarthy et al., 2008) and depredation surveys can be used to monitor carnivores' relative densities and distribution (Gittleman et al., 2001; Linnell et al., 1998).

Among many techniques used to monitor large predator populations, camera trapping is one of the modern and widely used techinique (Agha et al., 2018; Swann and Perkins, 2014). It has now become a universal tool in scientific studies related to ecology and conservation (Wearn and Glover-Kapfer, 2017). It includes camera trapping in diverse and challenging environments like deserts (Alqamy, 2010), high mountain ranges (Jackson et al., 2006), dense forests (Ahmad et al., 2016), and savannahs (Balme et al., 2010). Camera trap studies can be used for multiple ecological investigations, including population size and density (Noss et al., 2012), species presence (Ahmad et al., 2016), habitat use (Rich et al., 2013), and demographic structure (Karanth et al., 2011). Camera trapping is an easily employable, non-invasive tool that is suitable for detecting elusive and nocturnal species (Hossain et al., 2016). However, it may not be very good at detecting unique individuals every species from photos.

Molecular genetics is another promising technique for identifying individuals from the scats and hair of carnivore species. The technique is quite expensive, and a few studies have been conducted to date for snow leopards (Hacker et al., 2021). Fewer studies have attempted to estimate densities from genetically identified individuals. A major portion of snow leopard distribution range has not been studied with genetic tools, and identification through signs and expert opinion is questionable. Methodologies used in population or density estimation in genetic studies of snow leopards are mostly non-spatial and lack the consideration of spatial variation of study areas. Such studies have reported either minimal snow leopard individuals or derived their densities using non-spatial estimators (Aryal et al., 2014; Ferretti et al., 2014; Janečka et al., 2008; Karmacharya et al., 2011; Suryawanshi et al., 2017).

The double-observer technique for population estimation was initially developed to estimate the detection probabilities of aerial surveys of various species (Cook and Jacobson, 1979; Graham and Bell, 1989). It has been found to be applicable to birds (Nichols et al., 2000), bats (Duchamp et al., 2006), ungulates (Jenkins and Manly, 2008), and large rodents (Corlatti et al., 2015). In general, the technique involves two observers searching for and counting animals simultaneously while ensuring they do not cue each other to the locations of the animals (Suryawanshi et al., 2012). It was initially standardized by Forsyth and Hickling (1997) to estimate the abundance of the Himalayan tahr (*Hemitragus jemlahicus*) in New Zealand. This survey technique was further modified and applied to estimate mountain ungulate populations, e.g., bharal (*Pseudois nayaur*) and ibex (*Capra sibirica*) (Suryawanshi et al., 2012). The double-observer survey method is based on the principles of mark-recapture theory (Forsyth and Hickling, 1997). A capture history can be built for each observed individual, and data can be analysed in a capture-recapture-like pattern (Williams et al., 2002). The method is usually implemented for ungulate species population estimation but has also been used in some form for brown bear population estimation (Quang and Becker, 1997; Walsh et al., 2010).

1.3.5.2 Methodology advancements

Estimating densities from camera trap data implies conventional capture-recapture closed population models. The models are fit to the capture-recapture history of identified individuals to gain abundance, and then the effective study area is calculated to obtain a density estimate (Janečka et al., 2011; Ma and Xu, 2006; McCarthy et al., 2008; Sharma et al., 2014; Zhou et al., 2017). The main issue with conventional capture-recapture model was its inability to accommodate detection variability induced by the spatial distribution of animals. The new spatially explicit capture-recapture models (SECR) do not need to calculate effective area for density estimation, and are quite robust considering the spatial aspect of the area (Efford and Fewster, 2013; Royle et al., 2014). The assumptions of SECR models are that populations under study are geographically closed during survey period, the activity centers of individuals are fixed and are randomly distributed, and capture detection probabilities are inversely related to the distance from the camera trap (Royle and Chandler, 2014). These models perform well enough when studying large-ranging animals (Sollmann et al., 2012).

To explore the requirements of species and for conservation projects, the significance of species distribution models (SDMs) is increasing (Bosso et al., 2016; Sheehan et al., 2017; Smeraldo et al., 2017). SDMs are used extensively in evolution, ecology, biogeography, and conservation biology to overcome research challenges (Guisan and Thuiller, 2005). The habitat distribution of wildlife species is assessed through an ecological niche model called the maximum entropy (MaxEnt) model (Clements et al., 2012; Wilting et al., 2010). These models are simpler, reliable and allow researchers to develop data easily (Merow and Silander, 2014; Radosavljevic and Anderson, 2014). Globally, researchers are using the MaxEnt model to understand the habitat distributions of rare and endangered wildlife species (Bai et al., 2018; Dai et al., 2019; Hameed et al.,

according to the number of connected pathways, and the effective resistance between two populations is derived from the overall resistance across all pathways (Kabir et al., 2017). Though Circuitscape is often unable to compute grids larger than 6 million cells because of computer memory limitations, (Shah and McRae, 2008) it was suitable for this study area.

Predator species have different pelages and habitat preferences. Therefore, a method suitable for one species may not be suitable for other. Habitat utilization by Himalayan brown bears is quite different from that of other brown bear species. They generally inhabit open and high elevation plateau in Pakistan, India, China, and Central Asia. This habitat uniqueness offers different types of opportunities and challenges to monitoring bears. In this study, I tested two different approaches—camera trapping and the double-observer method— in Deosai National Park (DNP). The aims were to assess their effectiveness for brown bear population estimation in an open area and develop recommendations for monitoring Asian brown bear populations across their entire distribution range. To test the effectiveness of different methods, the population estimation of snow leopards was limited to areas considered species strongholds, because the quality and quantity of data required for the model was not fulfilling the entire area. Modern statistical models of spatial capture-recapture and double-observer methods were used to obtain reliable estimates on snow leopard and brown bear populations. The study focused on snow leopard and brown bear strongholds, i.e., suitable habitats, to produce suitable models. Khunjerab National Park and its surroundings were selected to test the method for snow leopard population estimation, while DNP and its surroundings were selected for brown bear population estimation.

1.4 AIM AND OBJECTIVES

I considered snow leopards and brown bears as model apex predators, due to their different habitats and foraging preferences. Both species are threatened in Pakistan and found throughout GB, Chitral, Swat, Dir, and Kohistan districts of KP, and Muzaffarabad and Neelum districts of AJK. Scientific knowledge of these two species is very limited, and does not allow for conservation planning.

The overall goal of this study was to fill critical knowledge gaps related to the species' distribution, population, and interactions with human populations. The study relied on empirical data collected through modern techniques like camera trapping and molecular genetics, in combination with advanced analytical methods. The specific objectives were to:

1. Assess the current distribution, habitat suitability and movement corridors of the study species,
2. Estimate the density of the study species in good-quality habitats,
3. Assess human-predator conflicts and the factors that shape human attitudes to large predators.

1.5 STUDY AREA

The study focused on the distribution ranges of snow leopards and brown bears in Pakistan (Fox, 1989; Roberts and d'Olanda, 1977) which encompass four high mountain ranges—the Himalayas, Karakorams, Pamirs, and Hindu Kush spread across three administrative units, i.e. KP, GB, and AJK. The area was comprised of watershed valleys based on natural watersheds. Targeting major protected areas and other potentially suitable habitats, we surveyed 47 watershed valleys, including 264 villages (Figure 1.1).

High altitudes and below freezing temperatures constituted the study area, one of the most heavily glaciated parts of the world outside the polar regions. The western Himalayan range is situated in AJK and GB to the south and east of the Indus River. The Hindu Kush rises southwest of the Pamirs. The Karakoram range runs along the borders between three countries; in the regions of GB in Pakistan, Ladakh in India, and the Xinjiang region in China. They are considered to extend from the Wakhjir Pass at the junctions of the Pamirs and Karakorams to the Khawak Pass north of Kabul. The mountains of Pakistan are relatively densely populated despite harsh geographic and climatic conditions. Nevertheless, the special ecological conditions and remoteness of these mountainous areas also support a unique biodiversity of plants and animals. Climatic conditions vary widely across the study area, ranging from the monsoon-influenced moist temperate zone in the western Himalayas to the semi-arid cold deserts of the northern Karakorams and Hindu

Kush. Four vegetation zones can be differentiated along altitudinal ascents: alpine dry steppes, subalpine scrub zones, alpine meadows, and permanent snowfields. Various rare and endangered animals occur in the study area, including the snow leopard *(Panthera uncia)*, grey wolf *(Canis lupus)*, brown bear *(Ursus arctos)*, Asiatic black bear *(Ursus thibetanus)*, Himalayan lynx *(Lynx lynx)*, Himalayan ibex *(Capra ibex sibirica)*, blue sheep or bharal *(Pseudois nayaur)*, flare-horned markhor *(C. falconeri. cashmirensis)*, musk deer *(Moschus chrysogaster)*, Marco Polo sheep *(Ovis ammon polii)*, Ladakh urial *(Ovis vignei)*, Pallas's cat *(Otocolobus manul)*, and woolly flying squirrel *(Eupetaurus cinereus)*.

Ten national parks are situated in the study area. These include Chitral Gol National Park, Broghil National Park, Khunjerab National Park, Central Karakoram National Park, Deosai National Park, Qurumber National Park, Shandur-Hundrap National Park, Machiara National Park, Musk Deer National Park, and Ghamot National Park.

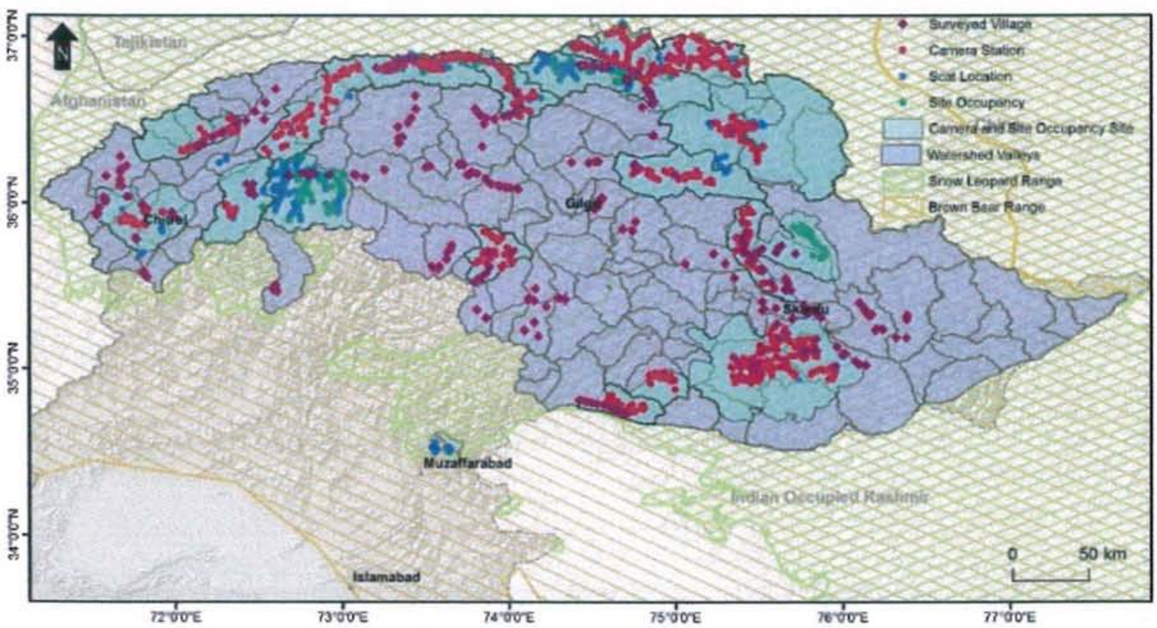


Figure 1.1. Map of study area showing sampling sites, surveyed villages, and watershed valleys.

1.6 THESIS STRUCTURE

This doctoral thesis comprises of nine chapters, arranged in seven independent papers (chapters 2–8). Chapter 1 describes the study background and provides a general introduction. Chapters 2–8 provide detailed studies on the objectives of the thesis together with the materials and methods used to attain these objectives. Details of the statistical computations of the attained data are presented in each chapter, and conclude with suggestions and recommendations for the conservation of the species and their habitat. Chapter 9 is overall conclusion and future implications.

Chapter 1 gives a general introduction, study area description, background research and study research question, study needs and available information. Main issues with conservation of target species, overall goal of the study and specific objectives of the thesis are also provided.

Chapter 2 includes the habitat suitability of snow leopards and their movement corridors in Pakistan. It describes various environmental factors influencing snow leopard distribution, statistical analysis, study background, snow leopard strongholds, protected area coverage, and priority landscapes for snow leopard conservation in Pakistan. The findings presented in this chapter have been published (Hameed et al., 2020).

Chapter 3 includes the habitat suitability of brown bears and their movement corridors in Pakistan. It describes various environmental factors influencing brown bear distribution, statistical analysis, study background, brown bear strongholds, protected area coverage, and priority areas for brown bear conservation in Pakistan.

Chapter 4 provides information on human perceptions of brown bears in the Hindu Kush range. It covers human-bear interaction, bear occurrence in the Hindu Kush range, public perceptions, and economic losses due to bears. The information in this chapter is the first of its kind for the Hindu Kush range. The findings presented have been published (Hameed et al., 2021).

Chapter 5 describes a suitable method for snow leopard population estimation. I collected data through camera trapping, and applied a spatial capture-recapture model to estimate abundance. It provided snow leopard population estimation in stronghold areas as identified through a habitat suitability model. The method is best suited to such data and species.

Chapter 6 describes a suitable method for brown bear population estimation in Pakistan. I collected data through camera trapping and the double-observer count method. Both methods were compared, and the double observer was found to be more suitable. It provided brown bear population estimation in stronghold areas as identified through a habitat suitability model. The method is best suited to such data and species.

Chapter 7 describes human-bear interactions in Deosai National Park and growing threats to the species. I collected data via questionnaire surveys. They included brown bear threats to communities in the form of livestock killings and the human threat to brown bears in term of public perceptions. It also describes livestock grazing pressure in the study area, which is another potential threat to brown bears.

Chapter 8 describes human-bear interactions across northern Pakistan. I included total livestock at the village level, livestock mortality due to both predators and diseases, and economic losses due to predation and diseases. Human acceptance and fear were observed against different factors like livestock mortality, disease, economic loss, landscape, district, location, age, education, etc. There were some interesting patterns in human attitudes.

Chapter 9 includes overall conclusion and future implications of the study.

1.7 REFERENCES FOR THE STUDIES PUBLISHED UNDER CHAPTER 2 AND CHAPTER 4

Hameed S, Din Ju, Ali H, Kabir M, Younas M, ur Rehman E, Bari F, Hao W, Bischof R, Ali Nawaz M. (2020) Identifying priority landscapes for conservation of snow leopards in Pakistan. PLoS ONE 15(11): e0228832. https://doi. org/10.1371/journal.pone.0228832.

Hameed S, Ahmad S, Din Ju, and Nawaz MA. (2021) Human perceptions about the Himalayan brown bear and other carnivores in Chitral district in the Hindu Kush Range, Pakistan. Pakistan J. Zool., pp 1-10 https://dx.doi.org/10.17582/journal.pjz/20200909220932.

1.8 REFERENCES

Adriaensen, F., Chardon, J.P., De Blust, G., Swinnen, E., Villalba, S., Gulinck, H., Matthysen, E., 2003. The application of "least-cost" modelling as a functional landscape model. Landsc. Urban Plan. 64. https://doi.org/10.1016/S0169-2046(02)00242-6

Agha, M., Batter, T., Bolas, E.C., Collins, A.C., Gomes da Rocha, D., Monteza-Moreno, C.M., Preckler-Quisquater, S., Sollmann, R., 2018. A review of wildlife camera trapping trends across Africa. Afr. J. Ecol. https://doi.org/10.1111/aje.12565

Ahmad, S., Hameed, S., Ali, H., Khan, T.U., Mehmood, T., Nawaz, M.A., 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-016-1029-6

Alexander, J.S., Cusack, J.J., Pengju, C., Kun, S., Riordan, P., 2016. Conservation of snow leopards: Spill-over benefits for other carnivores? Oryx 50, 239–243. https://doi.org/10.1017/S0030605315001040

Allen, B.L., Allen, L.R., Andrén, H., Ballard, G., Boitani, L., Engeman, R.M., Fleming, P.J.S., Ford, A.T., Haswell, P.M., Kowalczyk, R., Linnell, J.D.C., Mech, L.D., Parker, D.M., 2017. Large carnivore science: non-experimental studies are useful, but experiments are better. Food Webs. https://doi.org/10.1016/j.fooweb.2017.06.002

Alqamy, H.E., 2010. Mammals of Dubai Desert Conservation Reserve: Initial Assessment and Baseline Data. using camera-traps.

Anwar, M.B., Jackson, R., Nadeem, M.S., Janečka, J.E., Hussain, S., Beg, M.A., Muhammad, G., Qayyum, M., 2011. Food habits of the snow leopard Panthera uncia (Schreber, 1775) in Baltistan, Northern Pakistan. Eur. J. Wildl. Res. 57. https://doi.org/10.1007/s10344-011-0521-2

Aryal, A., Brunton, D., Ji, W., Barraclough, R.K., Raubenheimer, D., 2014. Human-carnivore conflict: Ecological and economical sustainability of predation on livestock by snow leopard and other carnivores in the Himalaya. Sustain. Sci. https://doi.org/10.1007/s11625-014-0246-8

Aryal, A., Raubenheimer, D., Sathyakumar, S., Poudel, B.S., Ji, W., Kunwar, K.J., Kok, J., Kohshima, S., Brunton, D., 2012. Conservation strategy for brown bear and its habitat in Nepal. Diversity. https://doi.org/10.3390/d4030301

Bagchi, S., Mishra, C., 2006. Living with large carnivores: Predation on livestock by the snow leopard (Uncia uncia). J. Zool. https://doi.org/10.1111/j.1469-7998.2005.00030.x

Bai, D.F., Chen, P.J., Atzeni, L., Cering, L., Li, Q., Shi, K., 2018. Assessment of habitat suitability of the snow leopard (Panthera uncia) in Qomolangma National Nature Reserve based on MaxEnt modeling. Zool. Res. https://doi.org/10.24272/j.issn.2095-8137.2018.057

Baldwin, R.A., 2009. Use of maximum entropy modeling in wildlife research. Entropy 11, 854–866. https://doi.org/10.3390/e11040854

Balme, G.A., Slotow, R., Hunter, L.T.B., 2010. Edge effects and the impact of non-protected areas in carnivore conservation: Leopards in the Phinda-Mkhuze Complex, South Africa. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2009.00342.x

Bauer, H., 2007. Status of large carnivores in Bouba Ndjida National Park, Cameroon. Afr. J. Ecol. 45. https://doi.org/10.1111/j.1365-2028.2006.00751.x

Beier, P., Penrod, K., Luke, C., Spencer, W., Cabañero, C., 2006. South Coast Missing Linkages: restoring connectivity to wildlands in the largest metropolitan area in the United States. Connect. Conserv. 555–586.

Bellemain, E., Nawaz, M.A., Valentini, A., Swenson, J.E., Taberlet, P., 2007. Genetic tracking of the brown bear in northern Pakistan and implications for conservation. Biol. Conserv. https://doi.org/10.1016/j.biocon.2006.09.004

Bhatnagar, Y.V., Mathur, V., Mccarthy, T., 2001. A regional perspective for snow leopard conservation in the Indian Trans-Himalaya. Natl. Park.

Bibi, S.S., Minhas, R.A., Awan, M.S., Ali, U., Dar, N.I., 2013. Study of ethno-carnivore relationship in Dhirkot, Azad Jammu and Kashmir (Pakistan). J. Anim. Plant Sci.

Boitani, L., 2012. Carnivore Ecology and Conservation: A Handbook of Techniques. Vasa.

Bosso, L., Mucedda, M., Fichera, G., Kiefer, A., Russo, D., 2016. A gap analysis for threatened bat populations on Sardinia. Hystrix. https://doi.org/10.4404/hystrix-27.2-11788

Bruskotter, J.T., Vucetich, J.A., Manfredo, M.J., Karns, G.R., Wolf, C., Ard, K., Carter, N.H., López-Bao, J.V., Chapron, G., Gehrt, S.D., Ripple, W.J., 2017. Modernization, Risk, and Conservation of the World's Largest Carnivores. Bioscience. https://doi.org/10.1093/biosci/bix049

Calabrese, J.M., Fagan, W.F., 2004. A comparison-shopper's guide to connectivity metrics. Front. Ecol. Environ. https://doi.org/10.1890/1540-9295(2004)002[0529:ACGTCM]2.0.CO;2

Carbone, C., Gittleman, J.L., 2002. A common rule for the scaling of carnivore density. Science (80-.). https://doi.org/10.1126/science.1067994

Cardillo, M., Purvis, A., Sechrest, W., Gittleman, J.L., Bielby, J., Mace, G.M., 2004. Human population density and extinction risk in the world's carnivores. PLoS Biol. https://doi.org/10.1371/journal.pbio.0020197

Chapron, G., Miquelle, D.G., Lambert, A., Goodrich, J.M., Legendre, S., Clobert, J., 2008. The impact on tigers of poaching versus prey depletion. J. Appl. Ecol. https://doi.org/10.1111/j.1365-2664.2008.01538.x

Clements, G.R., Rayan, D.M., Aziz, S.A., Kawanishi, K., Traeholt, C., Magintan, D., Yazi, M.F.A., Tingley, R., 2012. Predicting the distribution of the Asian tapir in Peninsular

Malaysia using maximum entropy modeling. Integr. Zool. https://doi.org/10.1111/j.1749-4877.2012.00314.x

Colman, N.J., Gordon, C.E., Crowther, M.S., Letnic, M., 2014. Lethal control of an apex predator has unintended cascading effects on forest mammal assemblages. Proc. R. Soc. B Biol. Sci. https://doi.org/10.1098/rspb.2013.3094

Cook, R.D., Jacobson, J.O., 1979. A Design for Estimating Visibility Bias in Aerial Surveys. Biometrics. https://doi.org/10.2307/2530104

Corlatti, L., Fattorini, L., Nelli, L., 2015. The use of block counts, mark-resight and distance sampling to estimate population size of a mountain-dwelling ungulate. Popul. Ecol. https://doi.org/10.1007/s10144-015-0481-6

Crooks, K.R., Soulé, M.E., 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature. https://doi.org/10.1038/23028

Dai, Y., Hacker, C.E., Zhang, Yuguang, Li, W., Zhang, Yu, Liu, H., Zhang, J., Ji, Y., Xue, Y., Li, D., 2019. Identifying climate refugia and its potential impact on Tibetan brown bear (Ursus arctos pruinosus) in Sanjiangyuan National Park, China. Ecol. Evol. https://doi.org/10.1002/ece3.5780

Damschen, E.I., Haddad, N.M., Orrock, J.L., Tewksbury, J.J., Levey, D.J., 2006. Corridors increase plant species richness at large scales. Science (80-.). 313, 1284–1286. https://doi.org/10.1126/science.1130098

Dar, N.I., Minhas, R.A., Zaman, Q., Linkie, M., 2009. Predicting the patterns, perceptions and causes of human-carnivore conflict in and around Machiara National Park, Pakistan. Biol. Conserv. https://doi.org/10.1016/j.biocon.2009.04.003

DeMatteo, K.E., Carrillo, O., Zuercher, G.L., Ramírez, S., Smith, K., 2004. A technique for attracting bush dogs Speothos venaticus in the wild. Canid News.

Din, U.J., Ali, H., Ali, A., Younus, M., Mehmood, T., Norma-Rashid, Y., Ali Nawaz, M.,

2017. Pastoralist-predator interaction at the roof of the world: Conflict dynamics and implications for conservation. Ecol. Soc. https://doi.org/10.5751/ES-09348-220232

Duchamp, J.E., Yates, M., Muzika, R.-M., Swihart, R.K., 2006. Estimating Probabilities of Detection for Bat Echolocation Calls: An Application of the Double-Observer Method. Wildl. Soc. Bull. https://doi.org/10.2193/0091-7648(2006)34[408:epodfb]2.0.co;2

Efford, M.G., Fewster, R.M., 2013. Estimating population size by spatially explicit capture-recapture. Oikos 122, 918–928. https://doi.org/10.1111/j.1600-0706.2012.20440.x

Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F., R. Leathwick, J., Lehmann, A., Li, J., G. Lohmann, L., A. Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., McC. M. Overton, J., Townsend Peterson, A., J. Phillips, S., Richardson, K., Scachetti-Pereira, R., E. Schapire, R., Soberón, J., Williams, S., S. Wisz, M., E. Zimmermann, N., 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography (Cop.). 29, 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x

Fagan, W.F., Calabrese, J.M., 2010. Quantifying connectivity: balancing metric performance with data requirements, in: Connectivity Conservation. https://doi.org/10.1017/cbo9780511754821.014

Farhadinia, M.S., Johnson, P.J., Hunter, L.T.B., Macdonald, D.W., 2017. Wolves can suppress goodwill for leopards: Patterns of human-predator coexistence in northeastern Iran. Biol. Conserv. https://doi.org/10.1016/j.biocon.2017.07.011

Ferretti, F., Lovari, S., Lucherini, M., Hayward, M., Stephens, P.A., 2020. Only the largest terrestrial carnivores increase their dietary breadth with increasing prey richness. Mammal Review, 50: 291-303.

Ferretti, F., Lovari, S., Minder, I., Pellizzi, B., 2014. Recovery of the snow leopard in

Sagarmatha (Mt. Everest) National Park: Effects on main prey. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-014-0810-7

Forsyth, D.M., Hickling, G.J., 1997. An improved technique for indexing abundance of Himalayan thar. N. Z. J. Ecol.

Fourcade, Y., Engler, J.O., Rödder, D., Secondi, J., 2014. Mapping species distributions with MAXENT using a geographically biased sample of presence data: A performance assessment of methods for correcting sampling bias. PLoS One 9, 1–13. https://doi.org/10.1371/journal.pone.0097122

Fox, J., 1994. Snow leopard conservation in the wild-a comprehensive perspective on a low density and highly fragmented population. Proc. Seventh Int. Snow Leopard Symp. 3–15.

Fox, J.L., 1989. A review of the status and ecology of the snow leopard. Panthera uncia 40.

Frank, L.G., Woodroffe, R., 2001. Behaviour of carnivores in exploited and controlled populations. Carniv. Conserv.

Ghoddousi, A., Bleyhl, B., Sichau, C., Ashayeri, D., Moghadas, P., Sepahvand, P., Kh Hamidi, A., Soofi, M., Kuemmerle, T., 2020. Mapping connectivity and conflict risk to identify safe corridors for the Persian leopard. Landsc. Ecol. https://doi.org/10.1007/s10980-020-01062-0

Gittleman, J.L., Funk, S.M., Macdonald, D.W., Wayne, R.K., 2001. Carnivore conservation. Cambridge: Cambridge University Press.

González, A., Novaro, A., Funes, M., Pailacura, O., Bolgeri, M.J., Walker, S., 2012. Mixed-breed guarding dogs reduce conflict between goat herders and native carnivores in Patagonia. Human-Wildlife Interact. https://doi.org/10.26077/2agv-bw33

Graham, A., Bell, R., 1989. Investigating Observer Bias in Aerial Survey by Simultaneous

Double-Counts. J. Wildl. Manage. https://doi.org/10.2307/3809603

Gross, L., 2008. No place for predators? PLoS Biol. 6, e40.

Guisan, A., Thuiller, W., 2005. Predicting species distribution: Offering more than simple habitat models. Ecol. Lett. https://doi.org/10.1111/j.1461-0248.2005.00792.x

Hacker, C.E., Jevit, M., Hussain, S., Muhammad, G., Munkhtsog, Bariushaa, Munkhtsog, Bayaraa, Zhang, Y., Li, D., Liu, Y., Farrington, J.D., Balbakova, F., Alamanov, A., Kurmanaliev, O., Buyanaa, C., Bayandonoi, G., Ochirjav, M., Liang, X., Bian, X., Weckworth, B., Jackson, R., Janecka, J.E., 2021. Regional Comparison of Snow Leopard (Panthera uncia) Diet using DNA Metabarcoding. Biodivers. Conserv. 30. https://doi.org/10.1007/s10531-021-02118-6

Hameed, S., Ahmad, S., Din, J.U., Nawaz, M.A., 2021. Human perceptions about the Himalayan brown bear and other carnivores in Chitral district in the Hindu Kush Range, Pakistan. Pak. J. Zool.

Hameed, S., Khadim Abbas, Muhammad Younas, Murtaza, G., Mehdi, G., Muhammad Ali Nawaz, 2013. Himalayan Brown Bear in Deosai National Park, Pakistan: Current Status and Threats, International Bear News Fall.

Hameed, S., ud Din, J., Ali, H., Kabir, M., Younas, M., Hao, W., Bischof, R., Nawaz, M.A., 2020. Identifying priority landscapes for conservation of snow leopards in Pakistan. bioRxiv. https://doi.org/10.1101/2020.01.27.920975

Haq, F., Rahatullah, H., 2012. Diversity and population status of Ursus arctos in Pakistan. Int. J. Biosci.

Hargrove, W.W., Hoffman, F.M., Efroymson, R.A., 2005. A practical map-analysis tool for detecting potential dispersal corridors. Landsc. Ecol. 20. https://doi.org/10.1007/s10980-004-3162-y

Hebblewhite, M., Merrill, E.H., McDonald, T.L., 2005. Spatial decomposition of predation risk using resource selection functions: An example in a wolf-elk predator-prey system. Oikos. https://doi.org/10.1111/j.0030-1299.2005.13858.x

Henke, S.E., Knowlton, F.F., 2005. Techniques for Estimating Coyote Abundance. University of Nebraska-Lincoln. Symposium Proceeding-Coyotes in Southwest: A Compendium of Our Knowledge.

Hirata, D., Mano, T., Abramov, A. V., Baryshnikov, G.F., Kosintsev, P.A., Vorobiev, A.A., Raichev, E.G., Tsunoda, H., Kaneko, Y., Murata, K., Fukui, D., Masuda, R., 2013. Molecular phylogeography of the brown bear (*Ursus arctos*) in Northeastern Asia based on analyses of complete mitochondrial DNA sequences. Mol. Biol. Evol. https://doi.org/10.1093/molbev/mst077

Horne, J.S., Garton, E.O., Krone, S.M., Lewis, J.S., 2007. Analyzing animal movements using Brownian bridges. Ecology 88. https://doi.org/10.1890/06-0957.1

Hossain, A.N.M., Barlow, A., Barlow, C.G., Lynam, A.J., Chakma, S., Savini, T., 2016. Assessing the efficacy of camera trapping as a tool for increasing detection rates of wildlife crime in tropical protected areas. Biol. Conserv. https://doi.org/10.1016/j.biocon.2016.07.023

Hussain, S., 2003. The status of the snow leopard in Pakistan and its conflict with local farmers. Oryx 37, 26–33. https://doi.org/10.1017/S0030605303000085

Inskip, C., Fahad, Z., Tully, R., Roberts, T., MacMillan, D., 2014. Understanding carnivore killing behaviour: Exploring the motivations for tiger killing in the Sundarbans, Bangladesh. Biol. Conserv. https://doi.org/10.1016/j.biocon.2014.09.028

Inskip, C., Zimmermann, A., 2009. Human-felid conflict: A review of patterns and priorities worldwide. ORYX. https://doi.org/10.1017/S003060530899030X

Jackson, R., Mallon, D., McCarthy, T., Chundaway, R.A., Habib, B., 2008. Panthera uncia. IUCN Red List Threat. Species.

Jackson, R.M., Hunter, D.O., 1996. Snow leopard survey and conservation handbook. International Snow Leopard Trust.

Jackson, R.M., Mishra, C., McCarthy, T.M., Ale, S.B., 2010. Snow leopards: conflict and conservation. Biol. Conserv. wild felids 417–430. https://doi.org/10.1111/1365-2664.12061

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2006. Estimating snow leopard population abundance using photography and capture-recapture techniques. Wildl. Soc. Bull. 34, 772–781.

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2005. Camera-Trapping of Snow Leopards. Cat News.

Janečka, J.E., Jackson, R., Yuquang, Z., Diqiang, L., Munkhtsog, B., Buckley-Beason, V., Murphy, W.J., 2008. Population monitoring of snow leopards using noninvasive collection of scat samples: A pilot study. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2008.00195.x

Janečka, J.E., Munkhtsog, B., Jackson, R.M., Naranbaatar, G., Mallon, D.P., Murphy, W.J., 2011. Comparison of noninvasive genetic and camera-trapping techniques for surveying snow leopards. J. Mammal. https://doi.org/10.1644/10-MAMM-A-036.1

Japan Bear Network, 2006. Understanding Asian Bears to Secure Their Future, Japan Bear Network.

Jenkins, K.J., Manly, B.F.J., 2008. A double-observer method for reducing bias in faecal pellet surveys of forest ungulates. J. Appl. Ecol. https://doi.org/10.1111/j.1365-2664.2008.01512.x

Johansson, Ö., McCarthy, T., Samelius, G., Andrén, H., Tumursukh, L., Mishra, C., 2015. Snow leopard predation in a livestock dominated landscape in Mongolia. Biol. Conserv. https://doi.org/10.1016/j.biocon.2015.02.003

Kabir, M., Ghoddousi, A., Awan, M.S., Awan, M.N., 2014. Assessment of human-leopard conflict in Machiara National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-013-0782-z

Kabir, M., Hameed, S., Ali, H., Bosso, L., Din, J.U., Bischof, R., Redpath, S., Nawaz, M.A., 2017. Habitat suitability and movement corridors of grey wolf (*Canis lupus*) in Northern Pakistan. PLoS One 12, e0187027.

Karanth, K.U., Nichols, J.D., Kumar, N.S., Jathanna, D., 2011. Estimation of demographic parameters in a tiger population from long-term camera trap data, in: Camera Traps in Animal Ecology: Methods and Analyses. https://doi.org/10.1007/978-4-431-99495-4_9

Karanth, K.U., Nichols, J.D., Kumar, N.S., Link, W.A., Hines, J.E., 2004. Tigers and their prey: Predicting carnivore densities from prey abundance. Proc. Natl. Acad. Sci. U. S. A. 101. https://doi.org/10.1073/pnas.0306210101

Kareiva, P., 2006. Introduction: evaluating and quantifying the conservation dividends of connectivity. Conserv. Biol. Ser. 14, 293.

Kareiva, P., Wennergren, U., 1995. Connecting landscape patterns to ecosystem and population processes. Nature 373, 299–302. https://doi.org/10.1038/373299a0

Karmacharya, D.B., Thapa, K., Shrestha, R., Dhakal, M., Janecka, J.E., 2011. Noninvasive genetic population survey of snow leopards (*Panthera uncia*) in Kangchenjunga conservation area, Shey Phoksundo National Park and surrounding buffer zones of Nepal. BMC Res. Notes. https://doi.org/10.1186/1756-0500-4-516

Kaul, R., 2003. Battles over Nature: Science and the Politics of Conservation. Soc. Change. https://doi.org/10.1177/004908570303300316

Keitt, T.H., T. Urban, D. & Milne, B., 1997. Detecting critical scales in fragmented landscapes: Detecting critical scales in fragmented landscapes. - Conservation Ecology 1. Ecol. Soc. 1.

Khanal, G., Mishra, C., Ramesh Suryawanshi, K., 2020. Relative influence of wild prey and livestock abundance on carnivore-caused livestock predation. Ecol. Evol. https://doi.org/10.1002/ece3.6815

Khatoon, R., Hussain, I., Anwar, M., Nawaz, M.A., 2017. Diet selection of snow leopard (Panthera uncia) in Chitral, Pakistan. Turkish J. Zool. 41. https://doi.org/10.3906/zoo-1604-58

Khorozyan, I., Soofi, M., Ghoddousi, A., Khaleghi Hamidi, A., Waltert, M., 2015. The relationship between climate, diseases of domestic animals and human-carnivore conflicts. Basic Appl. Ecol. https://doi.org/10.1016/j.baae.2015.07.001

Kuiper, T.R., Loveridge, A.J., Parker, D.M., Johnson, P.J., Hunt, J.E., Stapelkamp, B., Sibanda, L., Macdonald, D.W., 2015. Seasonal herding practices influence predation on domestic stock by African lions along a protected area boundary. Biol. Conserv. https://doi.org/10.1016/j.biocon.2015.08.012

Linnell, J.D.C., Swenson, J.E., Andersen, R., 2001. Predators and people: Conservation of large carnivores is possible at high human densities if management policy is favourable. Anim. Conserv. https://doi.org/10.1017/S1367943001001408

Linnell, J.D.C., Swenson, J.E., Kvam, T., Nikus, N., Fagrapport, N., Oppdragsmelding, N., 1998. Methods for monitoring European large carnivores - A worldwide review of relevant experience, NINA Oppdragsmelding.

Long, R.A., Donovan, T.M., Mackay, P., Zielinski, W.J., Buzas, J.S., 2007. Comparing Scat Detection Dogs, Cameras, and Hair Snares for Surveying Carnivores. J. Wildl. Manage. 71. https://doi.org/10.2193/2006-292

Loveridge, A.J., Wang, S.W., Frank, L.G., Seidensticker, J., 2010. People and wild felids: conservation of cats and management of conflicts. Biol. Conserv. Wild Felids.

Lucherini, M., Guerisoli, M. de las M., Luengos Vidal, E.M., 2018. Surplus killing by pumas Puma concolor: rumours and facts. Mamm. Rev.

https://doi.org/10.1111/mam.12135

Ma, M., Xu, F., 2006. Successful camera trapping on snow leopard in the Muzat Valley Tomur Feng Nature Reserve, Xinjiang, P. R. China (in mandarin). Arid L. Geogr. 29, 307–308.

Madhusudan, M.D., Mishra, C., 2003. Why Big, Fierce Animals are Threatened: Conserving Large Mammals in Densely Populated Landscapes, Battles over nature: science and the politics of wildlife conservation.

Maheshwari, A., 2013. Snow leopard (*Panthera uncia*) surveys in the Western Himalayas, India. J. Ecol. Nat. Environ. 5, 303–309. https://doi.org/10.5897/jene2013.0382

McCarthy, K.P., Fuller, T.K., Ming, M., McCarthy, T.M., Waits, L., Jumabaev, K., 2008. Assessing Estimators of Snow Leopard Abundance. J. Wildl. Manage. 72, 1826–1833. https://doi.org/10.2193/2008-040

McCarthy, T., Mallon, D., Jackson, R., Zahler, P., McCarthy, K., 2017. *Panthera uncia*. The IUCN Red List of Threatened Species 2017: e. T22732A50664030.

McCarthy, T.M., Chapron, G., 2003. Snow Leopard Survival Strategy. ISLT and SLN, Seattle, USA.

McLellan, B.N., Proctor, M.F., Huber, D., Michel, S., 2017. Ursus arctos (amended version of 2017 assessment), The IUCN Red List of Threatened Species. IUCN.

McRae, B.H., Beier, P., 2007. Circuit theory predicts gene flow in plant and animal populations. Proc. Natl. Acad. Sci. U. S. A. https://doi.org/10.1073/pnas.0706568104

McRae, B.H., Dickson, B.G., Keitt, T.H., Shah, V.B., 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89, 2712–2724.

McRae, B.H., Shah, V.B., 2009. Circuitscape user's guide. Univ. California, St. Barbar.

Merow, C., Silander, J.A., 2014. A comparison of Maxlike and Maxent for modelling species distributions. Methods Ecol. Evol. https://doi.org/10.1111/2041-210X.12152

Merow, C., Smith, M.J., Silander, J.A., 2013. A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. Ecography (Cop.). 36, 1058–1069. https://doi.org/10.1111/j.1600-0587.2013.07872.x

Miller, J.R.B., Jhala, Y. V., Jena, J., Schmitz, O.J., 2015. Landscape-scale accessibility of livestock to tigers: Implications of spatial grain for modeling predation risk to mitigate human-carnivore conflict. Ecol. Evol. https://doi.org/10.1002/ece3.1440

Minor, E.S., Urban, D.L., 2007. Graph theory as a proxy for spatially explicit population models in conservation planning. Ecol. Appl. 17. https://doi.org/10.1890/06-1073.1

Mishra, C., Madhusudan, M.D., Datta, A., 2006. Mammals of the high altitudes of western Arunachal Pradesh, eastern Himalaya: An assessment of threats and conservation needs. Oryx. https://doi.org/10.1017/S0030605306000032

Moilanen, A., Franco, A.M.A., Early, R.I., Fox, R., Wintle, B., Thomas, C.D., 2005. Prioritizing multiple-use landscapes for conservation: Methods for large multi-species planning problems. Proc. R. Soc. B Biol. Sci. https://doi.org/10.1098/rspb.2005.3164

Moilanen, A., Nieminen, M., 2002. Simple connectivity measures in spatial ecology. Ecology. https://doi.org/10.1890/0012-9658(2002)083[1131:SCMISE]2.0.CO;2

Moseby, K.E., Neilly, H., Read, J.L., Crisp, H.A., 2012. Interactions between a top order predator and exotic mesopredators in the Australian rangelands. Int. J. Ecol. https://doi.org/10.1155/2012/250352

Musiani, M., Mamo, C., Boitani, L., Callaghan, C., Gates, C.C., Mattei, L., Visalberghi, E., Breck, S., Volpi, G., 2003. Wolf Depredation Trends and the Use of Fladry Barriers to Protect Livestock in Western North America, in: Conservation Biology. https://doi.org/10.1111/j.1523-1739.2003.00063.x

Nawaz, M.A., 2007. Status of the brown bear in Pakistan. Ursus.

https://doi.org/10.2192/1537-6176(2007)18[89:SOTBBI]2.0.CO;2

Nawaz, M.A., Martin, J., Swenson, J.E., 2014. Identifying key habitats to conserve the threatened brown bear in the Himalaya. Biol. Conserv. https://doi.org/10.1016/j.biocon.2013.12.031

Nawaz, M.A., Swenson, J.E., Zakaria, V., 2008. Pragmatic management increases a flagship species, the Himalayan brown bears, in Pakistan's Deosai National Park. Biol. Conserv. https://doi.org/10.1016/j.biocon.2008.06.012

Nawaz, M.A., Valentini, A., Khan, N.K., Miquel, C., Taberlet, P., Swenson, J.E., 2019. Diet of the brown bear in Himalaya: Combining classical and molecular genetic techniques. PLoS One. https://doi.org/10.1371/journal.pone.0225698

Network, S.L., 2014. Snow leopard survival strategy. Seattle, Washington, USA 1–145.

Nichols, J.D., Hines, J.E., Sauer, J.R., Fallon, F.W., Fallon, J.E., Heglund, P.J., 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk. https://doi.org/10.2307/4089721

Noss, A.J., Gardner, B., Maffei, L., Cuéllar, E., Montaño, R., Romero-Muñoz, A., O'Connell, A.F., 2012. Comparison of density estimation methods for mammal populations with camera traps in the K aa-I ya del G ran C haco landscape. Anim. Conserv. 15, 527–535.

Nowell, K., Jackson, P., 1996. Wild cats: status survey and conservation action plan. IUCN Gland.

O'Bryan, C.J., Braczkowski, A.R., Beyer, H.L., Carter, N.H., Watson, J.E.M., McDonald-Madden, E., 2018. The contribution of predators and scavengers to human well-being. Nat. Ecol. Evol. https://doi.org/10.1038/s41559-017-0421-2

Odden, J., Herfindal, I., Linnell, J.D.C., Andersen, R., 2008. Vulnerability of Domestic Sheep to Lynx Depredation in Relation to Roe Deer Density. J. Wildl. Manage.

https://doi.org/10.2193/2005-537

Palmeira, F.B.L., Crawshaw, P.G., Haddad, C.M., Ferraz, K.M.P.M.B., Verdade, L.M., 2008. Cattle depredation by puma (*Puma concolor*) and jaguar (*Panthera onca*) in central-western Brazil. Biol. Conserv. https://doi.org/10.1016/j.biocon.2007.09.015

Phillips, S.J., 2008. Transferability, sample selection bias and background data in presence-only modelling: a response to Peterson et al. (2007). Ecography (Cop.). https://doi.org/10.1111/j.2007.0906-7590.05378.x

Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Modell. 190, 231–259.

Phillips, S.J., Dudík, M., 2008. Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation. Ecography (Cop.). https://doi.org/10.1111/j.0906-7590.2008.5203.x

Polis, G.A., Strong, D.R., 1996. Food web complexity and community dynamics. Am. Nat. https://doi.org/10.1086/285880

Quang, P.X., Becker, E.F., 1997. Combining Line Transect and Double Count Sampling Techniques for Aerial Surveys. J. Agric. Biol. Environ. Stat. https://doi.org/10.2307/1400405

Radosavljevic, A., Anderson, R.P., 2014. Making better Maxent models of species distributions: Complexity, overfitting and evaluation. J. Biogeogr. https://doi.org/10.1111/jbi.12227

Rao, A.L., Marwat, A.H., 2003. NASSD Background Paper: Forestry. IUCN Pakistan, Northern Areas Progamme, Gilgit.

Renner, I.W., Warton, D.I., 2013. Equivalence of MAXENT and Poisson Point Process Models for Species Distribution Modeling in Ecology. Biometrics 69, 274–281. https://doi.org/10.1111/j.1541-0420.2012.01824.x

Rich, L.N., Russell, R.E., Glenn, E.M., Mitchell, M.S., Gude, J.A., Podruzny, K.M., Sime, C.A., Laudon, K., Ausband, D.E., Nichols, J.D., 2013. Estimating occupancy and predicting numbers of gray wolf packs in Montana using hunter surveys. J. Wildl. Manage. https://doi.org/10.1002/jwmg.562

Ricketts, T.H., 2001. The matrix matters: Effective isolation in fragmented landscapes. Am. Nat. 158, 87–99. https://doi.org/10.1086/320863

Ripple, W.J., Beschta, R.L., 2006. Linking a cougar decline, trophic cascade, and catastrophic regime shift in Zion National Park. Biol. Conserv. https://doi.org/10.1016/j.biocon.2006.07.002

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., Schmitz, O.J., Smith, D.W., Wallach, A.D., Wirsing, A.J., 2014. Status and ecological effects of the world's largest carnivores. Science (80-.). https://doi.org/10.1126/science.1241484

Ritchie, E.G., Johnson, C.N., 2009. Predator interactions, mesopredator release and biodiversity conservation. Ecol. Lett. https://doi.org/10.1111/j.1461-0248.2009.01347.x

Roberts, T.J., d'Olanda.), B. (principe, 1977. The mammals of Pakistan.

Royle, J.A., Chandler, R.B., 2014. Spatial Capture-Recapture. Spat. Capture-recapture iii. https://doi.org/10.1016/B978-0-12-405939-9.00022-0

Royle, J.A., Chandler, R.B., Sollmann, R., Gardner, B., 2014. Spatial Capture-Recapture. https://doi.org/10.1016/B978-0-12-405939-9.00020-7

Schaller, G.B., 1979. Mountain monarchs. wild sheep and goats of the himalaya. The University of Chicago Press, Chicago and London, xviii + 425 pp., illus., 1977. J. Mammal. 60, 240–241. https://doi.org/10.2307/1379791

Schaller, G.B., 1976. Mountain Mammals in Pakistan. Oryx.

https://doi.org/10.1017/S0030605300014071

Schumaker, N.H., 1996. Using landscape indices to predict habitat connectivity. Ecology 77. https://doi.org/10.2307/2265590

Sergio, F., Caro, T., Brown, D., Clucas, B., Hunter, J., Ketchum, J., McHugh, K., Hiraldo, F., 2008. Top predators as conservation tools: Ecological rationale, assumptions, and efficacy. Annu. Rev. Ecol. Evol. Syst. https://doi.org/10.1146/annurev.ecolsys.39.110707.173545

Servheen, C., Herrero, S., Peyton, B., 1999. Status Survey and Conservation Action Plan for Bears. IUCN/SSC Bear and Polar Bear Specialist Groups. Gland. Switz. Cambridge, UK.

Shah, V.B., McRae, B.H., 2008. Circuitscape : A Tool for Landscape Ecology. Proc. 7th Python Sci. Conf. https://doi.org/10.1111/j.1523-1739.2008.00942.x

Sharma, K., Bayrakcismith, R., Tumursukh, L., Johansson, O., Sevger, P., McCarthy, T., Mishra, C., 2014. Vigorous dynamics underlie a stable population of the endangered snow leopard Panthera uncia in Tost Mountains, South Gobi, Mongolia. PLoS One 9. https://doi.org/10.1371/journal.pone.0101319

Sharma, K., Borchers, D., Mackenzie, D., Durbach, I., Sutherland, C., Nichols, J.D., Lovari, S., Zhi, L., Khan, A.A., Modaqiq, W., McCarthy, T.M., Alexander, J.S., Mishra, C., 2019. Guidelines for estimating snow leopard abundance and distribution using a combination of spatial capture-recapture and occupancy models. Submitted to the Steering Committee of the Global Snow Leopard and Ecosystem Protection Program; with financial suppor.

Sheehan, K.L., Esswein, S.T., Dorr, B.S., Yarrow, G.K., Johnson, R.J., 2017. Using species distribution models to define nesting habitat of the eastern metapopulation of double-crested cormorants. Ecol. Evol. https://doi.org/10.1002/ece3.2620

Sheikh, K., Molur, S., 2005. Status and red list of Pakistan's mammals, based on conservation assessment and management plan for mammals. IUCN, Pakistan 344.

Siira, A., Keranen, J., Kojola, I., 2009. Large carnivores snow-tracking counting in Kainuu 2008. Riista- ja kalatalous- Tutkimuksia. 30 p.

Smeraldo, S., Di Febbraro, M., Ćirović, D., Bosso, L., Trbojević, I., Russo, D., 2017. Species distribution models as a tool to predict range expansion after reintroduction: A case study on Eurasian beavers (*Castor fiber*). J. Nat. Conserv. https://doi.org/10.1016/j.jnc.2017.02.008

Smith, J.B., Nielsen, C.K., Hellgren, E.C., 2014. Illinois resident attitudes toward recolonizing large carnivores. J. Wildl. Manage. https://doi.org/10.1002/jwmg.718

Snow Leopard Working Secretariat, 2013. Global Snow Leopard and Ecosystem Protection Program Bishkek, Kyrgyz Republic. Kyrg. Repub. 92.

Sollmann, R., Gardner, B., Belant, J.L., 2012. How does spatial study design influence density estimates from spatial capture-recapture models? PLoS One 7. https://doi.org/10.1371/journal.pone.0034575

Soofi, M., Ghoddousi, A., Zeppenfeld, T., Shokri, S., Soufi, M., Egli, L., Jafari, A., Ahmadpour, M., Qashqaei, A., Ghadirian, T., Filla, M., Kiabi, B., Balkenhol, N., Waltert, M., Khorozyan, I., 2019. Assessing the relationship between illegal hunting of ungulates, wild prey occurrence and livestock depredation rate by large carnivores. J. Appl. Ecol. https://doi.org/10.1111/1365-2664.13266

Soto-Shoender, J.R., Main, M.B., 2013. Differences in stakeholder perceptions of the jaguar Panthera onca and puma Puma concolor in the tropical lowlands of Guatemala. ORYX. https://doi.org/10.1017/S003060531200107X

Stier, A.C., Samhouri, J.F., Novak, M., Marshall, K.N., Ward, E.J., Holt, R.D., Levin, P.S., 2016. Ecosystem context and historical contingency in apex predator recoveries. Sci. Adv. https://doi.org/10.1126/sciadv.1501769

Su, J., Aryal, A., Hegab, I.M., Shrestha, U.B., Coogan, S.C.P., Sathyakumar, S., Dalannast, M., Dou, Z., Suo, Y., Dabu, X., Fu, H., Wu, L., Ji, W., 2018. Decreasing brown bear (Ursus arctos) habitat due to climate change in Central Asia and the Asian Highlands. Ecol. Evol. https://doi.org/10.1002/ece3.4645

Summers, D.M., Bryan, B.A., Crossman, N.D., Meyer, W.S., 2012. Species vulnerability to climate change: Impacts on spatial conservation priorities and species representation. Glob. Chang. Biol. 18, 3268. https://doi.org/10.1111/j.1365-2486.2012.02771.x

Suryawanshi, K.R., Bhatnagar, Y.V., Mishra, C., 2012. Standardizing the double-observer survey method for estimating mountain ungulate prey of the endangered snow leopard. Oecologia. https://doi.org/10.1007/s00442-011-2237-0

Suryawanshi, K.R., Redpath, S.M., Bhatnagar, Y.V., Ramakrishnan, U., Chaturvedi, V., Smout, S.C., Mishra, C., 2017. Impact of wild prey availability on livestock predation by snow leopards. R. Soc. Open Sci. https://doi.org/10.1098/rsos.170026

Swann, D., Perkins, N., 2014. Camera Trapping for animal monitoring and management: a review of applications. Camera Trapp. Wildl. Manag. Res.

Syfert, M.M., Smith, M.J., Coomes, D.A., 2013. The Effects of Sampling Bias and Model Complexity on the Predictive Performance of MaxEnt Species Distribution Models. PLoS One 8. https://doi.org/10.1371/journal.pone.0055158

Terborgh, J., Estes, J., Paquet, P., Ralls, K., Boyd-Heger, D., Miller, B., Noss, R., 1999. The Role of Top Carnivores in Regulating Terrestrail Ecosystems, in: Continental Conservation: Scientific Foundations of Regional Reserve Networks.

Thorn, M., Green, M., Scott, D., Marnewick, K., 2013. Characteristics and determinants of human-carnivore conflict in South African farmland. Biodivers. Conserv. https://doi.org/10.1007/s10531-013-0508-2

Treves, A., Karanth, K.U., 2003. Human-Carnivore Conflict and Perspectives on Carnivore

Management Worldwide, in: Conservation Biology. https://doi.org/10.1111/j.1523-1739.2003.00059.x

Tyre, A.J., Tenhumberg, B., Field, S.A., Niejalke, D., Parris, K., Possingham, H.P., 2003. Improving precision and reducing bias in biological surveys: Estimating false-negative error rates. Ecol. Appl. 13, 1790–1801. https://doi.org/10.1890/02-5078

Ugarte, C.S., Moreira-Arce, D., Simonetti, J.A., 2019. Ecological Attributes of Carnivore-Livestock Conflict. Front. Ecol. Evol. https://doi.org/10.3389/fevo.2019.00433

Urban, D., Keitt, T., 2001. Landscape connectivity: A graph-theoretic perspective. Ecology 82. https://doi.org/10.1890/0012-9658(2001)082[1205:LCAGTP]2.0.CO;2

Václavík, T., Meentemeyer, R.K., 2009. Invasive species distribution modeling (iSDM): Are absence data and dispersal constraints needed to predict actual distributions? Ecol. Modell. https://doi.org/10.1016/j.ecolmodel.2009.08.013

Walpole, A.A., Bowman, J., Murray, D.L., Wilson, P.J., 2012. Functional connectivity of lynx at their southern range periphery in Ontario, Canada. Landsc. Ecol. https://doi.org/10.1007/s10980-012-9728-1

Walsh, P., Reynolds, J., Collins, G., Russell, B., Winfree, M., Denton, J., 2010. Application of a double-observer aerial line-transect method to estimate brown bear population density in Southwestern Alaska. J. Fish Wildl. Manag. https://doi.org/10.3996/JFWM-006

Wearn, R., Glover-Kapfer, P., 2017. Camera-trapping for conservation: a guide to best-practices, WWF Conservation Technology Series 1(1).

Weise, F.J., Hayward, M.W., Casillas Aguirre, R., Tomeletso, M., Gadimang, P., Somers, M.J., Stein, A.B., 2018. Size, shape and maintenance matter: A critical appraisal of a global carnivore conflict mitigation strategy – Livestock protection kraals in northern Botswana. Biol. Conserv. https://doi.org/10.1016/j.biocon.2018.06.023

Williams, B.K., Nichols, J.D., Conroy, M.J., 2002. Analysis and management of animal populations : modeling, estimation, and decision making, Academic Press San Diego California USA.

Wilting, A., Cord, A., Hearn, A.J., Hesse, D., Mohamed, A., Traeholdt, C., Cheyne, S.M., Sunarto, S., Jayasilan, M.A., Ross, J., Shapiro, A.C., Sebastian, A., Dech, S., Breitenmoser, C., Sanderson, J., Duckworth, J.W., Hofer, H., 2010. Modelling the species distribution of flat-headed cats (*Prionailurus planiceps*), an endangered South-East Asian small felid. PLoS One. https://doi.org/10.1371/journal.pone.0009612

Wingard, J., Zahler, P., Victurine, R., Bayasgalan, O., Bayarbaatar, B., 2015. Guidelines for Addressing the Impact of Linear Infrastructure on Migratory Large Mammals in Central Asia. C. Conv. Migr. Species.

Wolf, C., Ripple, W.J., 2016. Prey depletion as a threat to the world's large carnivores. R. Soc. Open Sci. https://doi.org/10.1098/rsos.160252

Woodroffe, R., 2001. Assessing the risks of intervention: Immobilization, radio-collaring and vaccination of African wild dogs. ORYX. https://doi.org/10.1046/j.1365-3008.2001.00186.x

Woodroffe, R., Frank, L.G., 2005. Lethal control of African lions (*Panthera leo*): Local and regional population impacts. Anim. Conserv. https://doi.org/10.1017/S1367943004001829

Woodroffe, R., Frank, L.G., Lindsey, P.A., Ole Ranah, S.M.K., Romañach, S., 2007. Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: A case-control study. Biodivers. Conserv. https://doi.org/10.1007/s10531-006-9124-8

Woodroffe, R., Thirgood, S., Rabinowitz, A., 2005. People and Wildlife, Conflict or Co-existence? Cambridge: Cambridge University Press.

Zahler, P., 2016. Linear infrastructure and snow leopard conservation. In: T. McCarthy and D. Mallon (eds), Snow Leopards. Elsevier, New York

Zhang, Yu, Clauzel, C., Li, J., Xue, Y., Zhang, Yuguang, Wu, G., Giraudoux, P., Li, L., Li, D., 2019. Identifying refugia and corridors under climate change conditions for the Sichuan snub-nosed monkey (*Rhinopithecus roxellana*) in Hubei Province, China. Ecol. Evol. https://doi.org/10.1002/ece3.4815

Zhou, X., Chong, J., Yang, X., Li, W., Guo, X., 2017. Ocean Surface Wind Retrieval Using SMAP L-Band SAR. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 10, 65–74. https://doi.org/10.1109/JSTARS.2016.2630919

ECOLOGY AND CONFLICT DYNAMICS OF APEX PREDATORS IN NORTHERN PAKISTAN

CHAPTER 2

Identifying Priority Landscapes for Conservation of Snow Leopards in Pakistan

2 Identifying Priority Landscapes for Conservation of Snow Leopards in Pakistan

ABSTRACT

Pakistan's total estimated snow leopard habitat is about 80,000 km^2 of which about half is considered prime habitat. However, this preliminary demarcation was not always in close agreement with the actual distribution—the discrepancy may be huge at the local and regional level. Recent technological developments like camera trapping and molecular genetics allow for collecting reliable presence records that could be used to construct realistic species distribution based on empirical data and advanced mathematical approaches like MaxEnt. The current study followed this approach to construct an accurate distribution of the species in Pakistan. Moreover, movement corridors, among different landscapes, were also identified through circuit theory. The probability of habitat suitability, generated from 98 presence points and 11 environmental variables, scored the snow leopard's assumed range in Pakistan, from 0 to 0.97. A large portion of the known range represented low-quality habitat, including areas in lower Chitral, Swat, Astore, and Kashmir. Conversely, Khunjerab, Misgar, Chapursan, Qurumber, Broghil, and Central Karakoram represented high-quality habitats. Variables with higher contributions in the MaxEnt model were precipitation during the driest month (34%), annual mean temperature (19.5%), mean diurnal range of temperature (9.8%), annual precipitation (9.4%), and river density (9.2). The model was validated through receiver operating characteristic (ROC) plots and defined thresholds. The average test AUC in Maxent for the replicate runs was 0.933 while the value of AUC by ROC curve calculated at 0.15 threshold was 1.00. These validation tests suggested a good model fit and strong predictive power.

The connectivity analysis revealed that the population in the Hindukush landscape appears to be more connected with the population in Afghanistan as compared to other populations in Pakistan. Similarly, the Pamir-Karakoram population is better connected with China and Tajikistan, while the Himalayan population was connected with the population in India.

Based on our findings we propose three model landscapes to be considered under the Global Snow Leopard Ecosystem Protection Program (GSLEP) agenda as regional priority areas, to safeguard the future of the snow leopard in Pakistan and the region. These landscapes fall within mountain ranges of the Himalayas, Hindu Kush and Karakoram-Pamir, respectively. We also identified gaps in the existing protected areas network and suggest new protected areas in Chitral and Gilgit-Baltistan to protect critical habitats of snow leopard in Pakistan.

Keywords: snow leopard, species distribution, habitat suitability, movement corridor, maxent, circuitscape, model landscape.

2.1 INTRODUCTION

The snow leopard, *Panthera uncia,* has attained an iconic status worldwide and is treated as a flagship species of the Greater Himalayan ecosystem (Alexander et al., 2016). The species is native to the mountain ranges of Central and Southern Asia—some of the world's most rugged landscapes (Bhatnagar et al., 2001; Jackson et al., 2008; Network, 2014). It occurs in the Hindu Kush, Karakoram, Altai, Sayan, Tien Shan, Kunlun, Pamir, and outer Himalayan ranges, and smaller isolated mountains in the Gobi region (Hussain, 2003; Nowell and Jackson, 1996; Schaller, 1976). Estimates of global range size vary from 1.2 million to over 3 million km^2 (Network, 2014) and the species is highly threatened throughout its range. A recent study estimated its occupied range to be about 2.8 million km^2 (McCarthy et al., 2017), across 12 countries—Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan, and Uzbekistan (Fox, 1994; Jackson and Hunter, 1996; Maheshwari, 2013). The potential range of snow leopard may also extend to northern Myanmar, but recent snow leopard presence in this area has not been confirmed (Network, 2014).

Pakistan's total estimated snow leopard habitat according to Roberts and d'Olanda (1977) range maps is approximately 80,000 km^2, and about half of it is considered prime habitat (Fox, 1989). However, this preliminary evaluation of the snow leopard's distribution is based on expert judgments, anecdotal information and topography. Consequently, these distribution maps are not always in close agreement with the actual distribution—the discrepancy may be large at the regional and global levels (Fox, 1994). Accurate modelling of the geographic distribution of species is crucial for various applications in ecology and conservation (Fourcade et al., 2014; Phillips and Dudík, 2008; Renner and Warton, 2013). Conservationists often need precise assessments of species' ranges and current species distribution patterns. Furthermore, the range description is essential, but concrete identification of factors that restrict distributions is also critical to support conservation management (Yackulic et al., 2013).

It is important to be aware of the variables constraining or facilitating species' occurrence to avoid under-prediction or over-prediction of its distribution or habitat suitability (Baldwin, 2009) and much of these data are readily available, in the form of digital elevation models (https://www.usgs.gov) and global databases of climate (https://www.worldclim.org), productivity, and human impacts/infrastructure (http://www.fao.org). Ecological niche models (ENMs) and species distribution models (SDMs) are increasingly being used to map potential distributions of species (Fourcade et al., 2014; Peterson, 2006; Syfert et al., 2013). These models incorporate species occurrence data with climatic and environmental variables to develop distribution maps of species (Bentlage et al., 2013). During this process, the models may also estimate species-specific environmental suitability across a given spatial extent (Phillips and Dudík, 2008). Information about species distribution and habitat suitability can in turn be used to design scientific surveys and plan conservation interventions (Reddy et al., 2015).

Many models like BIOCLIM, BLOMAPPER, DIVA, DOMAIN, CLIMEX, GAM, GLM, and GARP have been used in species distribution modelling (Elith et al., 2006; Guisan and Thuiller, 2005; Kriticos and Randall, 2001; Phillips et al., 2004; Sun and Liu, 2010), but Maximum Entropy (MaxEnt) model is widely used in habitat suitability modeling due to its accuracy, additional descriptive properties (Bai et al., 2018) and better predictive functions (Kumar et al., 2014). MaxEnt estimates the probability of the presence of a species based on occurrence records and randomly generates background points by finding the maximum entropy distribution (Phillips et al., 2006; Reddy et al., 2015). These models can use either presence/absence data or presence-only data. The use of presence/absence data in wildlife management and biological surveys is widespread (Tyre et al., 2003). However, species absence data are often not available or believed to be too difficult to interpret (Václavík and Meentemeyer, 2009). Nevertheless, SDMs trained on presence-only data are frequently used in ecological research and conservation planning (Bai et al., 2018; Syfert et al., 2013). Presence-based modelling methods only require a set of known occurrences together with predictor variables such as topographic, climatic and biogeographic variables (Phillips, 2008).

Connectivity among habitats and populations is another critical factor that influences a variety of ecological phenomena, including gene flow, metapopulation dynamics, demographic rescue, seed dispersal, infectious disease spread, range expansion, exotic invasion, population persistence, and maintenance of biodiversity (Calabrese and Fagan, 2004; Damschen et al., 2006; Fagan and Calabrese, 2010; Kareiva and Wennergren, 1995; Moilanen et al., 2005; Moilanen and Nieminen, 2002; Ricketts, 2001). Preserving and restoring connectivity is one of the top conservation priorities and conservation organizations are devoting substantial resources to accomplish these goals (Beier et al., 2006; Kareiva, 2006). A reliable, efficient, and process-based approach is required to achieve this objective in complex landscapes. A new class of ecological connectivity models based on electrical circuit theory was introduced by McRae et al. (2008). Resistance, current and voltage calculated across graphs or raster grids can be associated with ecological processes like: individual movement and gene flow, that take place across large population networks or landscapes.

Given the multitude of threats to snow leopards and their habitat, it is imperative that comprehensive landscape-level conservation strategies be developed that are based on reliable information on species survival requirements. A global strategy to safeguard snow leopards and the vast ecosystem they inhabit—which includes 12 nations and supports 1 billion people—has already been established: The Global Snow Leopard Ecosystem Protection Program (GSLEP). Its overall aim was to secure at least 20 snow leopard model landscapes across the species' range by 2020 (Zakharenka et al., 2016). Under the GSLEP initiative, the selection of model landscapes requires a clear understanding of areas that represent the species' prime habitat so that conservation efforts in the next decade can focus on securing areas that hold or have the potential to hold larger populations; at least 100 breeding age snow leopards. Recent technological developments, like camera trapping (Plate 2.1) and molecular genetics, allow for the collection of reliable presence records across large spatial expanses that could be used to construct realistic species distribution maps. Relying on these technologies, this study aimed to support the GSLEP initiative by identifying core habitats and movement corridors of snow leopard in Pakistan.

Plate 2.1. Photo of an adult snow leopard taken with a camera trap in Hopper-Hisper Valley in northern Pakistan during non-invasive surveys in 2016.

2.2 MATERIALS AND METHODS

2.2.1 Study Area

The study focused on the known snow leopard range in Pakistan (Fox, 1989; Roberts and d'Olanda), 1977) which encompasses four high mountain ranges, i.e., Himalayas, Karakoram, Pamir and Hindu Kush spread across three administrative units, i.e. Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and Azad Jammu and Kashmir (AJK). Targeting major protected areas and other potentially suitable habitats, I surveyed 20 sites with a collective area of around 31,000 km^2 (Figure 2.1). The surveyed areas constitute 39% of reported snow leopard habitat in Pakistan (80,000 km^2) (Figure 2.1) (McCarthy and Chapron, 2003).

High altitudes and sub-zero temperatures made our study area one of the most heavily glaciated parts of the world, outside the Polar Regions. The Western Himalayan Range is situated in AJK and GB to the south and east of the Indus River. The Hindukush rise southwest of the Pamirs. The Karakoram Range covers the borders between three countries in the regions of GB in Pakistan, Ladakh in India, and the

Xinjiang region in China. They are considered to extend from the Wakhjir Pass at the junctions of the Pamirs and Karakoram to the Khawak Pass north of Kabul. The mountains of Pakistan are relatively denser human settlements harsh geographic and climatic conditions. Nevertheless, the special ecological conditions and remoteness of these mountainous areas also support unique biodiversity of plants and animals. Climatic conditions vary widely across the study area, ranging from the monsoon-influenced moist temperate zone in the western Himalayas to the semi-arid cold deserts of the northern Karakorum and Hindu Kush. Four vegetation zones can be differentiated along with the altitudinal ascents: alpine dry steppes, subalpine scrub zones, alpine meadows, and permanent snowfields. Various rare and endangered animals occur in the study area, including the snow leopard (*Panthera uncia*), grey wolf (*Canis lupus*), brown bear (*Ursus arctos*), Asiatic black bear (*Ursus thibetanus*), Himalayan lynx (*Lynx lynx*), Himalayan Ibex (*Capra ibex sibirica*), blue sheep (*Pseudois nayaur*), flare-horned markhor (*Capra falconeri. cashmirensis*), musk deer (*Moschus chrysogaster*), Marco Polo sheep (*Ovis ammon polii*), Ladakh urial (*Ovis vignei*), Pallas's cat (*Otocolobus manul*) and woolly flying squirrel (*Eupetaurus cinereus*).

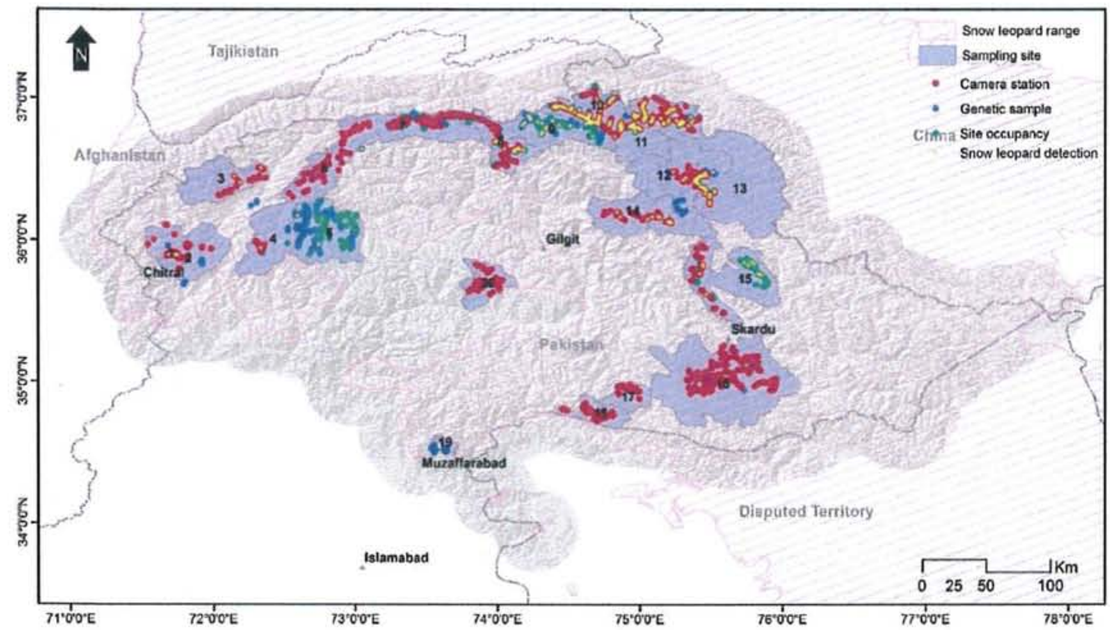


Figure 2.1. Map of study area showing sampling sites and IUCN range of snow leopard in Pakistan. 1=Chitral Gol National Park, 2=Chitral and Surrounding-Tooshi, 3= Terich, 4= Laspur, 5= Phandar, 6= Yarkhun, 7= Broghil National Park, 8= Qurumber National Park, 9=Chapursan, 10= Misgar, 11= KVO-Sukhtarabad, 12= Shimshal, 13= Khunjerab National

Park, 14= Hoper-Hisper, 15= Basha-Arandu, 16, Deosai National Park and surroundings, 17= Kalapani-Astore, 18= Musk Deer National Park, 19= Machiara National Park, 20= Khanbari.

2.2.2 Data Collection

Presence records were collected using three methods: camera trapping, sign surveys and genetic sampling. Camera trapping is being increasingly adopted for the monitoring of shy and rare wildlife (Jackson et al., 2006; Kabir et al., 2017; Karanth and Nichols, 1998). We deployed 806 camera stations in Chitral Gol National Park (CGNP), the buffer areas of CGNP and Tooshi Game Reserve (TGR), Laspur Valley, Khunjerab National Park (KNP), Shimshal, Khunjerab Villagers Organization (KVO) area, Qurumber National Park, Broghil National Park, Deosai National Park, Yarkhun Valley, Misgar, Kalapani-Astore, Musk Deer National Park, Khanbari Valley, Terich Valley, Hopper-Hisper, Basha-Arandu and buffer areas of Central Karakoram National Park (CKNP), during the period 2006–2017 (Figure 2.1). These cameras remained active for 23,133 trap-days in the field with an average of 28.7 ± 15.6 (SD) days per camera. The camera brands used were CamTrakker™ (Ranger, Watkinsville, GA, USA) and ReconyxTM (HC500 HyperfireTM and PC900 HyperfireTM; Reconyx, Holmen, Wisconsin, USA). The sites for camera installation were selected near tracks, scrapes, scats, and other snow leopard signs. A minimum aerial distance of 1 km was kept between the two nearest camera stations. Installation and setup followed guidelines provided by Jackson et al. (2006). Detail of camera station was recorded (APPENDIX 2.1). The majority of the camera stations were supplied with a different type of lures—castor, skunk, and fish oil—to enhance capture probability (Bischof et al., 2014).

Site Occupancy based sign surveys were conducted in KNP-KVO-Shimshal, Qurumber-Broghil national parks, Misgar-Chapursan, Phandar Valley and Basha-Arandu from 2010 to 2017. Each study area was divided into small grids cells of 5 × 5 km—except in KNP-KVO-Shimshal where we kept grid size to 10 × 10 km on GIS maps. Each grid cell (site) was approached by GPS and multiple points were led to search the signs for snow leopards. A total of 193 sites with 1,607 repeat survey points were searched for signs of snow leopards (Figure 2.1). The presence was detected through five types of signs (scrapes, pugmarks, faeces, scent spray, and claw marks). However, in this analysis, we only included scrapes and pugmarks to confirm snow leopard presence, as these are considered as the most reliable (Elith et al., 2011). All the details were recorded on survey sheet (APPENDIX 2.2)

Faecal samples were collected from 2009 to 2013 during the sign and camera trap surveys. We collected over 1,000 faecal samples of all carnivore species (Figure 2.1) encountered in the field and preserved them in 95% alcohol in 20 ml bottles. The details of scats and locations were recorded (APPENDIX 3.3) The DNA extraction was performed in Laboratoire d'Ecologie Alpine, Université Joseph Fourier, France: a laboratory dedicated to the extraction of degraded DNA. Total DNA was extracted from c. 15 mg of faeces using the DNeasy Blood and Tissue Kit (QIAgen GmbH, Hilden, Germany) following the maker's guidelines with a small modification following Shehzad et al. (2012b). Blank extractions were performed to scrutinize contamination. Species identification was performed through next-generation sequencings (NGS) by amplifying DNA extract using primer pair 12SV5F (5'-TAGAACAGGCTCCTCTAG-3') and 12SV5R (5'- TTAGATACCC CACTATGC-3' targeting about 100-bp of the V5 loop of the mitochondrial 12S gene (Kabir et al., 2017; Shehzad et al., 2012b) The sequence analysis and taxon assignation were done using OBITools as described in Shehzad et al. (2012a, 2012b).

Snow Leopard Foundation signed Memorandum of Understating (MoU) with the Provincial Wildlife Departments, which legally allowed for doing research in the national parks and other habitats.

2.2.3 Data Analysis

We used MaxEnt 3.3.3k (Phillips et al., 2006) to predict snow leopard distribution in Pakistan. MaxEnt predicts species distribution, using presence-only data and environmental variables, and estimates species' probability distribution by finding the probability distribution of maximum entropy, i.e. the most spread out or closest to uniform, subject to a set of constraints; mainly the possibility of over-fitting which limits the capacity of the model to generalize well to independent data (Phillips et al., 2006). It is amongst the most popular species distribution modelling methods with more than 1,000 published usages since 2005(Fourcade et al., 2014; Merow et al., 2013). MaxEnt has also surpassed other methods and exhibited higher predictive accuracy (Elith et al., 2006; Summers et al., 2012).

We used a random seed option and kept 25% of data for random tests—25 replicates were run with typeset as a subsample. The rest of the settings were kept as default, which included a maximum of 10,000 randomly generated background points, 5,000 maximum iterations with a convergence threshold of 0.00001, and a regularization multiplier of 1.

1. Data Preparation

We used snow leopard range with an added buffer of 30 km to model prediction using MaxEnt. All environmental layers were converted to the same size (extent) and resolution, i.e. 1 × 1 km. Snow leopard occurrence points were also converted into a grid file. All environmental variables and presence points were then converted into ASCII files as required by MaxEnt, by using the 'conversion' tool in Arc GIS 10.2. Features in Maxent are derived from two types of environmental variables: continuous and categorical (Phillips, 2008).

We considered 28 variables initially (Table 2.1), but removed highly correlated variables from the analysis, using Pearson correlation matrix (Booth et al., 1994). After multicollinearity test, 11 environmental variables were retained ($r < 0.70$), including 4 bioclimatic variables (bio1, bio2, bio12, and bio14), distances from the river, roads and settlements, slope, ruggedness, soil, and a normalized difference vegetation index (NDVI) (Kabir et al., 2017). Bioclimatic variables were derived from the mean temperature, minimum temperature, maximum temperature, and precipitation to generate more biologically meaningful variables—these are often used in ecological niche modelling. Details of each variable used, and their sources are shown in Table 2.1. Records obtained via sign surveys, genetic sampling, and camera trapping were screened in SDMtoolbox, a tool of GIS, to remove spatially correlated data points, located within 5 km of each other, to guarantee independence (Aryal et al., 2016; Boria et al., 2014; Brown, 2014). After this selection, 98 unrelated locations were used in the analysis.

Table 2.1. List of environmental variables used in MaxEnt modelling

Environmental variable	Interpretation	Source
bio1	Annual mean temperature	http://www.worldclim.org

bio2	Mean diurnal range (mean of monthly [max temp - min temp])	http://www.worldclim.org
bio3	Isothermality (Bio2/Bio7) (* 100)	http://www.worldclim.org
bio4	Temperature seasonality (standard deviation *100)	http://www.worldclim.org
bio5	Max temperature of warmest month	http://www.worldclim.org
bio6	Min temperature of coldest month	http://www.worldclim.org
bio7	Temperature annual range (bio5-bio6)	http://www.worldclim.org
bio8	Mean temperature of wettest quarter	http://www.worldclim.org
bio9	Mean temperature of driest quarter	http://www.worldclim.org
bio10	Mean temperature of warmest quarter	http://www.worldclim.org
bio11	Mean temperature of coldest quarter	http://www.worldclim.org
bio12	Annual precipitation	http://www.worldclim.org
bio13	Precipitation of wettest month	http://www.worldclim.org
bio14	Precipitation of driest month	http://www.worldclim.org
bio15	Precipitation seasonality (coefficient of variation)	http://www.worldclim.org
bio16	Precipitation of wettest quarter	http://www.worldclim.org
bio17	Precipitation of driest quarter	http://www.worldclim.org
bio18	Precipitation of warmest quarter	http://www.worldclim.org
bio19	Precipitation of coldest quarter	http://www.worldclim.org
alt	elevation above sea level (m)	SRTM
Slope	Slope of the area	derived from alt in Arc GIS 10.2
River	Density of rivers (m)	calculated in Arc GIS 10.2
Road	Density of roads (m)	calculated in Arc GIS 10.2
Settlement	Density of settlements (m)	calculated in Arc GIS 10.2
ndvi (MODIS)	Normalized difference vegetation index	NASA: http://modis-land.gsfc.nasa.gov/vi.html
Soil	Digital soil map of the world	FAO, 2003
Vrmint	Vector ruggedness measure	Generated from SRTM 90m DEM by the Center for Nature and Society, Peking University using the Terrain Ruggedness (VRM) Tool
glc2000	Global landcover 2000	USGS: http://edcsns17.cr.usgs.gov/glcc

2. *Model Evaluation*

The fit or accuracy of the model should be tested, for every modelling approach, to determine its prediction. This can be done in two ways in MaxEnt: 1) through receiver operating characteristic (ROC) plots, and 2) through defined thresholds (Baldwin, 2009). We used both approaches to determine model accuracy.

Model robustness is commonly evaluated by area under the curve (AUC) values of the ROC (DeLong et al., 1988) that range from 0 to 1—AUC values in the range 0.5–0.7 are considered low, 0.7–0.9 moderate, and 0.9–1 high (Franklin, 2010; Shrestha and Bawa, 2014). Values close to 0.5 indicate a fit no better than that expected by random, while a value of 1.0 indicates a perfect fit. It is also possible to have values less than 0.5—this indicates that a model fits worse than random (Engler et al., 2004). It is a graded approach for evaluating model fit that verifies the probability of a presence location being graded higher than random background locations that serve as pseudo-absences for all analyses in MaxEnt (Phillips et al., 2006). The AUC quantifies the significance of this curve, and we used its values to determine model accuracy. ROC is a plot of the sensitivity vs. 1-specificity over the entire range of threshold values between 0 and 1 (Fielding and Bell, 1997). Using this method, the commission and omission errors are, therefore, weighted with equal importance for determining model performance (Slater and Michael, 2012).

Another approach entails selecting thresholds to determine sites that are considered suitable or unsuitable for the species of interest. These thresholds are established by maximizing sensitivity while minimizing specificity (Fielding and Bell, 1997; Phillips et al., 2006). The proportion of sites that are precisely categorized as suitable locations can be compared to the proportion of unsuitable sites to verify model accuracy. We checked our model output against different defined thresholds and selected the one with the lowest error.

Due to the scarcity of snow leopard presence data, it was not possible to get a new presence record for model validation. Therefore, presence locations excluded by the collinearity model were used for model evaluation along with absence locations. Absence locations were obtained in two ways, a) from surveyed sites where snow leopards were not detected (214 locations), and b) through 102 locations which were extracted from areas higher than 6,500 m—no-go areas for snow leopards. Although using these locations was not ideal but the only option, we had, to get almost confirmed absence location from the study area (McCarthy et al., 2017) (Figure 2.2).

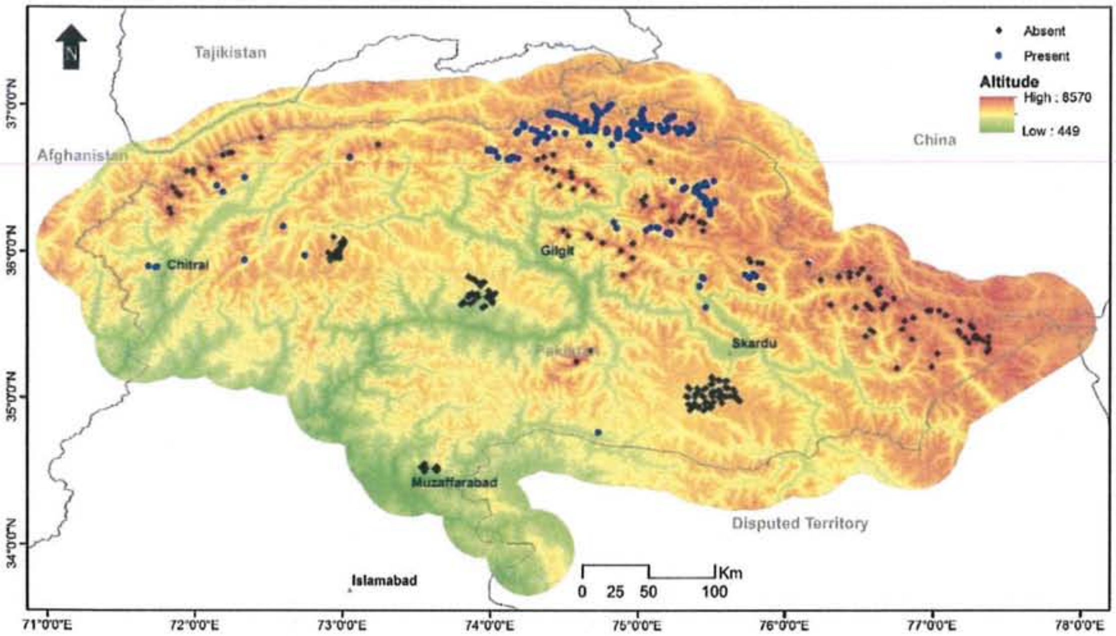


Figure 2.2. Presence (blue) and absence (black) locations of snow leopards used for model evaluation.

2.2.4 Modelling Potential Movement Corridors

Using the snow leopard suitability map generated by MaxEnt, we also modelled for potential movement corridors. This was achieved through Circuitscape 4.0 (software) (McRae and Shah, 2009), an open-source program that uses circuit theory to predict connectivity in heterogeneous landscapes for individual movement. The landscape is treated as a conductance surface by Circuitscape, where each pixel represents a resistor with an assigned resistance value. Pairwise electrical resistances between locations are calculated by running a theoretical electrical current between each population pair, with one population being set as the current source and the other as the ground (McRae and Shah, 2009). We used Circuitscape because it has not only the strength to describe both wildlife movement (Walpole et al., 2012) and gene flow (McRae and Beier, 2007), but also due to its capacity to describe probabilities of habitat connectivity for both small and large-scale landscapes. Circuitscape is based on random walks and does not assume that animals disperse according to previous knowledge of the surroundings as other least cost resistance methods do (McRae and Shah, 2009). It thus links populations through multiple pathways (McRae and Shah, 2009), such that connectivity between habitat patches increases according to the number of connected pathways, and the effective resistance between two populations is derived from the overall resistance across all pathways (Kabir et al., 2017). Though Circuitscape is often unable to compute grids larger than 6 million cells, because of computer memory limitations (Shah and McRae, 2008), but it was fine for our study area. Also, a feature of current density maps produced by Circuitscape is that relatively high current is produced near the nodes is unwanted when there is no priority to place nodes in a particular location (Koen et al., 2014) but this did not affect our output as we have already chosen node locations.

I used our habitat suitability output as a conductance layer and 38 nodes to run movement corridors of snow leopard. These nodes represent different areas where we had confirmed snow leopard presence in Pakistan. We limited the number of nodes to 38 points, which cover all important areas of snow leopard in Pakistan, and not too numerous to impart unnecessary complexity in the analysis. The nodes were converted into a grid file in Arc GIS 10.2, and both the habitat suitability map (Maxent output) and the nodes file were converted into ASCII format to run in Circuitscape model. We used the option of conductance instead of resistance because, in our model, higher values indicate greater ease of movement and we were interested in generating cumulative current maps (Cushman et al., 2013; Roscioni et al., 2014; Saura et al., 2011). Pairwise modelling mode was used which iterates across all pairs in a focal node. We connected the eight neighbouring cells, instead of four, as an average cost (Koen et al., 2014).

2.3 RESULTS

Snow leopard detection was low as it was photo-captured in 97 capture events at just 60 stations (out of 806 stations) (Fig 2.2). In most of our study areas, there was either single capture—Laspur Valley, Qurumber National Park, Musk Deer National Park, Terich Valley—or no capture (Broghil National Park, Deosai National Park, Yarkhun Valley, etc.). Multiple captures occurred only in the Khunjerab National Park, Shimshal, Misgar valleys, Hopper-Hisper and buffer areas of Central Karakoram National Park; Basha-Arandu.

In sign-based site-occupancy surveys, signs older than ten days were also excluded to minimize the risk of misidentification. After this screening, we obtained 213 locations in different areas with fresh signs—either scrapes or pugmarks, or both. Among 1,000 faecal samples, genetic analysis confirmed 111 to be of snow leopards scats. Combining all three methods, we obtained 384 (Figure 2.1) confirmed locations of snow leopards. These locations were overlapping in some areas where multiple surveys were conducted and after removing spatially correlated data points, 98 unrelated locations were used to generate the current SDM of the snow leopard.

2.3.1 Range-wide Habitat Suitability

MaxEnt produced outputs for 25 replicates and averaged them into one model along with response curves and AUC. This average model was used for drawing inferences about habitat suitability and calculating potential movement corridors.

The habitat suitability score ranged from 0 to 0.97 across the snow leopard's assumed range in Pakistan (Figure 2.3). A large portion of previously known range fell in low-quality habitat, including areas in lower Chitral, Swat, Astor and AJK. Conversely, KNP, Misgar, Chapursan, Qurumber National Park, Broghil National Park, and CKNP contained high-quality habitat.

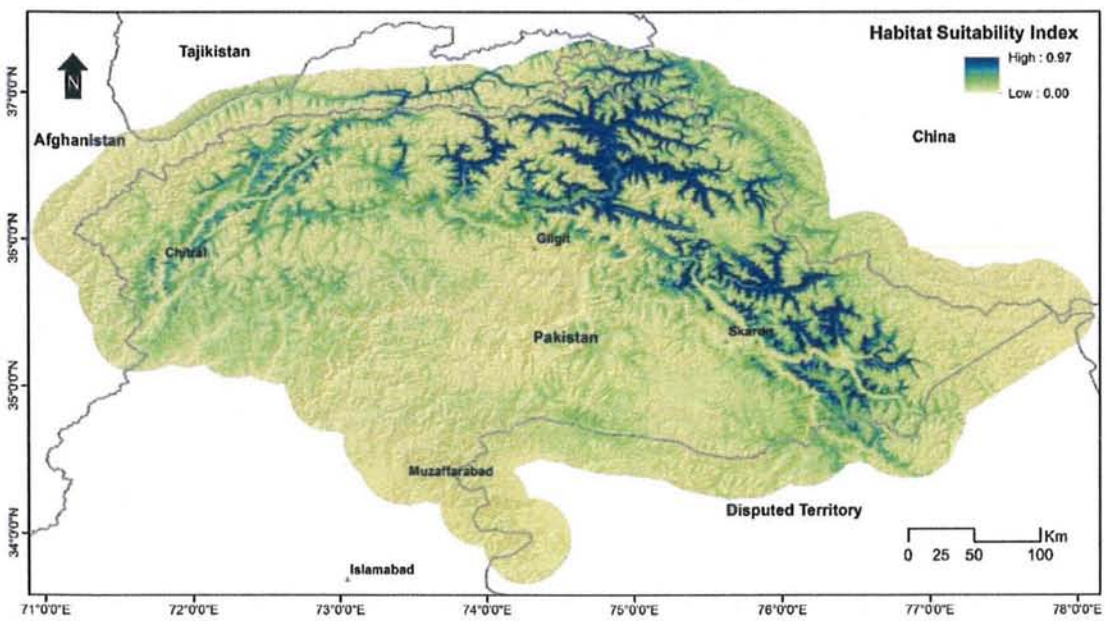


Figure 2.3. Habitat suitability of snow leopards in Pakistan, calculated with MaxEnt.

2.3.2 Factors Determining Habitat Suitability

Variables with higher contributions in the MaxEnt model were precipitation of driest month (34%), annual mean temperature (19.5%), mean diurnal range of temperature (9.8%), annual precipitation (9.4%), and river density (9.2). The contribution of other variables included in the model was low (Table 2.2).

The Jackknife Test of variable importance showed that the environmental variable with the highest gain, when used in isolation, is the density of the river, which, therefore, appears to have the most useful information by itself. The environmental variable that decreased the gain the most when it was omitted was the annual mean temperature (bio1), which, therefore, appears to have the most information that is not present in other variables. The values shown are averages over replicate runs. (Figure 2.4).

Table 2.2. Estimates of relative contributions of the environmental variables to the Maxent model.

Variable	*Interpretation*	*Percent contribution*	*Permutation importance*
bio14	Precipitation of driest month	34	7.5
bio1	Annual mean temperature	19.5	21.8
bio2	Mean diurnal range (mean of monthly [max temp - min temp])	9.8	4.3
bio12	Annual precipitation	9.4	61.8
river	Density of rivers	9.2	0.2
road	Density of roads	5.6	2.5
soil	Soil	5.5	0.9
vrmint	Vector ruggedness measure	5.2	0.6
settlement	Density of Settlement	0.9	0.3
slope	Slope of the area	0.7	0.1
ndvi	Normalized difference vegetation index	0.2	0.1

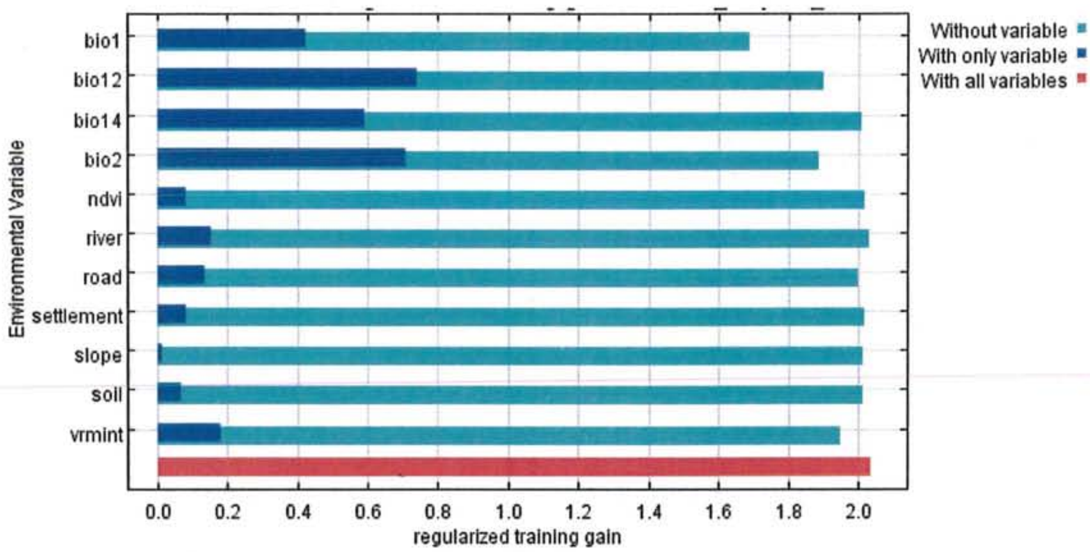
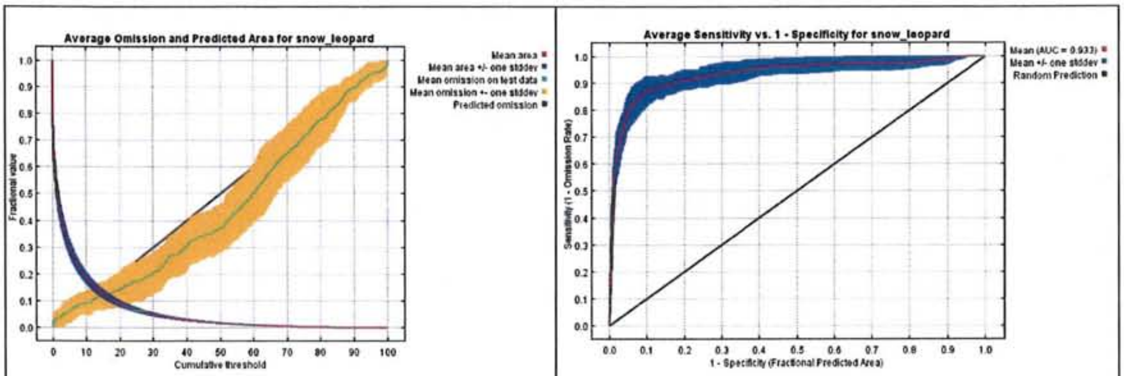


Figure 2.4. Jackknife test of regularized training gain of variables tested in snow leopard habitat suitability model. Blue bar= The gain when the environmental variable is used in isolation, Green bar= The gain when the environmental variable is omitted, Red bar= The gain with all environmental variables.

2.3.3 Model Evaluation and Threshold Selection

MaxEnt performed some basic statistics on the model and calculated an averaged AUC for the model. Analysis of omission/commission was done by MaxEnt and Figure 2.5a shows the test omission rate and predicted area as a function of the cumulative threshold averaged over the replicate runs. The omission rate should be close to the predicted omission because of the definition of the cumulative threshold and, in our case, is very close to the predicted one.



a b

Figure 2.5. Model evaluations, (a)Averaged omission and predicted area for snow leopard, (b) The ROC curve calculated by MaxEnt as averaged sensitivity versus 1-specificity for snow leopard

The ROC curve (Figure 2.5b) for the data were also calculated by MaxEnt, again, averaged over the replicate runs. Here, specificity is defined using the predicted area rather than true commission (Phillips et al., 2006). The average test AUC for the replicate runs was 0.933 ± 0.024 (SD).

Measuring the error of false positive (FP) and false-negative (FN) rates against a range of defined thresholds (Figure 2.6), the lowest error was found at a threshold of 0.15. The binomial map was re-evaluated by plotting presence and absence points and it showed that almost all presence points were in suitable habitat areas and absence points in unsuitable areas. The values of 235 presence points and 316 absence points were extracted from the model and plotted against different thresholds. The value of AUC by ROC curve calculated at 0.15 was 1.000; which means our model performed very well.

It was calculated that 235 points were true positives (TPs) and 275 were true negatives (TNs), while FPs were 41 and FNs were 0. The true positive rate (TPR) was calculated at 1.000 while the false positive rate (FPR) was 0.130. Accuracy and specificity were calculated at 0.926 and 0.870, respectively, while the positive predictive value (PPV) was 0.851 and the negative predictive value (NPV) was 1.000. The false discovery rate (FDR) was calculated at 0.149.

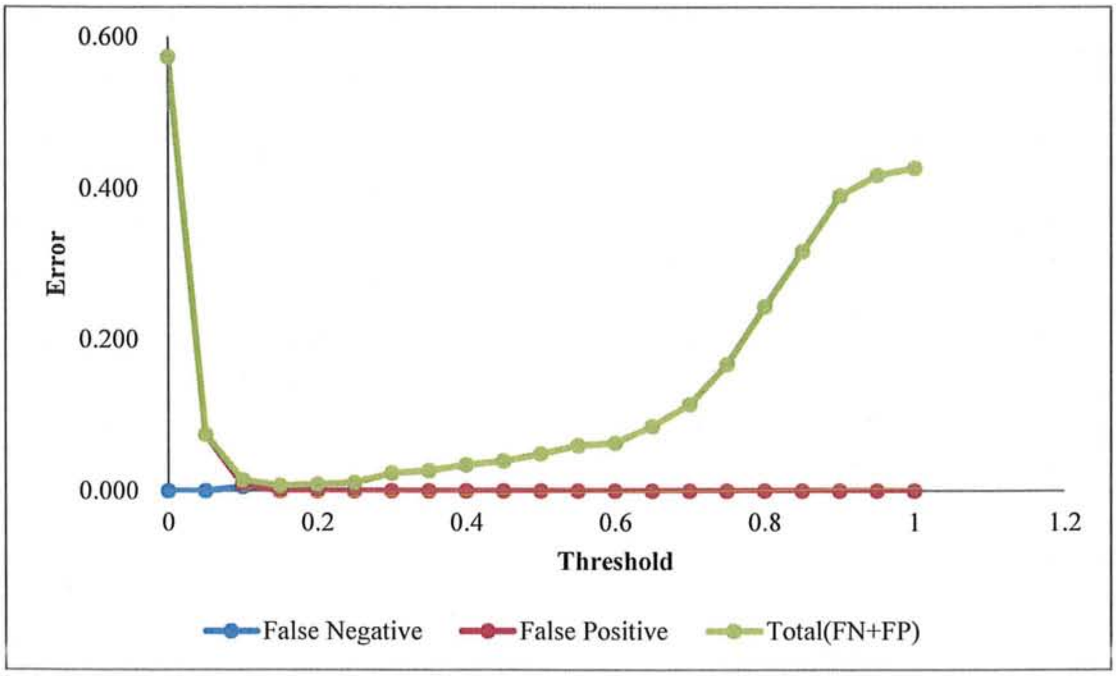


Figure 2.6. Graph showing the relationship of false negative and false positive rates against different thresholds of model prediction.

2.3.4 Potential Movement Corridors of the Snow Leopard

The circuit model (Figure 2.7) revealed an interesting pattern concerning the snow leopard's habitat connectivity. The population in the Hindukush landscape appears to be more connected with the population in Afghanistan as compared to other populations in Pakistan. Similarly, the Pamir-Karakoram population is better connected with China and Tajikistan, and the Himalayan population with the population in India.

We observed that Chitral had weak connections with other areas when we examined habitat connectivity in Pakistan. However, the populations of Phandar, Laspur Valley, and Yarkhun Valley seemed connected. Interestingly, Broghil National Park had a weak connection with its adjacent Qurumber National Park, but had strong links with Yarkhun Valley, while Qurumber National Park had strong links with Chapursan which is connected to Misgar, which had a strong link with KNP. The populations of CKNP and Musk Deer National Park were also shown to be isolated from others and the latter did not have any movement corridors close to it.

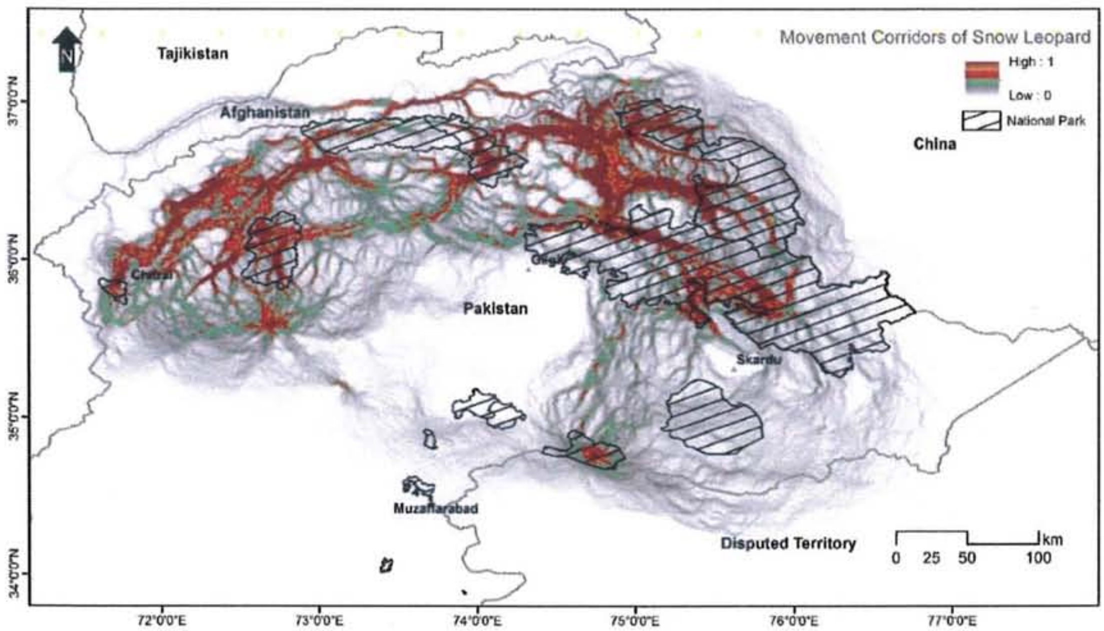


Figure 2.7. Potential movement corridors of snow leopards, calculated through Circuitscape, between different National Parks in northern Pakistan. Low values represent weak connectivity.

2.3.5 Protected Areas Coverage in Snow Leopard's Habitat in Pakistan

Habitat Suitability model was also assessed against current protected area coverage (Figure 2.8). Our analysis revealed that most of the suitable habitat of snow leopard in Pakistan has already been protected, however, there are some areas like Misgar, Chapursan, and Terich that are outside of any declared protected area.

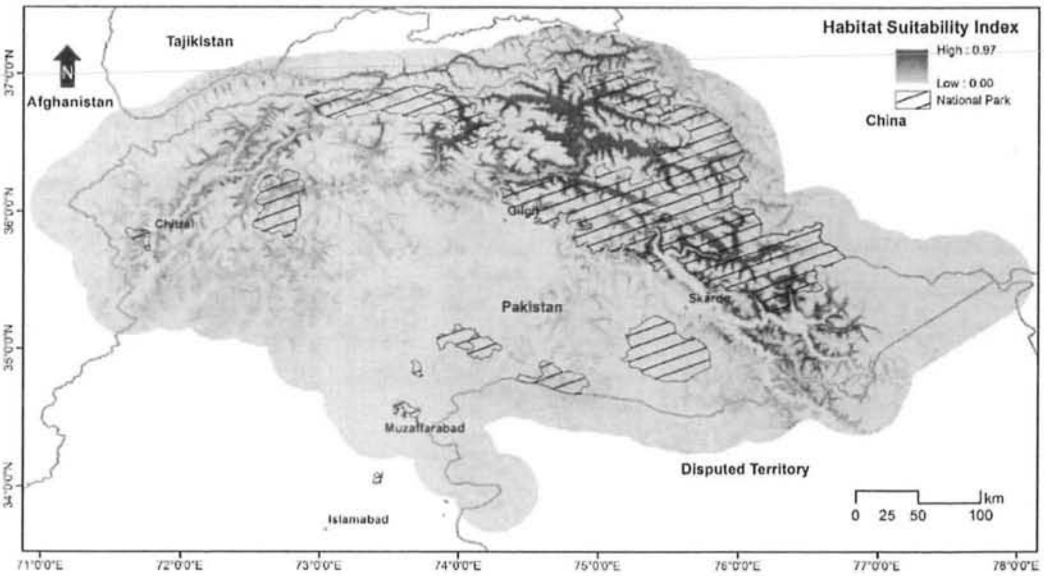


Figure 2.8. Overlay of existing national parks on habitat suitability map of snow leopards.

It was also observed that most of the national parks had weak links in regards to the movement of snow leopard across different habitats (Fig 2.8). Even some adjacent protected areas, like Broghil-Qurumber National Parks and Khujerab-Central Karakoram National Parks had no or very weak movement corridors of snow leopard at their shared borders.

2.4 DISCUSSION

Our study yielded the first empirically based inferences on snow leopard's distributional patterns and habitat connectivity in Pakistan. We found that the distributional range estimated here does not correspond well with the ones described by Roberts (1977) and Fox (1989), which is not surprising given the elusive nature of the snow leopard and the lack of data available at that time. We recorded snow leopard presence using multiple techniques, including comparatively modern methods such as camera trapping and non-invasive genetic sampling which can be applied efficiently at large spatial scales. This allowed us to survey over 31,000 km^2 which covered about 39% of the presumed snow leopard range in Pakistan. The study showed on the one hand that the snow leopard range in Pakistan extends into areas beyond previously described distribution of the species (Fox, 1989; Roberts and d'Olanda, 1977) and, on the other hand, that some areas previously believed to be part of the range either have very low suitability or are unsuitable.

This study showed that most of the snow leopard habitat in Pakistan is patchy, having no or weak links among the patches. Though there are potential movement corridors between different areas, e.g., between KNP and CKNP, these are not strong enough to be called permanent routes (Figure 2.7). The connectivity model also revealed that in some areas, snow leopard possibly favoured movement across borders instead of inside Pakistan, e.g., Broghil National Park had more connectivity to Afghanistan than to its adjacent national park, Qurumber National Park. Also, KNP and CKNP did not show any connectivity at their shared border, but there is a movement corridor between these two parks via Hopper-Hisper valleys through Gojal area. These connectivity patterns seem unusual on maps, but other factors like the presence of large glaciers explain the absence of any movement corridors at the borders of these parks. The connectivity model proposed by McRae et al. (2008) applying electrical circuit theory is a useful addition to the approaches available to ecologists and conservation planners. Circuit theory can be applied to predict the movement patterns and probabilities of successful dispersal or mortality of random walkers moving across complex landscapes, to generate measures of connectivity or isolation of habitat patches, populations, or protected areas, and to identify important connective elements (e.g., corridors) for conservation planning (McRae et al., 2008). The establishment of movement corridors can offset the negative effects of habitat fragmentation by connecting isolated habitat populations or patches (Downes et al., 1997; Wang et al., 2014). Nevertheless, core habitats shall remain a priority for protection as they sustain viable populations. Corridors facilitate the movement of animals across larger landscapes, particularly through fragmented and less suitable areas, to maintain gene flow and connectivity among populations at the regional level.

Our habitat suitability model was also useful for assessing the effectiveness of existing protected areas, specifically national parks in the snow leopard's habitat. Although a substantial proportion of suitable snow leopard habitat in Pakistan falls in national parks, there are still many areas that should be considered for inclusion in the protected area's network (Figure 2.8), to safeguard the future of the species. Misgar and Chapursan falling between KNP and Qurumber National Park are some of the most suitable areas for snow leopards still without protection. Areas on the eastern side of CKNP are also not protected. Qurumber National Park is unique in the sense that its entire area is favorable for snow leopards. But there should be a new protected area or extension of Qurumber National Park on its southern and southwest side. Yasin Valley is another important area adjacent to the southern side of Broghil National Park that requires protection. The upper part of the Chitral district in KP province is also suitable for snow leopards yet in need of protection.

There are two main limitations to our model. First, no estimates of prey population are available, which could have improved model predictions. Secondly, the low detection of snow leopard in the majority of the surveyed areas, resulted in scarce data, though this is typical for species like snow leopards.

2.4.1 Management Implications

The Global Snow Leopard Ecosystem Protection Program (GSLEP) is a joint initiative of 12 snow leopard range countries, established to safeguard snow leopards and the vast ecosystem. The overall aim of GSLEP is to secure at least 20 snow leopard landscapes (SLL) across the cat's range (Phillips, 2008). Among these 20 model landscapes, three were proposed in Pakistan. Each SLL is defined as an area that can support at least 100 snow leopards of breeding age, has adequate and stable prey populations, and has functional connectivity to other snow leopard landscapes, including across international boundaries (Phillips, 2008). However, in reality, the definition of these landscapes is theoretical, and their boundaries are delineated using limited information except for a few areas where empirical data were available. Our study allows us to propose three model landscapes to be included in the GSLEP agenda, based on habitat suitability of the snow leopards across Pakistan. These are named after mountain ranges, they fall in; Himalayas, Karakoram-Pamir and Hindukush (Figure 2.9). We also recommend that the Government of Pakistan may establish new national parks to protect critical habitats of snow leopards falling in Misgar, Chapursan, and Terichmir areas in Gilgit-Baltistan and Chitral.

The geographic extents (km^2) of three proposed model landscapes are; Himalayas

= 7055, Karakoram = 38,245, Hindukush=13,883. The snow leopard densities reported in the past studies range between 0.14-8.7 (average = 2.0) individual per 100 km^2 (Khan, 2019; Suryawanshi et al., 2019). Density estimated in one part of the Karakoram range is 0.55 animals/100 km^2 (Nawaz et al., 2020). Though density estimates for the proposed landscapes are not available, each landscape is expected to support a sizeable population of snow leopards in view of the aforementioned densities from the region. All three landscapes also host good populations of prey species. For example, abundant prey in the Karakoram landscape is Himalayan ibex, though smaller populations of Ladakh urial, markhor and blue sheep are also available. Similarly, the Himalayas landscape has populations of ibex and musk deer. Hindu Kush landscape supports populations of ibex and markhor. These landscapes also provide connectivity of the snow leopards populations with regional populations. For instance, the Himalayas landscape provides connectivity with the cat population in India on eastern side and connects with the Karakoram in the north-west. The Karakoram landscape provides wider connectivity with the populations in China in north and connects to Hindukush in the west. The Hindukush provides connectivity with the Central Asian populations through Afghanistan and Tajikistan. These factors justify these areas to be model

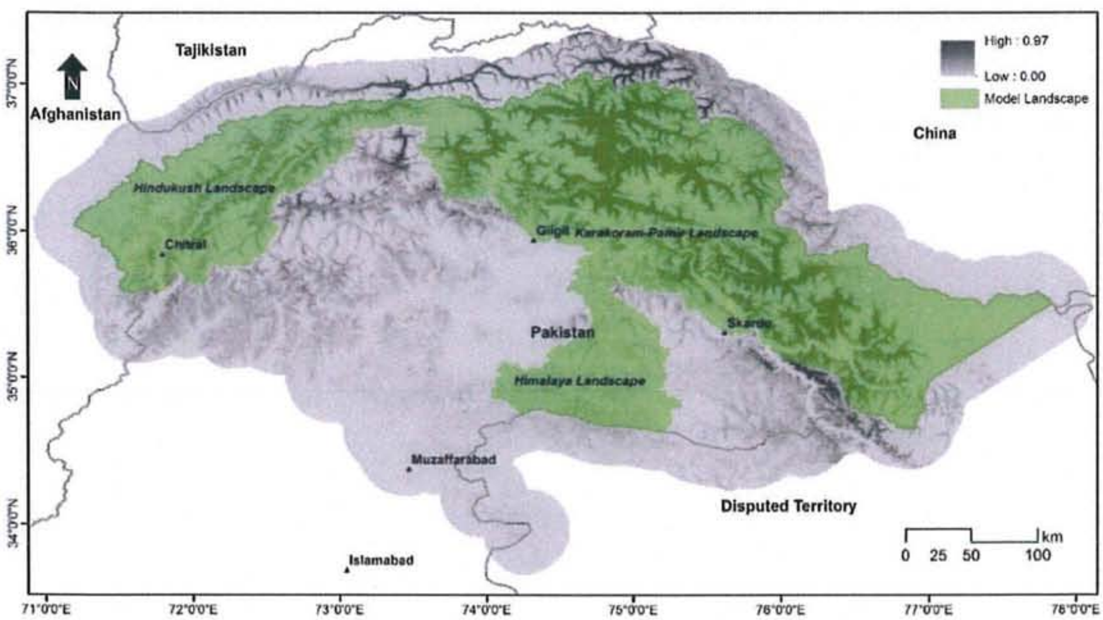


Figure 2.9. Recommended model landscapes for adoption under Global Snow Leopard and Ecosystem Protection Program (GSLEP).

landscapes for snow leopards in Pakistan.

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2.6 REFERENCES

Alexander, J.S., Cusack, J.J., Pengju, C., Kun, S., Riordan, P., 2016. Conservation of snow leopards: Spill-over benefits for other carnivores? Oryx 50, 239–243. https://doi.org/10.1017/S0030605315001040

Aryal, A., Shrestha, U.B., Ji, W., Ale, S.B., Shrestha, S., Ingty, T., Maraseni, T., Cockfield, G., Raubenheimer, D., 2016. Predicting the distributions of predator (snow leopard) and prey (blue sheep) under climate change in the Himalayas. Ecol. Evol. 6, 4065–4075.

Bai, D.F., Chen, P.J., Atzeni, L., Cering, L., Li, Q., Shi, K., 2018. Assessment of habitat suitability of the snow leopard (*Panthera uncia*) in Qomolangma National Nature Reserve based on MaxEnt modeling. Zool. Res. https://doi.org/10.24272/j.issn.2095-8137.2018.057

Baldwin, R.A., 2009. Use of maximum entropy modeling in wildlife research. Entropy 11, 854–866. https://doi.org/10.3390/e11040854

Beier, P., Penrod, K., Luke, C., Spencer, W., Cabañero, C., 2006. South Coast Missing Linkages: restoring connectivity to wildlands in the largest metropolitan area in the United States. Connect. Conserv. 555–586.

Bentlage, B., Peterson, A.T., Barve, N., Cartwright, P., 2013. Plumbing the depths:

Extending ecological niche modelling and species distribution modelling in three dimensions. Glob. Ecol. Biogeogr. 22, 952–961. https://doi.org/10.1111/geb.12049

Bhatnagar, Y.V., Mathur, V., Mccarthy, T., 2001. A regional perspective for snow leopard conservation in the Indian Trans-Himalaya. Natl. Park.

Bischof, R., Hameed, S., Ali, H., Kabir, M., Younas, M., Shah, K.A., Din, J.U., Nawaz, M.A., 2014. Using time-to-event analysis to complement hierarchical methods when assessing determinants of photographic detectability during camera trapping. Methods Ecol. Evol. 5. https://doi.org/10.1111/2041-210X.12115

Booth, G.D., Niccolucci, M.J., Schuster, E.G., 1994. Identifying proxy sets in multiple linear-regression - an aid to better coefficient interpretation. USDA For. Serv. Intermt. Res. Stn. Res. Pap.

Boria, R.A., Olson, L.E., Goodman, S.M., Anderson, R.P., 2014. Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. Ecol. Modell. 275, 73–77. https://doi.org/10.1016/j.ecolmodel.2013.12.012

Brown, J.L., 2014. SDMtoolbox : a python-based GIS toolkit for landscape genetic , biogeographic and species distribution model analyses 694–700. https://doi.org/10.1111/2041-210X.12200

Calabrese, J.M., Fagan, W.F., 2004. A comparison-shopper's guide to connectivity metrics. Front. Ecol. Environ. https://doi.org/10.1890/1540-9295(2004)002[0529:ACGTCM]2.0.CO;2

Cushman, S.A., Landguth, E.L., Flather, C.H., 2013. Evaluating population connectivity for species of conservation concern in the American Great Plains. Biodivers. Conserv. https://doi.org/10.1007/s10531-013-0541-1

Damschen, E.I., Haddad, N.M., Orrock, J.L., Tewksbury, J.J., Levey, D.J., 2006. Corridors increase plant species richness at large scales. Science (80-.). 313, 1284–1286. https://doi.org/10.1126/science.1130098

DeLong, E.R., DeLong, D.M., Clarke-Pearson, D.L., 1988. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics 837–845.

Downes, S.J., Handasyde, K.A., Elgar, M.A., 1997. The Use of Corridors by Mammals in Fragmented Australian Eucalypt Forests: Uso de Corredores por Mamíferos en Bosques de Eucalipto en Australia. Conserv. Biol. 11, 718–726.

Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F., R. Leathwick, J., Lehmann, A., Li, J., G. Lohmann, L., A. Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., McC. M. Overton, J., Townsend Peterson, A., J. Phillips, S., Richardson, K., Scachetti-Pereira, R., E. Schapire, R., Soberón, J., Williams, S., S. Wisz, M., E. Zimmermann, N., 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography (Cop.). 29, 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x

Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E., Yates, C.J., 2011. A statistical explanation of MaxEnt for ecologists. Divers. Distrib. 17, 43–57.

Engler, R., Guisan, A., Rechsteiner, L., 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. J. Appl. Ecol. 41, 263–274. https://doi.org/10.1111/j.0021-8901.2004.00881.x

Fagan, W.F., Calabrese, J.M., 2010. Quantifying connectivity: balancing metric performance with data requirements, in: Connectivity Conservation. https://doi.org/10.1017/cbo9780511754821.014

Fielding, A.H., Bell, J.F., 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ. Conserv. 24, 38–49.

Fourcade, Y., Engler, J.O., Rödder, D., Secondi, J., 2014. Mapping species distributions with MAXENT using a geographically biased sample of presence data: A performance assessment of methods for correcting sampling bias. PLoS One 9, 1–13. https://doi.org/10.1371/journal.pone.0097122

Fox, J., 1994. Snow leopard conservation in the wild-a comprehensive perspective on a low density and highly fragmented population. Proc. Seventh Int. Snow Leopard Symp. 3–15.

Fox, J.L., 1989. A review of the status and ecology of the snow leopard. Panthera uncia 40.

Franklin, J., 2010. Mapping species distributions: spatial inference and prediction. Cambridge University Press.

Guisan, A., Thuiller, W., 2005. Predicting species distribution: Offering more than simple habitat models. Ecol. Lett. https://doi.org/10.1111/j.1461-0248.2005.00792.x

Hussain, S., 2003. The status of the snow leopard in Pakistan and its conflict with local farmers. ORYX. https://doi.org/10.1017/S0030605303000085

Jackson, R., Mallon, D., McCarthy, T., Chundaway, R.A., Habib, B., 2008. Panthera uncia. IUCN Red List Threat. Species.

Jackson, R.M., Hunter, D.O., 1996. Snow leopard survey and conservation handbook. International Snow Leopard Trust.

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2006. Estimating snow leopard population abundance using photography and capture-recapture techniques. Wildl. Soc. Bull. 34, 772–781.

Kabir, M., Hameed, S., Ali, H., Bosso, L., Din, J.U., Bischof, R., Redpath, S., Nawaz, M.A., 2017. Habitat suitability and movement corridors of grey wolf (*Canis lupus*) in Northern Pakistan. PLoS One 12, e0187027.

Karanth, K.U., Nichols, J.D., 1998. Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79, 2852–2862. https://doi.org/10.1890/0012-9658(1998)079[2852:EOTDII]2.0.CO;2

Kareiva, P., 2006. Introduction: evaluating and quantifying the conservation dividends of connectivity. Conserv. Biol. Ser. 14, 293.

Kareiva, P., Wennergren, U., 1995. Connecting landscape patterns to ecosystem and population processes. Nature 373, 299–302. https://doi.org/10.1038/373299a0

Khan, B.U., 2019. Effect of Study Design on Density Estimates of Large Ranging Species. Quaid-i-Azam University.

Koen, E.L., Bowman, J., Sadowski, C., Walpole, A.A., 2014. Landscape connectivity for wildlife: Development and validation of multispecies linkage maps. Methods Ecol. Evol. https://doi.org/10.1111/2041-210X.12197

Kriticos, D.J., Randall, R.P., 2001. A comparison of systems to analyze potential weed distributions. Weed risk Assess.

Kumar, S., Graham, J., West, A.M., Evangelista, P.H., 2014. Using district-level occurrences in MaxEnt for predicting the invasion potential of an exotic insect pest in India. Comput. Electron. Agric. 103, 55–62. https://doi.org/10.1016/j.compag.2014.02.007

Maheshwari, A., 2013. Snow leopard (Panthera uncia) surveys in the Western Himalayas, India. J. Ecol. Nat. Environ. 5, 303–309. https://doi.org/10.5897/jene2013.0382

McCarthy, T., Mallon, D., Jackson, R., Zahler, P., McCarthy, K., 2017. Panthera uncia. The IUCN Red List of Threatened Species 2017: e. T22732A50664030.

McCarthy, T.M., Chapron, G., 2003. Snow Leopard Survival Strategy. ISLT and SLN, Seattle, USA.

McRae, B.H., Beier, P., 2007. Circuit theory predicts gene flow in plant and animal populations. Proc. Natl. Acad. Sci. U. S. A. https://doi.org/10.1073/pnas.0706568104

McRae, B.H., Dickson, B.G., Keitt, T.H., Shah, V.B., 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89, 2712–2724.

McRae, B.H., Shah, V.B., 2009. Circuitscape user's guide. Univ. California, St. Barbar.

Merow, C., Smith, M.J., Silander, J.A., 2013. A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. Ecography (Cop.). 36, 1058–1069. https://doi.org/10.1111/j.1600-0587.2013.07872.x

Moilanen, A., Franco, A.M.A., Early, R.I., Fox, R., Wintle, B., Thomas, C.D., 2005. Prioritizing multiple-use landscapes for conservation: Methods for large multispecies planning problems. Proc. R. Soc. B Biol. Sci. https://doi.org/10.1098/rspb.2005.3164

Moilanen, A., Nieminen, M., 2002. Simple connectivity measures in spatial ecology. Ecology. https://doi.org/10.1890/0012-9658(2002)083[1131:SCMISE]2.0.CO;2

Nawaz, M.A., Khan, B.U., Mahmood, A., Younas, M., Din, J.U., Sutherland, C., 2020. An empirical demonstration of the effect of study design on density estimation.

Network, S.L., 2014. Snow leopard survival strategy. Seattle, Washington, USA 1–145.

Nowell, K., Jackson, P., 1996. Wild cats: status survey and conservation action plan. IUCN Gland.

Peterson, A.T., 2006. Uses and Requirements of Ecological Niche Models and Related Distributional Models. Biodivers. Informatics. https://doi.org/10.17161/bi.v3i0.29

Phillips, S., 2008. Transferability, sample selection bias and background data in presence-only modelling: a response to Peterson et al. (2007). Ecography (Cop.). 0, 080227084236895–0. https://doi.org/10.1111/j.2007.0906-7590.05378.x

Phillips, S.J., 2008. Transferability, sample selection bias and background data in presence-only modelling: a response to Peterson et al. (2007). Ecography (Cop.). https://doi.org/10.1111/j.2007.0906-7590.05378.x

Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Modell. 190, 231–259.

Phillips, S.J., Dudík, M., 2008. Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation. Ecography (Cop.). https://doi.org/10.1111/j.0906-7590.2008.5203.x

Phillips, S.J., Dudík, M., Schapire, R.E., 2004. A maximum entropy approach to species distribution modeling, in: Proceedings, Twenty-First International Conference on Machine Learning, ICML 2004. https://doi.org/10.1145/1015330.1015412

Reddy, M.T., Begum, H., Sunil, N., Pandravada, S.R., Sivaraj, N., Kumar, S., 2015. Mapping the Climate Suitability Using MaxEnt Modeling Approach for Ceylon Spinach (*Basella alba L.*) Cultivation in India. J. Agric. Sci. 10, 87.

https://doi.org/10.4038/jas.v10i2.8054

Renner, I.W., Warton, D.I., 2013. Equivalence of MAXENT and Poisson Point Process Models for Species Distribution Modeling in Ecology. Biometrics 69, 274–281. https://doi.org/10.1111/j.1541-0420.2012.01824.x

Ricketts, T.H., 2001. The matrix matters: Effective isolation in fragmented landscapes. Am. Nat. 158, 87–99. https://doi.org/10.1086/320863

Roberts, T.J., d'Olanda.), B. (principe, 1977. The mammals of Pakistan.

Roscioni, F., Rebelo, H., Russo, D., Carranza, M.L., Di Febbraro, M., Loy, A., 2014. A modelling approach to infer the effects of wind farms on landscape connectivity for bats. Landsc. Ecol. https://doi.org/10.1007/s10980-014-0030-2

Saura, S., Estreguil, C., Mouton, C., Rodríguez-Freire, M., 2011. Network analysis to assess landscape connectivity trends: Application to European forests (1990-2000). Ecol. Indic. https://doi.org/10.1016/j.ecolind.2010.06.011

Schaller, G.B., 1976. Mountain Mammals in Pakistan. Oryx. https://doi.org/10.1017/S0030605300014071

Shah, V.B., McRae, B.H., 2008. Circuitscape : A Tool for Landscape Ecology. Proc. 7th Python Sci. Conf. https://doi.org/10.1111/j.1523-1739.2008.00942.x

Shehzad, W., McCarthy, T.M., Pompanon, F., Purevjav, L., Coissac, E., Riaz, T., Taberlet, P., 2012a. Prey preference of snow leopard (Panthera uncia) in South Gobi, Mongolia. PLoS One 7, e32104.

Shehzad, W., Riaz, T., Nawaz, M.A., Miquel, C., Poillot, C., Shah, S.A., Pompanon, F., Coissac, E., Taberlet, P., 2012b. Carnivore diet analysis based on next-generation sequencing: Application to the leopard cat (*Prionailurus bengalensis*) in Pakistan. Mol. Ecol. 21, 1951–1965. https://doi.org/10.1111/j.1365-294X.2011.05424.x

Shrestha, U.B., Bawa, K.S., 2014. Impact of climate change on potential distribution of Chinese caterpillar fungus (*Ophiocordyceps sinensis*) in Nepal Himalaya. PLoS One 9, 1–10. https://doi.org/10.1371/journal.pone.0106405

Slater, H., Michael, E., 2012. Predicting the current and future potential distributions of lymphatic filariasis in africa using maximum entropy ecological niche modelling. PLoS One 7. https://doi.org/10.1371/journal.pone.0032202

Summers, D.M., Bryan, B.A., Crossman, N.D., Meyer, W.S., 2012. Species vulnerability to climate change: Impacts on spatial conservation priorities and species representation. Glob. Chang. Biol. 18, 3268. https://doi.org/10.1111/j.1365-2486.2012.02771.x

Sun, W.T., Liu, Y.T., 2010. Research progress of risk analysis of biological invasion. Chin. Agr. Sci. Bull 26, 233–236.

Suryawanshi, K.R., Khanyari, M., Sharma, K., Lkhagvajav, P., Mishra, C., 2019. Sampling bias in snow leopard population estimation studies. Popul. Ecol. https://doi.org/10.1002/1438-390X.1027

Syfert, M.M., Smith, M.J., Coomes, D.A., 2013. The Effects of Sampling Bias and Model Complexity on the Predictive Performance of MaxEnt Species Distribution Models. PLoS One 8. https://doi.org/10.1371/journal.pone.0055158

Tyre, A.J., Tenhumberg, B., Field, S.A., Niejalke, D., Parris, K., Possingham, H.P., 2003. Improving precision and reducing bias in biological surveys: Estimating false-negative error rates. Ecol. Appl. 13, 1790–1801. https://doi.org/10.1890/02-5078

Václavík, T., Meentemeyer, R.K., 2009. Invasive species distribution modeling (iSDM): Are absence data and dispersal constraints needed to predict actual distributions? Ecol. Modell. https://doi.org/10.1016/j.ecolmodel.2009.08.013

Walpole, A.A., Bowman, J., Murray, D.L., Wilson, P.J., 2012. Functional connectivity of lynx at their southern range periphery in Ontario, Canada. Landsc. Ecol. https://doi.org/10.1007/s10980-012-9728-1

Wang, F., McShea, W.J., Wang, D., Li, S., Zhao, Q., Wang, H., Lu, Z., 2014. Evaluating landscape options for corridor restoration between giant panda reserves. PLoS One 9, e105086.

Yackulic, C.B., Chandler, R., Zipkin, E.F., Royle, J.A., Nichols, J.D., Campbell Grant, E.H., Veran, S., 2013. Presence-only modelling using MAXENT: When can we trust the inferences? Methods Ecol. Evol. 4, 236–243. https://doi.org/10.1111/2041-210x.12004

Zakharenka, A., Sharma, K., Kochorov, C., Rutherford, B., Varma, K., Seth, A., Kushlin, A., Lumpkin, S., Seidensticker, J., Laporte, B., Tichomirow, B., Jackson, R.M., Mishra, C., Abdiev, B., Modaqiq, A.W., Wangchuk, S., Zhongtian, Z., Khanduri, S.K., Duisekeyev, B., Dorjgurkhem, B., Pandey, M.B., Nasir, S.M., Nawaz, M.A., Fominykh, I., Saidov, N., Yunusov, N., 2016. The Global Snow Leopard and Ecosystem Protection Program, in: Snow Leopards: Biodiversity of the World: Conservation from Genes to Landscapes. https://doi.org/10.1016/B978-0-12-802213-9.00045-6

APPENDIX 2.1. CAMERA TRAP STATION SHEET

		CAMERA TRAP STATION SHEET Set by:				
STATION ID		LURE TYPE	□skunk + fish oil	□castor + fish oil	□fish oil	□none
WATERSHED		HABITAT	□scrub	□forest	□pasture	□barren □agric.
e.g. MISGAR-WS1		(in immediate surroundings)				
N	□□.□□□□□□	TERRAIN	□ridge	□cliff base □draw	□valley □saddle	□plateau
E	□□.□□□□□□	SUBSTRATE	□sand	□soil	□rock/gravel □snow	□vegetation
ELEVATION	meters	Station potential		□good	□medium	□poor
CAMERA ID						
STATION VISIT⇩	**Sign in buffer area ⇨**					

	DATE	**TIME**	**SIGN AT STATION**	**SD CARD**	**Camera Operational**	**NR NEW PHOTOS**
SETUP					□ YES □ NO	
RE-BAITING					□ YES □ NO	

APPENDIX 2.2 . OCCUPANCY SURVEY SHEET

Date:	**Time:**	**Block ID:**	**Point ID:**
Latitude:□□.□□□□□	Longitude:□□.□□□□□		Elevation: m
Topography:	Terrain:	Habitat:	Disturbance:
Observer(s):			

#	**Species**	**Sign type**	**Sign age**	**Measurement (LxD) cm**	**Substrate type**	**Notes**

Key:

Block ID: From map; e.g.: S-01 Point ID: Block-ID-Point; e.g.: S-01-01

Topography: Ridge, Cliff base, Draw, Valley, Saddle, Plateau

Terrain: Brokenness Index, (1–4)

Habitat: Scrub, Forest, Pasture, Barren, Agriculture/Plantation

Disturbance: High, Medium, Low, None

Species: Snow Leopard, Brown Bear, Wolf, Lynx, Ibex, wild ungulate, livestock, etc.

Sign type: Pugmark, Scrape, Feces, Scent, Claw Rake, Digging.

Sign age: <10 days; < 1 month; >1 month

APPENDIX 2.3. SCAT COLLECTION SHEET

ID:	**Species:**	**Location:**	**Collected by:**
Date:	**Grid:**	**Station/Point:**	**Substrate:**
Latitude (N): □□.□□□□□□		**Longitude (E):** □□.□□□□□□	
Habitat: (A) Scrub **(B)**Forest **(C)**Pasture **(D)**Barren **(E)**Agriculture/Plantation			
Topography: (A) Ridge **(B)**Cliff base **(C)**Draw **(D)**Valley **(E)**Saddle **(F)**Plateau			
Disturbance: (A) None **(B)**Low **(C)**Medium **(E)**High			
Scat collected: (A) While in study area **(B)**In buffer area of camera station **(C)**In view of camera (D)In Occupancy Point			
Type: (A) Same day **(B)**2-3 days old **(C)**One week Old **(D)**< 1 month **(E)**> 1 month			
Comments:			
ID:	**Species:**	**Location:**	**Collected by:**
Date:	**Grid:**	**Station/Point:**	**Substrate:**
Latitude (N): □□.□□□□□□		**Longitude (E):** □□.□□□□□□	
Habitat: (A) Scrub **(B)**Forest **(C)**Pasture **(D)**Barren **(E)**Agriculture/Plantation			
Topography: (A) Ridge **(B)**Cliff base **(C)**Draw **(D)**Valley **(E)**Saddle **(F)**Plateau			
Disturbance: (A) None **(B)** Low **(C)** Medium **(E)** High			
Scat collected: (A) While in study area **(B)**In buffer area of camera station **(C)**In view of camera (D)In Occupancy Point			
Type: (A) Same day **(B)**2-3 days old **(C)**One week Old **(D)**< 1 month **(E)**> 1 month			
Comments:			
ID:	**Species:**	**Location:**	**Collected by:**
Date:	**Grid:**	**Station/Point:**	**Substrate:**
Latitude (N): □□.□□□□□□		**Longitude (E):** □□.□□□□□□	
Habitat: (A) Scrub **(B)**Forest **(C)**Pasture **(D)**Barren **(E)**Agriculture/Plantation			
Topography: (A) Ridge **(B)**Cliff base **(C)**Draw **(D)**Valley **(E)**Saddle **(F)**Plateau			
Disturbance: (A) None **(B)** Low **(C)** Medium **(E)** High			
Scat collected: (A) While in study area **(B)**In buffer area of camera station **(C)**In view of camera (D)In Occupancy Point			
Type: (A) Same day **(B)**2-3 days old **(C)**One week Old **(D)**< 1 month **(E)**> 1 month			
Comments:			

Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

CHAPTER 3

Habitat Suitability and Movement Corridors of Himalayan Brown Bear in Pakistan

3 Habitat Suitability and Movement Corridors of Himalayan Brown Bear in Pakistan

ABSTRACT

The Himalayan brown bear (*Ursus arctos isabellinus*) is a subspecies of brown bear that represents an ancient lineage of the brown bear. In Pakistan, the brown bear is listed as a critically endangered species and its distribution is patchy—the species survives in seven isolated populations over approximately 150,000 km^2 across the mountain ranges of the Himalayas, Karakoram, and Hindu Kush, and these populations are either completely isolated or weakly connected. Information available on brown bear habitat in Pakistan is limited and specific to certain national parks. This study focus entire distribution range of the species in Pakistan with the primary objective of identifying suitable habitats and movement corridors used by the species. Surveys were conducted in 20 different study sites covering an area of about 31,000 km^2. Multiple survey techniques like camera trapping, visual sightings, site occupancy, and molecular genetics were used to obtain data on presence brown bears. A total of 184 brown bear presence points were obtained and used to construct realistic species distribution using the software MaxEnt. The study followed this approach to construct an accurate distribution of the species in Pakistan. Moreover, Circuitscape (software) was used, and identified movement corridors among different populations. A probability of habitat suitability map, generated from 59 presence points and 14 environmental variables, scored brown bear assumed range in Pakistan from 0 to 0.92. A large portion of the known range represented low-quality habitat, including areas in Swat, Lower Chitral, Neelum Valley, Naran-Kaghan, Khanbari, parts of Central Karakoram National Park (CKNP), and the surrounding areas of Gilgit. On the other hand, Deosai National Park (DNP) and surrounding areas, Khunjerab National Park (KNP), Qurumber National Park (QNP), Broghil National Park (BNP), Musk Deer National Park (MDNP), Misgar, Chapursan, parts of Astore Valley, Yarkhun Valley, Laspur Valley, and Phandar Valley, Kharmang Valley represented high-quality habitats. Variables with higher contributions in the MaxEnt model were temperature annual range (bio7) (49.1%), the max temperature of the warmest month (bio5, 13.2%), precipitation seasonality (bio15, 11.6%), and land cover (8%). Factors with the least contribution in determining brown

bear habitat suitability were rivers (0.3%), settlements (0.3%), slope (0.9%), mean diurnal range (bio2, 1.6%), and roads (1.9%). The model was validated through receiver operating characteristic (ROC) plots and defined thresholds. We used both approaches to determine model accuracy. The average test AUC in MaxEnt for the replicate runs was 0.926 while the value of AUC by ROC curve calculated at 0.44 was 1.000. The validation tests suggested a good model fit and strong predictive power. The connectivity model shows that the population in the Hindu Kush range is isolated. The brown bear populations in BNP and QNP ae connected with the population in Afghanistan, while the KNP population is connected with China. In the Himalayas, the brown bear population had a weak connection with the population in Indian Administered Kashmir. Inside Pakistan, the brown bear population in KNP, BNP, QNP, Misgar, and Chapursan are connected. The CKNP population is either isolated or weakly connected with KNP. The brown bear population in DNP and surrounding areas had a connection with that of MDNP. Based on our findings, most brown bear habitats fall with protected areas, but few suitable sites are outside the protected areas. Therefore, it is recommended that a few sites outside protected areas, where quality brown bear habitat exists, be declared as protected areas to ensure protection and conservation.

Keywords: brown bear, MaxEnt, habitat suitability, protected area, movement corridor, Circuitscape.

3.1 INTRODUCTION

The Himalayan brown bear (*Ursus arctos isabellinus*) is a subspecies of brown bear that represents an ancient lineage of the brown bear (Galbreath et al., 2007; Japan Bear Network, 2006). The historical distribution range of the Himalayan brown bear extends from the Pamir, Hindu Kush, western Himalayan, western Kunlun, Karakoram, Shan, and Tian Shan ranges in southern Asia (Nawaz, 2007; Roberts and d'Olanda, 1977). The species' global population has not yet been estimated. In Pakistan, information about brown bear distribution and population status is patchy. However, according to Nawaz (2007), approximately 150–200 bears may survive as seven populations over approximately 150,000 km^2 in three major mountain ranges—Himalayas, Karakoram and Hindu Kush. Connectivity among these populations is limited, and some are completely isolated (Nawaz, 2007).

In Pakistan, the presence of brown bears in the western Himalayas has been confirmed from several localities, namely Neelum Valley, Kaghan Valley, Nanga Parbat, Astore Valley and Deosai Plateau (Ahmad et al., 2016; Nawaz, 2007; Roberts and d'Olanda, 1977). Brown bear presence is also recorded from different valleys, glaciers, and high meadows in the Pamirs, Karakoram, and Hindu Kush (Roberts and d'Olanda.), 1977; Schaller, 1976). The species is also found in Chitral, Kalam (Kohistan), Pallas Valley (Indus Kohistan) (Nawaz, 2007; Roberts and d'Olanda, 1977). In southern Asia, the species exists in small and isolated populations in remote and rugged mountainous areas, and it has been declared endangered (Servheen et al., 1999). In Pakistan, the species faces many threats, e.g., loss of habitat, climate change, growing human population, decline in food supply, increasing number of domestic animals, increasing competition with humans and increasing human dependency on natural resources (Nawaz, 2007). Due to such threats and decreasing trends in population, the brown bear in Pakistan is classified as a critically endangered species (Sheikh and Molur, 2005).

Climate change had significant direct and indirect impacts on terrestrial species by being a major cause of speciation and species extirpation (Pound and Salzmann, 2017). In Central Asia and the Asian Highlands, brown bear distribution is mostly limited to higher elevation areas where more pronounced effects of climate change have been reported (Aryal et al., 2014). The habitat of the Himalayan brown bear is the most vulnerable to climate change. In Pakistan, total suitable brown bear habitat is approximately 68,503 km^2, which is about two percent of total suitable habitat in Central Asia and the Asian Highlands (Su et al., 2018). It is believed that the habitat of brown bears in Pakistan is most vulnerable to climate change after India, and suitable habitat will shrink to 56,501.30 km^2 (17.52% loss) by 2050 (Su et al., 2018). However, this assessment of brown bear habitat is based on secondary information from past studies which were limited to certain areas, and no field efforts were undertaken to reach these conclusions.

The spatial and temporal distribution of species is a fundamental subject of ecology. To explore the requirements of species for conservation projects, the significance of species distribution models (SDMs) is increasing even more (Bosso et al., 2016; Sheehan et al., 2017; Smeraldo et al., 2017). SDMs are used extensively in evolution, ecology, biogeography and conservation biology to overcome research challenges (Guisan and Thuiller, 2005). The habitat distribution of wildlife species is assessed through an ecological niche model called maximum entropy (MaxEnt) (Clements et al., 2012; Wilting et al., 2010). These models are uncomplicated, reliable, and enable worker to develop data easily (Merow and Silander, 2014; Radosavljevic and Anderson, 2014). Globally, researchers are using the MaxEnt model to understand the habitat distribution of rare and endangered wildlife species (Bai et al., 2018; Dai et al., 2019; Hameed et al., 2020; Kabir et al., 2017; Zhang et al., 2019). Initially, these models were devised to assess the present density of a target species (Phillips et al., 2006). In biological surveys and wildlife management, the application of presence/absence data are very common, and these models make use of either presence/absence data or only presence data (Tyre et al., 2003). The absence data of species is challenging to understand and mostly unavailable (Václavík and Meentemeyer, 2009). In conservation planning and ecological research, only presence data are often applied in SDMs (Bai et al., 2018; Syfert et al., 2013). Modelling methods based on presence data just demand some known facts with climatic, biographic, and topographic variables (Phillips, 2008).

MaxEnt is a method with an easy, but accurate mathematical formulation that demands only species presence data and environmental variable quantities (Phillips et al., 2006). For studying rare and endangered species, MaxEnt is an appropriate model as it can be operated with a small sample size and minimum means (Pearson et al., 2006; Phillips et al., 2006). One must avoid variables that limit or assist the occurrence of species to prevent over-prediction or under-prediction of habitat suitability or distribution (Baldwin, 2009), and such data are easily accessible in the form of global databases of climate (https://www.worldclim.org), human impacts/infrastructure and productivity (http://www.fao.org) and digital elevation models (https://www.usgs.gov). The specific environmental suitability of a species across a given spatial range is estimated by the models during this process (Phillips and Dudík, 2008). Useful quantitative data on threats, such as anthropogenic, or resource-wise is offered by such models (Guisan and Thuiller, 2005) and supports in detecting conservation urgencies (Roscioni et al., 2014, 2013). The existing distribution pattern and range size of species assist conservationists in making accurate evaluations. For conservation management, the information of range description, and particularly those aspects which constrain the distribution of a species, is important (Yackulic et al., 2013). While designing scientific surveys and making conservation action plans, information about habitat suitability and species distribution can be used (Reddy et al., 2015).

Because of mortalities due to anthropogenic activities in human-controlled environs and habitat loss and fragmentation, large carnivores are vanishing from their historical ranges across many countries (Di Marco et al., 2014; Wolf and Ripple, 2016). Large carnivores are looking for suitable habitat in neighbouring landscapes and dispersal corridors, as existing protected areas, are not enough to hold sustainable populations (Crooks et al., 2011; Di Minin et al., 2016). Many large carnivore species are facing challenges of the use of reliable corridors and habitat patches beyond protected areas (Ghoddousi et al., 2020). Such a landscape feature, which, without facing any major hurdles, links two or more habitat patches or populations to move between are called corridors (Tischendorf and Fahrig, 2000). The possible meta-population is preserved by gene flow between local species populations through ecological corridors (Huck et al., 2010) and helps in the free scattering of individuals between local populations (Beier and Noss, 1998). These ecological corridors, by enabling gene flow between local populations, reduce deleterious impacts due to inbreeding, casual demographic processes and isolation (Christie and Knowles, 2015). Hence, major factors that limit functional connectivity require knowledge of finding useful corridors (Vasudev et al., 2015). Normally, corridor identification concentrates on factors that affect structural connectivity, such as high elevation, roads or harsh environment surrounding habitat patches (Kramer-Schadt et al., 2013; Tischendorf and Fahrig, 2000).

Minimal information is available on brown bear habitat suitability in Asia and Central Asia (Dai et al., 2019; Ghoddousi et al., 2020; Nawaz et al., 2014; Su et al., 2018). The assessment of available suitable habitat and identification of possible movement corridors are of prime importance for developing conservation strategies for threatened species. The Himalayan brown bear (Plate 3.1) is a threatened species in Pakistan, and only a single study has been conducted so far on its habitat assessment in Deosai National Park (DNP) (Nawaz et al., 2014). Our goal was to identify available suitable habitat, the extent of connectivity between populations and climatic and topographic factors limiting brown bear distribution across their distribution range in Pakistan.

Plate 3.1. Photo of an adult brown bear taken with a camera trap in Deosai National Park in northern Pakistan during non-invasive surveys in 2012.

3.2 MATERIAL AND METHODS

3.2.1 Study Area

The present study was focused on the known brown bear distribution range in Pakistan which encompasses four high mountain ranges —Hindu Kush, Karakoram, Himalayas, and Pamirs— which spread across three administrative units, i.e. Azad Jammu and Kashmir (AJK), Gilgit-Baltistan (GB) and Khyber Pakhtunkhwa (KP). A total of 20 study sites covering an area of about 31,000 km^2 were surveyed, including major protected areas and other potentially suitable brown bear habitats (Figure 3.1).

Climatic conditions vary widely, ranging from the semi-arid cold deserts of the northern Karakorams and Hindu Kush to the monsoon-influenced moist temperate zone in the western Himalayas (Jacobose, 1993). Their high altitudes and sub-zero temperatures make our study area one of the most heavily glaciated parts of the world outside the polar regions. The western Himalayan range is situated in GB and AJK to the south and east of the Indus River. The Hindu Kush rises southwest of the Pamirs. The Karakoram range covers the borders between three countries in the Xinjiang region of China, GB in Pakistan, and Ladakh in India. They are considered to extend from the Wakhjir Pass at the junctions of the Pamirs and Karakorams to the Khawak Pass north of Kabul (Hameed et al., 2020). Four vegetation zones can be differentiated along with the altitudinal ascents: subalpine scrub zones, alpine meadows, alpine dry steppes, and permanent snowfields (Kabir et al., 2017). Various rare and endangered animals occur in the study area, including the grey wolf (*Canis lupus*), brown bear (*Ursus arctos*), Asiatic black bear (*Ursus thibetanus*), Himalayan lynx (*Lynx lynx*), Pallas's cat (*Otocolobus manul*), snow leopard (Panthera uncia), flare-horned markhor (*Capra falconeri cashmirensis*), musk deer (*Moschus chrysogaster*), Marco Polo sheep (*Ovis ammon polii*), Himalayan ibex (*Capra ibex sibirica*), etc.

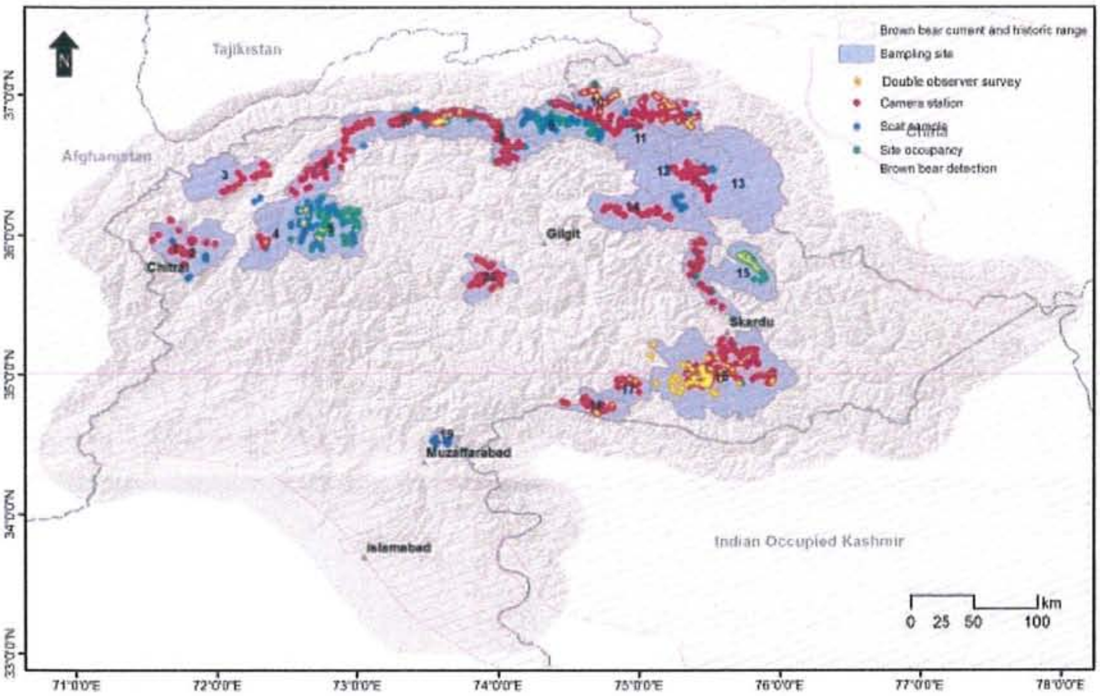


Figure 3.1. Map of study area showing sampling sites and IUCN range of Himalayan brown bear in Pakistan. 1=Chitral Gol National Park, 2=Chitral and Surrounding-Tooshi, 3= Terich, 4= Laspur, 5= Phandar, 6= Yarkhun, 7= Broghil National Park, 8= Qurumber National Park, 9=Chapursan, 10= Misgar, 11= KVO-Sukhtarabad, 12= Shimshal, 13= Khunjerab National Park, 14= Hoper-Hisper, 15= Basha-Arandu, 16, Deosai National Park and surroundings, 17= Kalapani-Astore, 18= Musk Deer National Park, 19= Machiara National Park, 20= Khanbari.

3.2.2 Data Collection Techniques

3.2.2.1 Camera Trapping

In the present study, the camera was deployed at a total of 834 camera stations in different study sites, including Qurumber National Park (QNP), Deosai National Park (DNP), Khunjerab National Park (KNP), Broghil National Park (BNP), buffer areas of Central Karakoram National Park (CKNP) and Margalla Hills National Park (MHNP), Musk Deer National Park (MDNP), Chitral Gol National Park (CGNP), the buffer areas of CGNP, Tooshi Game Reserve (TGR), Khanbari Valley, Basha, and Arandu Valley, Misgar Valley, Kalapani-Astore, Hoper-Hisper Valleys, Khunjerab Villagers Organization (KVO), Shimshal Valley, Terich Valley, Laspur Valley, and Yarkhun Valley during the period 2006–2017. A single motion-triggered digital camera with infrared flash (HC500/PC900, Reconyx, Holmen, WI, USA) was deployed at each location on a steel pole (about 50 cm) driven into the ground, and the two nearest cameras were separated by a spatial distance of at least 1 km (Figure 3.1). Installation and set-up followed guidelines provided by Jackson et al. (2006). The majority of the camera stations were supplied with different types of lures—castor, skunk, and fish oil—to enhance capture probability (Ahmad et al., 2016; Kabir et al., 2017). Camera traps were set to take consecutive images (1-s picture interval) when triggered and were typically kept active at a given location for 10-40 days (Bischof et al., 2014).

3.2.2.2 Double Observer Method

The double-observer survey for brown bears was conducted in DNP only, during 2012. The treeless vegetation in Deosai and relatively gentle terrain allow a good visibility, which helps locate bears from a longer distance (2–3 km) and permits following them even without technology. This allows a direct count of bears, a method that had been used in annual census of bears during 1994–2006 (Nawaz et al., 2008). In Deosai brown bears are morphologically recognizable (Nawaz et al. 2008) due to following factors:

- Color variation: Four pelage colors were identifiable; blonde, silvertip, light brown and dark brown. Individuals generally darkened with age, and females were usually lighter, in colour, than males.
- White patches: Many individuals had characteristic white patches. These patches are variable; some individuals had a white snout and others white ear tips. White oval patches on the shoulders were relatively common, but their sizes were variable.
- Size: Brown bears are sexually size dimorphic, adult females in Deosai have a mass of 60-80 kg, adult males 120-150 kg, and sub-adult males 50-60 kg.

The park area was divided into 45 blocks, based on major watersheds and roads to implement the double-observer method (Suryawanshi et al., 2012). Surveys were conducted from 25-August to 01-September 2012 because whole area was accessible, and chances of bear sighting were better. Out of 45 blocks, the brown bear counting was conducted in 27 blocks through the double-observer method. Our survey team was divided into two groups of observers, group A and group B, who were asked to maintain temporal distance throughout the survey without cueing each other—they were separated by a distance of 1–2 km. Both observers groups recorded the sightings along with other relevant information about size, sex, habitat and disturbance (Appendix 3.1). On return from the survey, both teams tallied their observations and developed capture-recapture histories. Captures and recaptures were marked as '1s' and '0s' on the sheet. If an animal or group was sighted by both observers, it was marked as '11', or '10' or '01' if it was missed by either of the observers.

3.2.2.3 Scat Sample Collection Survey

Faecal samples were collected from 2009 to 2013 during the sign and camera trap surveys. The faecal samples survey was conducted in Machiara National Park (MNP), MDNP, KNP, BNP, QNP, DNP, Yarkhun, Laspur, Chapursan, and Misgar. All of the study sites were divided into 5 × 5 km blocks, except KVO, KNP, and Shimshal (10 × 10 km). Surveys points were randomly selected within each grid cell, and a 50-m radius around each point was searched for brown bear scats (Kabir et al., 2017). A total of 1,736 points within the study area were searched. The areas around camera trap locations were also searched for brown bear scats. The locations of scats found during tracking along livestock trails and manmade tracks were also recorded. Brown bear scats are easily identifiable in the field, so genetic base identification was not performed in the laboratory.

3.2.2.4 Site Occupancy Survey

During the period 2010–2017, site occupancy-based sign surveys were conducted in KNP-QNP, BNP, Phandar Valley, KVO-Shimshal, Misgar-Chapursan, and Basha-Arandu. The study sites were divided into grids of equal size (5 × 5 km) except in KNP-KVO-Shimshal where grid size was kept 10 × 10 km. Multiple points were selected in each grid and were searched for signs of brown bears. A total of 193 sites with 1,607 repeat survey points were searched for signs of brown bears (Figure 3.1). Presence was detected through three types of signs—den, scat, and claw marks. However, in this analysis, only scat points were used.

3.2.3 Data Analysis

A maximum entropy SDM was used (Phillips and Dudík, 2008; Su et al., 2018) to map the current distribution of brown bears in the study area. MaxEnt is a widely used tool (Aryal et al., 2016; Gomes et al., 2018; Ma and Sun, 2018) for modelling species distributions using presence data and various environmental parameters (Kramer-Schadt et al., 2013). The use of presence-only is recommended when absence data have a high degree of uncertainty relative to presence data, which is especially true when detection rates are poor (Subba et al., 2017). It is amongst the most popular SDM methods with more than 1,000 published usages since 2005 (Fourcade et al., 2014). MaxEnt has also surpassed other methods and exhibited higher predictive accuracy (Summers et al., 2012). The parameters of the MaxEnt model were set to 25% for random test percentage with typeset as a subsample. The rest of the settings were kept as default, which included a maximum of 10,000 randomly generated background points, a maximum of 5,000 iterations with a convergence threshold of 0.00001, and a regularization multiplier of 1. A total of 25 replicates were run and cross-validated (Phillips et al., 2006; Vedel-Sørensen et al., 2013). Percentage contribution was used to estimate the importance of variables. The logistic results of MaxEnt were regarded as the probability of species occurrence, with values ranging from 0 to 1. A threshold value was used to distinguish between suitable and unsuitable regions.

3.2.3.1 Data Preparation

We used brown bear distribution range in Pakistan as a study area and added a 30-km buffer area to the model using MaxEnt. Initially, a set of 29 variables were considered for the habitat suitability analysis (Table 3.1). These variables included 19 bioclimatic variables, including slope, ruggedness, elevation, soil, land cover, normalized difference vegetation index (NDVI), glaciers, distance to rivers, distance to roads, and distance to settlements. The 19 bioclimatic factors (at 1-km resolution) under current (average for 1970–2000) were extracted from the WorldClim database (http://www.worldclim.org/version2) (Dai et al., 2019). Land cover was obtained from the Global Land Cover 2000 (available from https://lta.cr.usgs.gov/glcc/globdoc2_0). Altitude was derived from the ASTER GDEM V2 digital elevation model (at 30-m resolution; http://www.gscloud.cn/) (Dai et al., 2020). We prepared slope layers using a digital elevation model (DEM) layer using ArcGIS (Su et al., 2018). Glacier data were obtained from PANGAEA (https://doi.org/10.1594/PANGAEA.894707) (Mölg et al., 2018). Distances from rivers, roads, and settlements were prepared using the density tool under the spatial analyst tool in ArcGIS. Ruggedness (SRTM 90m DEM) and NDVI were obtained from NASA (http://modis-land.gsfc.nasa.gov/vi.html).

All variables (climate and non-climate) were resampled to 1-km resolution and unified in a projection coordinate system (WGS_1984) and extent in ArcGIS 10.8 (Hameed et al., 2020). Before the MaxEnt analysis, all variables of the same resolution, projection, and extent were converted into ASCII files using a conversion tool (raster to ASCII) in ArcGIS 10.8 as a MaxEnt requirement. Pearson's correlation test in Programme R (R Core Team, 2019) was run before the MaxEnt analysis to remove variables that were highly correlated ($r > 0.70$) (Booth et al., 1994). After the Pearson collinearity test, a total of 14 variables were retained for the final analysis in MaxEnt. The final variable used in the MaxEnt analysis included six bioclimatic variables (bio15, bio13, bio7, bio5, bio13, and bio2), distances from roads, river, and slope, ruggedness, NDVI, glaciers, soil, land cover, and settlements (Table 3.1). Brown bear presence point data were saved in an MS Excel spreadsheet in CSV format. The presence records (184 locations) obtained through the sign survey and camera trapping in different sites of the study area were screened in SDMtoolbox in ArcGIS to remove those located at a distance of less than 5 km (Kabir et al., 2017; Hameed et al., 2020). After spatial autocorrelation, a total of 59 unrelated presence points were left for the habitat suitability analysis.

Table 3.1 List of environmental variables used in MaxEnt modelling.

Environmental variable	*Interpretation*	*Source*
bio1 V2.1	Annual mean temperature	http://www.worldclim.org
bio2 V2.1	Mean diurnal range (mean of monthly [max temp - min temp])	http://www.worldclim.org
bio3 V2.1	Isothermality (Bio2/Bio7) (* 100)	http://www.worldclim.org
bio4 V2.1	Temperature Seasonality (standard deviation *100)	http://www.worldclim.org
bio5 V2.1	Max Temperature of Warmest Month	http://www.worldclim.org
bio6 V2.1	Min Temperature of Coldest Month	http://www.worldclim.org
bio7 V2.1	Temperature Annual Range (Bio5-Bio6)	http://www.worldclim.org

bio8 V2.1	Mean Temperature of Wettest Quarter	http://www.worldclim.org
bio9 V2.1	Mean Temperature of Driest Quarter	http://www.worldclim.org
bio10 V2.1	Mean Temperature of Warmest Quarter	http://www.worldclim.org
bio11 V2.1	Mean Temperature of Coldest Quarter	http://www.worldclim.org
bio12 V2.1	Annual precipitation	http://www.worldclim.org
bio13 V2.1	Precipitation of Wettest Month	http://www.worldclim.org
bio14 V2.1	Precipitation of driest month	http://www.worldclim.org
bio15 V2.1	Precipitation Seasonality (Coefficient of Variation)	http://www.worldclim.org
bio16 V2.1	Precipitation of Wettest Quarter	http://www.worldclim.org
bio17 V2.1	Precipitation of Driest Quarter	http://www.worldclim.org
bio18 V2.1	Precipitation of Warmest Quarter	http://www.worldclim.org
bio19 V2.1	Precipitation of Coldest Quarter	http://www.worldclim.org
Glacier	Glaciers in the area	https://doi.org/10.1594/PANGAEA.894707
Slope	The slope of the area	derived from alt in Arc GIS 10.2
Elevation	elevation above sea level (m)	SRTM
Settlement	The density of settlements (m)	calculated in Arc GIS 10.2
River	The density of rivers (m)	calculated in Arc GIS 10.2
Road	The density of roads (m)	calculated in Arc GIS 10.2
NDVI (MODIS)	Normalized difference vegetation index	NASA: http://modis-land.gsfc.nasa.gov/vi.html
Vrmint	Vector ruggedness measure	Generated from SRTM 90m DEM by the Center for Nature and Society, Peking University using the Terrain Ruggedness (VRM) Tool
glc2000	Global land cover 2000	USGS: http://edcsns17.cr.usgs.gov/glcc
Soil	Digital soil map of the world	FAO, 2003

3.2.4 Model Evaluation

The fit or accuracy of the model should be tested for every modelling approach to determine its prediction. This can be done in two ways in MaxEnt: 1) through an area under the receiver operating characteristic curve (AUC) of the receiver operator characteristic (ROC) curve (Bai et al., 2018; Roura-Pascual et al., 2009) and 2) through defined thresholds (Baldwin, 2009).

The results of the MaxEnt model were verified by ROC values: values ranged from 0 to 1, with those closer to 1 indicating a more accurate model (Araujo et al., 2005; Phillips et al., 2006). A model is rejected with a ROC value 0.5–0.6; poor with 0.6–0.7; normal with 0.7–0.8; good with 0.8–0.9; and excellent with 0.9–1.0 (Bai et al., 2018).

Another approach entails selecting thresholds to determine sites that are considered suitable or unsuitable for the species of interest. These thresholds are established by maximizing sensitivity while minimizing specificity (Fielding and Bell, 1997; Phillips et al., 2006). The proportion of sites that are precisely categorized as suitable locations can be compared to the proportion of unsuitable sites to verify model accuracy. We checked our model output against different defined thresholds and selected the one with the lowest error.

Due to the scarcity of brown bear presence data, it was not possible to obtain a new presence record for model validation. Therefore, presence locations excluded by the collinearity model were used for model evaluation along with absence locations. Absence locations were obtained in two ways, a) through 29 locations which were extracted from areas higher than 6,500 m (upper elevation limit) b) from surveyed sites where brown bears were not detected (60 locations). Although using these locations was not ideal, it was the only option for obtaining an almost confirmed absence locations from the study area (Figure 3.2).

3.2.5 Modelling Potential Movement Corridors

In recent years, a new use of graph models to understand habitat connectivity has emerged that conceptualizes a landscape akin to an electrical circuit, with each cell in a raster grid presenting a given "resistance" to the movement of modelled organisms (Koen et al., 2012; McRae BH, 2006). Foremost among these is the framework implemented in the Circuitscape programme (McRae et al., 2008; McRae and Shah, 2009), which has reshaped the science and capacity for estimating and understanding landscape connectivity. Using the brown bear suitability map generated by MaxEnt, potential movement corridors were also modelled. This was achieved through Circuitscape 4.0 (software) (McRae and Shah, 2009), an open-source programme that uses circuit theory to predict connectivity in heterogeneous landscapes for individual movement.

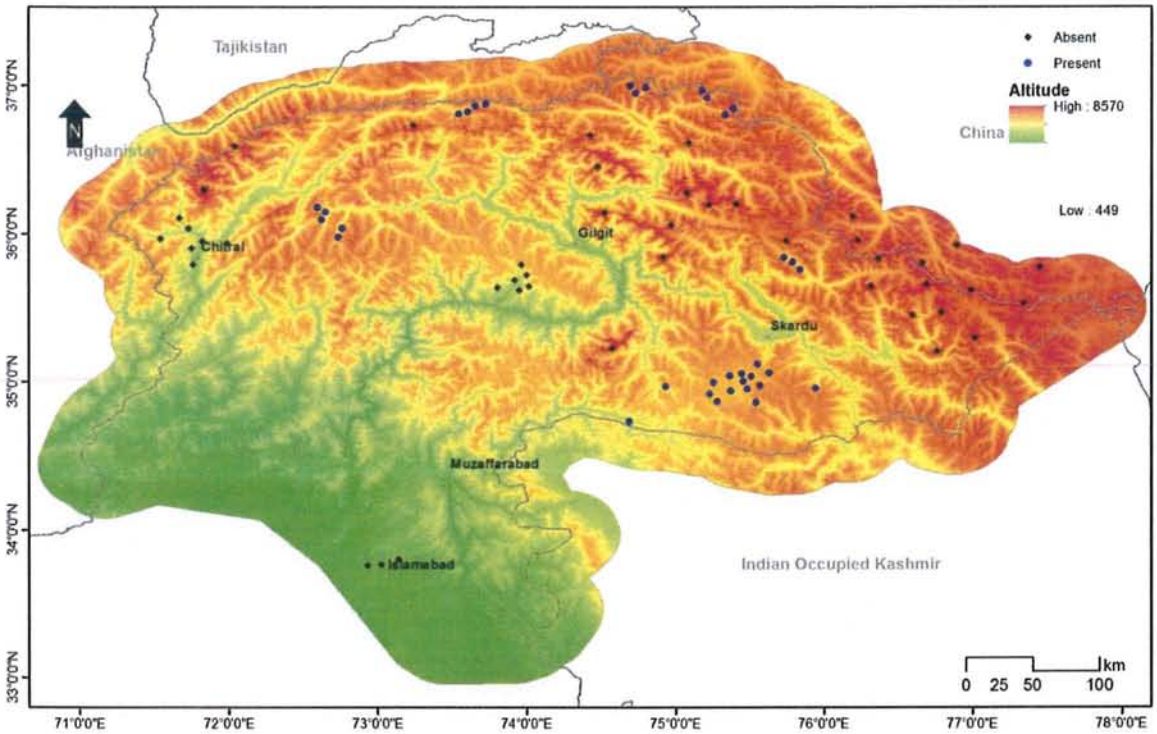


Figure 3.2. Presence and absence locations of brown bear used for model evaluation.

Circuitscape was used in this analysis because it has not only the strength to describe both wildlife movement (Walpole et al., 2012) and gene flow (McRae and Beier, 2007) but also due to its capacity to describe probabilities of habitat connectivity for both small and large-scale landscapes. Circuitscape is based on random walks (McRae and Shah, 2009), such that connectivity between habitats patches increases according to the number of connected pathways, and the effective resistance between two populations is derived from the overall resistance across all pathways (Kabir et al., 2017).

Habitat suitability output was used as a conductance layer and 38 nodes to run movement corridors of brown bears (Hameed et al., 2020). We used nodes to represent different areas where we had confirmed brown bear presence in Pakistan. We limited the number of nodes to 38 points, covering all important brown bear areas in Pakistan to avoid any complexity. We converted the nodes into a grid file in Arc GIS 10.8. Both the habitat suitability map (created by MaxEnt) and the nodes file were converted into ASCII format for a Circuitscape model run (Kabir et al., 2017). We used the option of conductance instead of resistance because, in our model, higher values indicate greater ease of movement and we were interested in generating cumulative and maximum current maps (Cushman et al., 2013; Roscioni et al., 2014). We used pairwise modelling mode, which iterates across all pairs in a focal node file. We connected the eight neighbouring cells, instead of four, as an average cost (Koen et al., 2014).

3.3 RESULTS

During the survey, brown bear presence was confirmed 184 locations across the distribution range through camera trapping, sign base occupancy surveys and direct sightings. The brown bear was photo-captured at 29 different camera stations in different study sites. Mostly, brown bears were photo-captured in protected areas (QNP, BNP, DNP, KNP). Brown bear sightings were recorded at 26 locations in DNP during the double-observer survey (Figure 3.1).

In sign-based site-occupancy surveys, signs older than ten days were excluded to minimize the risk of misidentification, and we retained 129 signs or scats locations. Most of the collected scats were from DNP and KNP. These locations were overlapping in some areas where multiple surveys were conducted, and after removing spatially correlated data points, 59 unrelated locations were used to generate the current distribution model.

3.3.1 Range-wide Habitat Suitability

The habitat suitability analysis of the brown bear run in MaxEnt produced outputs for 25 replicates and averaged them into a single model along with response curves and areas under the curve (AUC). The habitat suitability score calculated by MaxEnt ranged from 0 to 0.92 across the IUCN-declared brown bear range in Pakistan (Figure 3.3). The mean AUC value of 0.92 indicated that the habitat suitability estimate obtained from MaxEnt was excellent. The interpretation of habitat suitability and possible movement corridor of brown bears in Pakistan was performed using this average model.

A major portion of the IUCN-declared range of brown bears in Pakistan falls in low-quality habitat. Major areas of low-quality habitat include Naran-Kaghan Valley, Swat, Lower Chitral, Khanbari area, Gilgit and surrounding areas, and parts of Neelum Valley. On the other hand, high-quality habitat based on the MaxEnt prediction included DNP, KNP, QNP, BNP, Hopper-Hisper, Misgar, and Chapursan (Figure 3.3).

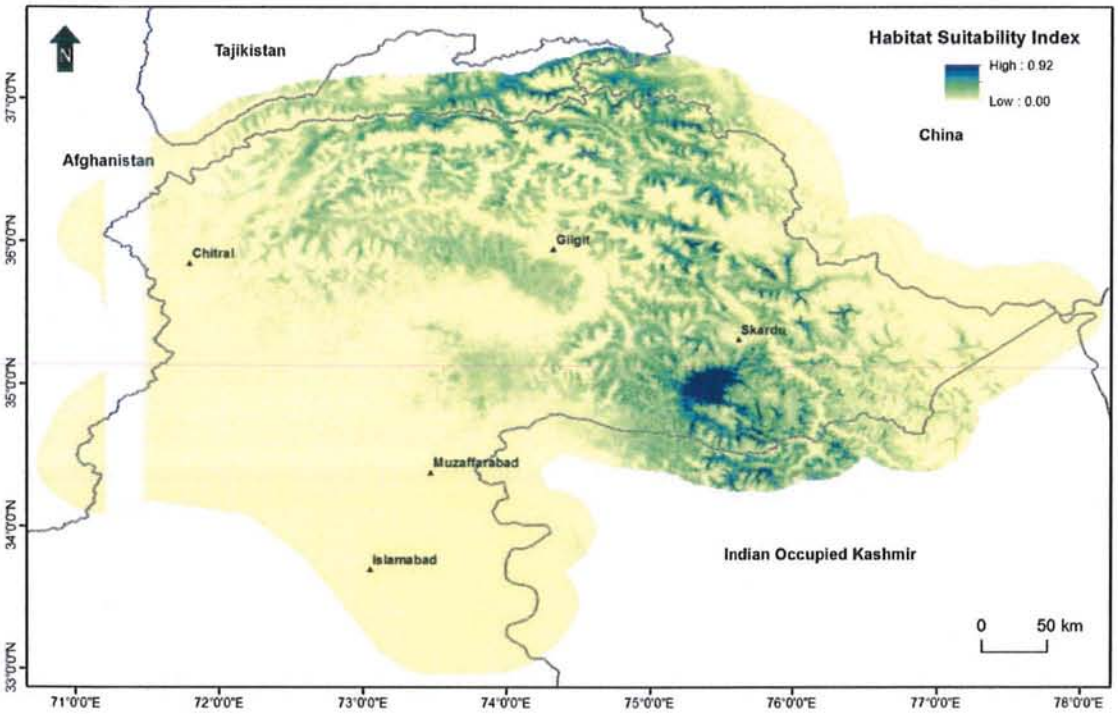


Figure 3.3. Brown bear habitat suitability in Pakistan, calculated with MaxEnt.

3.3.2 Factors Determining Habitat Suitability

Several climatic and non-climatic factors contributed to brown bear habitat suitability in the present analysis. Variables with higher contributions in the MaxEnt model were temperature annual range (bio7) that contributed 49.1%. This was followed by the max temperature of the warmest month (bio5, 13.2%), precipitation seasonality (bio15, 11.6%), and land cover (8%). Factors with the least contribution in determining habitat suitability were rivers (0.3%), settlements (0.3%), slope (0.9%), mean diurnal range (bio2, 1.6%), and roads (1.9%) (Table 3.2). The NDVI contribution was zero.

The Jackknife test of variable importance showed that the environmental variable with the highest gain, when used in isolation, was bio7, which, therefore, appeared to have the most useful information by itself. The environmental variable that decreases the gain the most when it was omitted was bio7, which, therefore, appeared to have the most information that was not present in the other variables. Values shown are averages over replicate runs (Figure 3.4).

Table 3.2. Estimates of relative contributions of the environmental variables to the Maxent model.

Variable	*Interpretation*	*Percent contribution*	*Permutation importance*

bio7	Temperature annual range	49.1	51.4
bio5	Max temperature of the warmest month	13.2	17.4
bio15	Precipitation seasonality	11.6	14.1
glc2000	Land cover	8	0.8
soil	Soil	3.9	2.8
bio13	Precipitation of wettest month	3.8	6.8
vrmint	Vector ruggedness measure	2.8	1.2
glaciers	Glaciers in the area	2.7	2.1
road	Density of roads	1.9	0.8
bio2	Mean diurnal range (Mean of monthly (max temp - min temp))	1.6	1.6
slope	The slope of the area	0.9	0.3
settlement	Density of Settlement	0.3	0.3
river	Density of rivers	0.3	0.1
ndvi	Normalized difference vegetation index	0.0	0.3

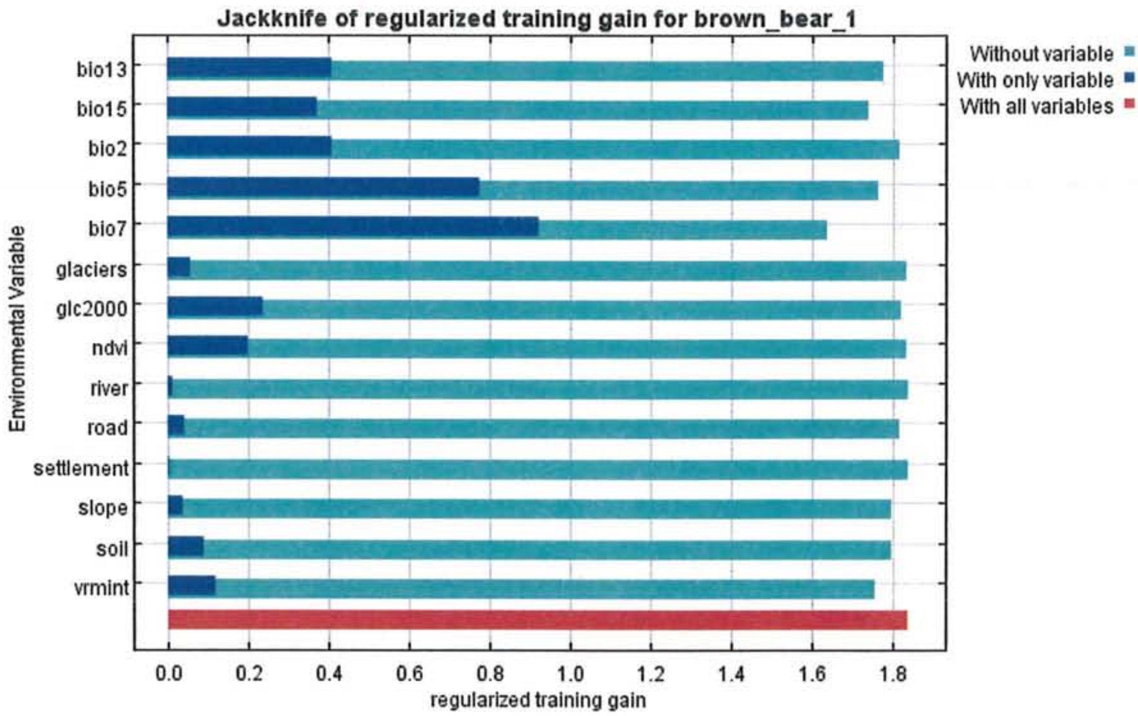


Figure 3.4. Jackknife test of variables in regularized training gain for brown bear in MaxEnt. The gain of variables tested in brown bear habitat suitability model. Blue bar= the gain when

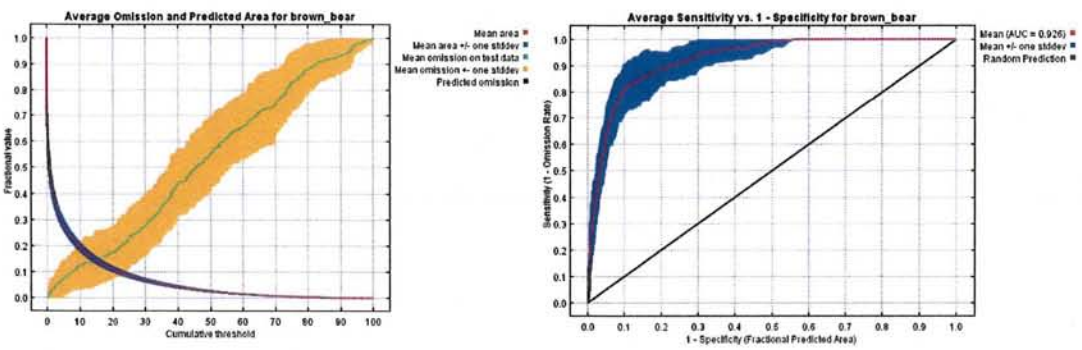
the environmental variable is used in isolation, Green bar= the gain when the environmental variable is omitted, Red bar= the gain with all environmental variables.

3.3.3 Model Evaluation and Threshold Selection

Some basic statistics were performed on the model by MaxEnt, and an average AUC for the model was calculated. An analysis of omission/commission showed the test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs (Figure 3.5a). The omission rate should be close to the predicted omission because of the definition of the cumulative threshold and, in our case, was very close to the predicted one.

MaxEnt also calculated the ROC curve for the same data, again averaged over the replicate runs (Figure 3.5b). The specificity was defined using predicted area rather than true commission. The average test AUC for the replicate runs was 0.926 ± 0.026 (SD).

The lowest error was recorded at a threshold of 0.05 while measuring the error of false-negative (FN) and false positive (FP) rates against a range of defined thresholds (Figure 3.6). By plotting the absence and presence points, the binomial map was reassessed. The location of points on the map showed that all absence points fell in the area unsuitable for brown bears, while the presence points fell in a suitable area.



a b

Figure 3.5 Model evaluations, (a) Predicted area and averaged omission for brown bear, (b) The ROC curve calculated by MaxEnt as 1-specificity vs averaged sensitivity for brown bear.

The values of 44 absence and 35 presence locations were extracted from the model and plotted against different thresholds. The value of AUC by ROC curve calculated at 0.44 was 1.000—which means our model performed very well. It was calculated that 34 points were true positives (TPs) and 43 were true negatives (TNs), while FPs were 1 and FNs were 1. The true positive rate (TPR) was calculated at 0.971, while the false positive rate (FPR) was 0.023. Accuracy and specificity were calculated at 0.975 and 0.977, respectively, while the positive predictive value (PPV) was found to be 0.971, and the negative predictive value (NPV) was 0.977. The false discovery rate (FDR) was calculated at 0.029.

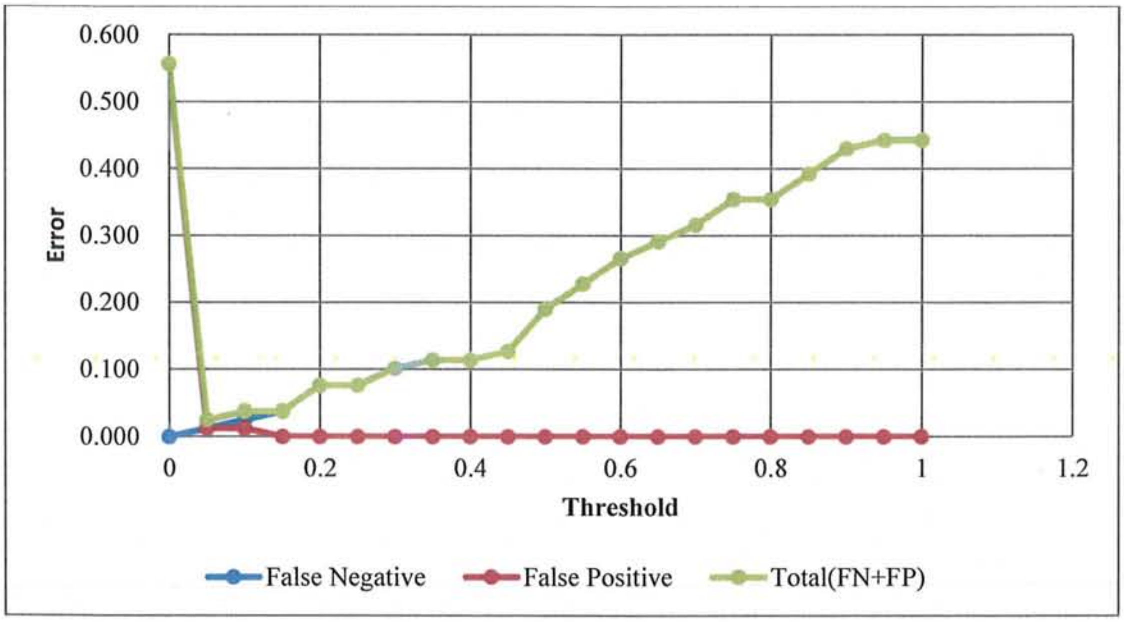


Figure 3.6. Relationship of False Positive and False Negative rates against different thresholds of the model prediction.

3.3.4 Potential Movement Corridors of the Brown Bear

The Circuitscape analysis showed the brown bear habitat connectivity pattern (Figure 3.8). The population of brown bears in the Pamir-Karakoram range is connected with the population of China and Afghanistan. The Hindu Kush population is isolated and has no connection with any other population. The Himalayan population has a weak connection with the population of Indian Administered Kashmir.

Inside Pakistan, the population of Laspur Valley, Yarkhun Valley, and Phandar Valley in the Hindu Kush are strongly connected, but this population is completely isolated and has no connection with any other brown bear population in Pakistan. The population of BNP has a strong connection with QNP, while the KNP population is strongly connected with the Chipurson and Misgar populations. In CKNP, the population of Hoper-Hisper has a connection with the population of Basha-Arandu, but this population has a very poor connection with the brown bear population in the upper part of the Karakorams (KNP, Chapursan, and Misgar). The population of DNP has a moderate connection with that of MDNP in Neelum Valley in the Himalayan region of Pakistan.

3.3.5 Protected Areas Coverage in Brown Bear Habitat in Pakistan

The habitat suitability model for the brown bear was also assessed against current protected area coverage in northern Pakistan. Our analysis revealed that most of the suitable brown bear habitat fell within protected areas (DNP, KNP, QNP, BNP, MDNP, and CKNP). However, there are some areas like Astore Valley, Laspur Valley, Yarkhun Valley, Phandar Valley, Kharmang Valley, Misgar Valley, and Chapursan Valley that are outside protected areas (Figure 3.7).

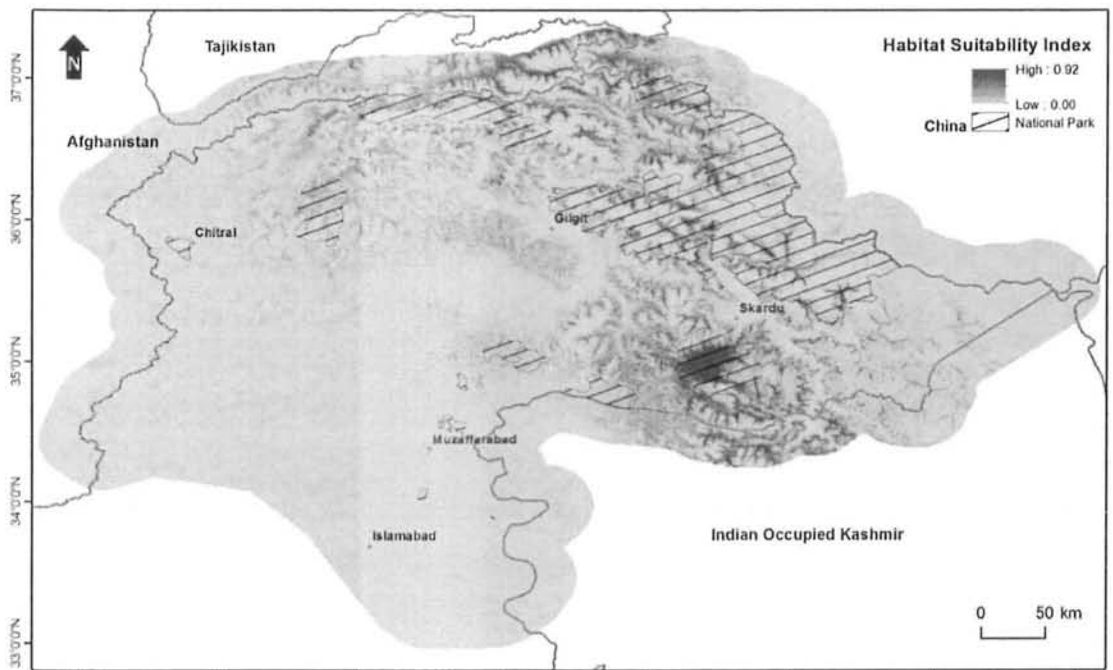


Figure 3.7. Overlay of existing national parks on habitat suitability map of brown bears.

The Circuitscape analysis also showed that most of the brown bear population within protected areas had either no connection or very poor connection. The population of DNP had no connection with CKNP and had very weak movement corridors with that of MDNP. Similarly, the CKNP population had no connection with that of KNP (Figure 3.8).

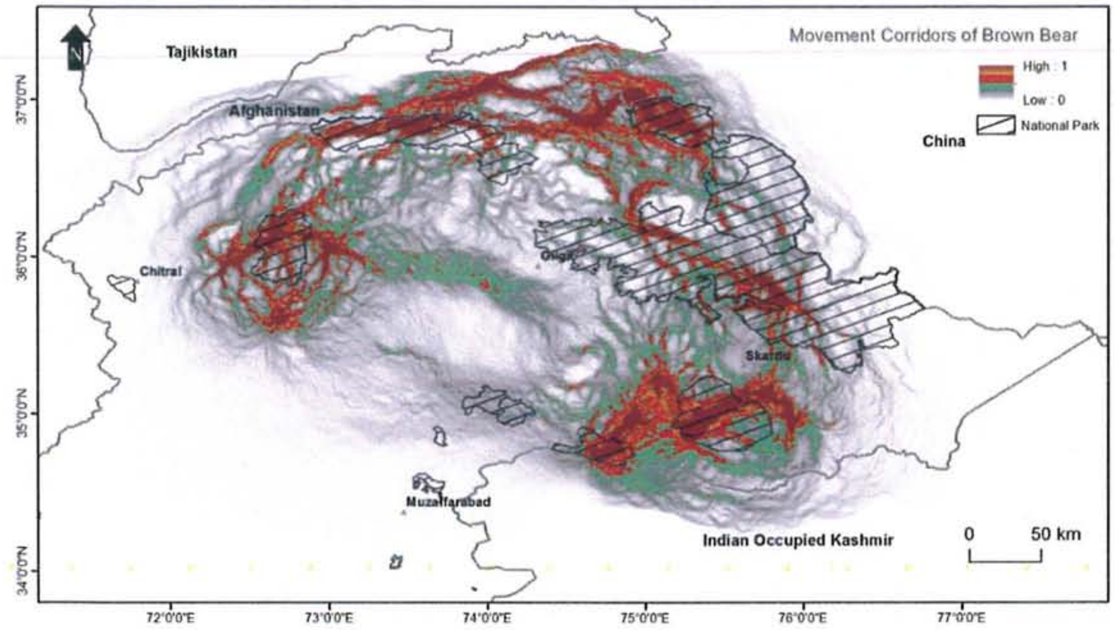


Figure 3.8. Potential movement corridors of brown bear, calculated through Circuitscape, between different National Parks in northern Pakistan. Low values represent weak connectivity.

3.4 DISCUSSION

This study was conducted at 20 different sites (31,000 km^2) across brown bear distribution range within Pakistan, covering 23.28% of the distribution range, adding a 30-km buffer area that included potential areas through which brown bears might move (Hameed et al., 2020). Various survey techniques, like camera trapping, site occupancy surveys, scat collection surveys and double-observer survey methods were used. Brown bear presence was confirmed at 184 locations in different study sites. The present study is the first study in Pakistan to document brown bear distribution (in Pakistan) based on habitat suitability analysis, as only a single study exists before this on suitable habitat for brown bears in DNP (Nawaz et al., 2014). Su et al. (2018) carried out a habitat suitability analysis for the brown bears of Central Asia and the Asian Highlands, and document a suitable area of 68,503 km^2 within Pakistan. The current study revealed that the area of suitable habitat in Pakistan is about 58,424.56 km^2 which is less than China (2,259,810 km^2) and India (141,002 km^2) while greater than Afghanistan (47,474.70 km^2). Furthermore, Su et al. (2018) study showed suitable habitat in the Hindu Kush range, while Nawaz (2007) showed that the species is rare in the Hindu Kush and extirpated from a large part of Chitral district (Hameed et al., 2021 in press). For example, it has been wiped out from CGNP and surrounding areas (Mirza, 2003). Additionally, Su et al.'s (2018) study showed the Siachen glacier as suitable habitat for brown bear but this is not possible because this glacier is one of the largest and there is no available food for brown bears. In comparison to the IUCN distribution range of brown bears in Pakistan, the present analysis shows that much of the previous brown bear distribution area is either low suitability or completely unsuitable.

Many populations of brown bear are now isolated and of conservation concern, particularly in the southern parts of their distribution range (McLellan et al., 2017). In many parts of the brown bear distribution range, the phylogeography has been studied comprehensively (Hirata et al., 2013), but information about population status in Central Asia is very little, and many of these populations are further fragmented into several other small populations and listed as critically endangered by the IUCN (McLellan et al., 2017). This study shows that brown bears in Pakistan are distributed in Hindu Kush, Himalayas, Karakoram and Pamir ranges, and some populations are either completely isolated, like the populations in the Hindu Kush range and Himalayan ranges, or have very poor connectivity (Nawaz, 2007), e.g., the population of CKNP has poor connectivity with KNP and surrounding areas. On the other hand, a few populations like QNP and BNP have well-connected corridors, and these populations are also connected with KNP and surrounding areas.

Habitat loss and fragmentation are significant threats to the persistence of wildlife populations because they can decrease the functional connectivity of the landscape (Goodwin and Fahrig, 2002). Low functional connectivity can result in small isolated populations that have an increased risk of extinction because of inbreeding depression, demographic stochasticity and reduced opportunities for rescue (Keller and Waller, 2002; O'Grady et al., 2006). Thus, identifying and protecting landscapes with high functional connectivity could have substantial conservation benefits. Circuit theory can be applied to predict the movement patterns and probabilities of successful dispersal or mortality of random walkers moving across complex landscapes, to generate measures of connectivity or isolation of habitat patches, populations, or protected areas, and to identify important connective elements (e.g., corridors) for conservation planning (McRae et al., 2008). The establishment of movement corridors can offset the negative effects of habitat fragmentation by connecting isolated habitat populations or patches (Wang et al., 2014). Nevertheless, core habitats remain a priority for protection as they sustain viable populations. Corridors facilitate the movement of animals across larger landscapes, particularly through fragmented and less suitable areas, to maintain gene flow and connectivity among populations at the regional level.

The connectivity models show that brown bears in some areas favour movement across the border, e.g., the population of BNP and QNP had connected with Afghanistan. Similarly, the population of KNP had connectivity with China, but the population of these areas is also interconnected. Also, KNP and CKNP did not show any connectivity at their shared border, but there is a weak movement corridor between these two parks. These connectivity patterns appear unusual on maps, but other factors like the presence of large glaciers explain the absence of any movement corridors at the borders of these parks.

Our habitat suitability model was also useful for assessing the effectiveness of existing protected areas, specifically national parks in brown bear habitat. The habitat suitability analysis shows that most of the highly suitable habitats of brown bears are within protected areas (DNP, MDNP, KNP, CKNP, QBP, and BNP), but some outside protected areas, e.g., Astore Valley, Yarkhun Valley, Laspur Valley, Phandar Valley, Kharmang Valley, Misgar Valley, and Chapursan valley, are also highly suitable. Any loss to suitable brown bear habitat may result in moving bears out of suitable habitat, and such movement may increase human-bear interaction and bear mortality (Su et al., 2018). Recently, the Government of Pakistan declared two areas in the brown bear range as protected areas—the Himalaya National Park and Nanga Parbat National Park, covering an area of about 3,600 km^2. Proper management and protection in these two parks will help protect brown bear habitat, particularly in Astore Valley. There are still many areas that should be considered for inclusion in the protected areas network, e.g., Misgar and Chapursan, Yarkhun Valley, Laspur Valley, and Phandar Valley to safeguard the future of the species. Misgar and Chapursan are within two national parks

(KNP and QNP), but both valleys are unprotected (Hameed et al., 2020). Similarly, Shandur Handarab National Park is under proposal, and if it is declared a national park, it will safeguard highly suitable brown bear habitat in Yarkhun Valley, Laspur Valley, and Phandar Valley.

There are two main constraints in present brown bear habitat suitability modelling. First, the low number presence of brown bears in the majority of areas due to their sparse distribution and their rarity throughout the landscape. Second, the non-availability of data about the estimation of its prey.

3.4.1 Management Implications

This study is the first on the habitat suitability of threatened brown bears across their distribution using multiple survey techniques. Many isolated brown bears have been identified across the Hindu Kush, Himalayan, and Karakoram ranges in Pakistan. Most suitable brown bear habitat occurs inside protected areas like DNP, KNP, QNP, and BNP. However, this assessment identified some suitable habitats and important movement corridors outside protected areas that need to be protected. Based on this, it is recommended that the Misghar and Chipurson valleys be included in the list of protected areas and that the proposed Shandur Handarab National Park be given the status of a protected area. This will help protect highly suitable brown bear habitat in Yarkhun Valley, Laspur Valley, and Phandar Valley.

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3.6 REFERENCES

Ahmad, S., Hameed, S., Ali, H., Khan, T.U., Mehmood, T., Nawaz, M.A., 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res.

https://doi.org/10.1007/s10344-016-1029-6

Araujo, M., Pearson, R., Thuiller, W., Erhard, M., 2005. Validation of species-climate impact models under climate change. Glob. Chang. Biol. https://doi.org/10.1111/j.1365-2486.2005.001000.x

Aryal, A., Brunton, D., Ji, W., Barraclough, R.K., Raubenheimer, D., 2014. Human-carnivore conflict: Ecological and economical sustainability of predation on livestock by snow leopard and other carnivores in the Himalaya. Sustain. Sci. https://doi.org/10.1007/s11625-014-0246-8

Aryal, A., Shrestha, U.B., Ji, W., Ale, S.B., Shrestha, S., Ingty, T., Maraseni, T., Cockfield, G., Raubenheimer, D., 2016. Predicting the distributions of predator (snow leopard) and prey (blue sheep) under climate change in the Himalaya. Ecol. Evol. 6, 4065–4075.

Bai, D.F., Chen, P.J., Atzeni, L., Cering, L., Li, Q., Shi, K., 2018. Assessment of habitat suitability of the snow leopard (Panthera uncia) in Qomolangma National Nature Reserve based on MaxEnt modeling. Zool. Res. https://doi.org/10.24272/j.issn.2095-8137.2018.057

Baldwin, R.A., 2009. Use of maximum entropy modeling in wildlife research. Entropy 11, 854–866. https://doi.org/10.3390/e11040854

Beier, P., Noss, R.F., 1998. Do habitat corridors provide connectivity? Conserv. Biol. https://doi.org/10.1111/j.1523-1739.1998.98036.x

Bischof, R., Hameed, S., Ali, H., Kabir, M., Younas, M., Shah, K.A., Din, J.U., Nawaz, M.A., 2014. Using time-to-event analysis to complement hierarchical methods when assessing determinants of photographic detectability during camera trapping. Methods Ecol. Evol. 5. https://doi.org/10.1111/2041-210X.12115

Booth, G.D., Niccolucci, M.J., Schuster, E.G., 1994. Identifying proxy sets in multiple linear-regression - an aid to better coefficient interpretation. USDA For. Serv. Intermt. Res. Stn. Res. Pap.

Bosso, L., Mucedda, M., Fichera, G., Kiefer, A., Russo, D., 2016. A gap analysis for threatened bat populations on Sardinia. Hystrix. https://doi.org/10.4404/hystrix-27.2-11788

Christie, M.R., Knowles, L.L., 2015. Habitat corridors facilitate genetic resilience irrespective of species dispersal abilities or population sizes. Evol. Appl. https://doi.org/10.1111/eva.12255

Clements, G.R., Rayan, D.M., Aziz, S.A., Kawanishi, K., Traeholt, C., Magintan, D., Yazi, M.F.A., Tingley, R., 2012. Predicting the distribution of the Asian tapir in Peninsular Malaysia using maximum entropy modeling. Integr. Zool. https://doi.org/10.1111/j.1749-4877.2012.00314.x

Crooks, K.R., Burdett, C.L., Theobald, D.M., Rondinini, C., Boitani, L., 2011. Global patterns of fragmentation and connectivity of mammalian carnivore habitat. Philos. Trans. R. Soc. B Biol. Sci. https://doi.org/10.1098/rstb.2011.0120

Cushman, S.A., Landguth, E.L., Flather, C.H., 2013. Evaluating population connectivity for species of conservation concern in the American Great Plains. Biodivers. Conserv. https://doi.org/10.1007/s10531-013-0541-1

Dai, Y., Hacker, C.E., Zhang, Yuguang, Li, W., Zhang, Yu, Liu, H., Zhang, J., Ji, Y., Xue, Y., Li, D., 2019. Identifying climate refugia and its potential impact on Tibetan brown bear (*Ursus arctos pruinosus*) in Sanjiangyuan National Park, China. Ecol. Evol. https://doi.org/10.1002/ece3.5780

Di Marco, M., Boitani, L., Mallon, D., Hoffmann, M., Iacucci, A., Meijaard, E., Visconti, P., Schipper, J., Rondinini, C., 2014. A Retrospective evaluation of the global decline of carnivores and ungulates. Conserv. Biol. https://doi.org/10.1111/cobi.12249

Di Minin, E., Slotow, R., Hunter, L.T.B., Montesino Pouzols, F., Toivonen, T., Verburg, P.H., Leader-Williams, N., Petracca, L., Moilanen, A., 2016. Global priorities for national carnivore conservation under land use change. Sci. Rep. https://doi.org/10.1038/srep23814

Fielding, A.H., Bell, J.F., 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ. Conserv. 24, 38–49.

Fourcade, Y., Engler, J.O., Rödder, D., Secondi, J., 2014. Mapping species distributions with MAXENT using a geographically biased sample of presence data: A performance assessment of methods for correcting sampling bias. PLoS One 9, 1–13. https://doi.org/10.1371/journal.pone.0097122

Galbreath, G.J., Groves, C.P., Waits, L.P., 2007. Genetic resolution of composition and phylogenetic placement of the Isabelline Bear. Ursus. https://doi.org/10.2192/1537-6176(2007)18[129:GROCAP]2.0.CO;2

Ghoddousi, A., Bleyhl, B., Sichau, C., Ashayeri, D., Moghadas, P., Sepahvand, P., Kh Hamidi, A., Soofi, M., Kuemmerle, T., 2020. Mapping connectivity and conflict risk to identify safe corridors for the Persian leopard. Landsc. Ecol. https://doi.org/10.1007/s10980-020-01062-0

Gomes, V.H.F., Ijff, S.D., Raes, N., Amaral, I.L., Salomão, R.P., Coelho, L.D.S., Matos, F.D.D.A., Castilho, C. V., Filho, D.D.A.L., López, D.C., Guevara, J.E., Magnusson, W.E., Phillips, O.L., Wittmann, F., Carim, M.D.J.V., Martins, M.P., Irume, M.V., Sabatier, D., Molino, J.F., Bánki, O.S., Guimarães, J.R.D.S., Pitman, N.C.A., Piedade, M.T.F., Mendoza, A.M., Luize, B.G., Venticinque, E.M., Novo, E.M.M.D.L., Vargas, P.N., Silva, T.S.F., Manzatto, A.G., Terborgh, J., Reis, N.F.C., Montero, J.C., Casula, K.R., Marimon, B.S., Marimon, B.H., Coronado, E.N.H., Feldpausch, T.R., Duque, A., Zartman, C.E., Arboleda, N.C., Killeen, T.J., Mostacedo, B., Vasquez, R., Schöngart, J., Assis, R.L., Medeiros, M.B., Simon, M.F., Andrade, A., Laurance, W.F., Camargo, J.L., Demarchi, L.O., Laurance, S.G.W., Farias, E.D.S., Nascimento, H.E.M., Revilla, J.D.C., Quaresma, A., Costa, F.R.C., Vieira, I.C.G., Cintra, B.B.L., Castellanos, H., Brienen, R., Stevenson, P.R., Feitosa, Y., Duivenvoorden, J.F., Aymard, G.A.C., Mogollón, H.F., Targhetta, N., Comiskey, J.A., Vicentini, A., Lopes, A., Damasco, G., Dávila, N., García-Villacorta, R., Levis, C., Schietti, J., Souza, P., Emilio, T., Alonso, A., Neill, D., Dallmeier, F., Ferreira, L.V., Araujo-Murakami, A., Praia, D., Do Amaral, D.D., Carvalho, F.A., De Souza, F.C., Feeley, K., Arroyo, L., Pansonato, M.P., Gribel, R., Villa, B., Licona, J.C., Fine, P.V.A., Cerón, C., Baraloto, C., Jimenez, E.M., Stropp, J., Engel, J., Silveira, M., Mora, M.C.P., Petronelli, P., Maas, P., Thomas-Caesar, R., Henkel, T.W., Daly, D., Paredes, M.R., Baker, T.R., Fuentes, A., Peres, C.A., Chave, J., Pena, J.L.M., Dexter, K.G., Silman, M.R., Jørgensen, P.M., Pennington, T., Di Fiore, A., Valverde, F.C., Phillips, J.F., Rivas-Torres, G., Von Hildebrand, P., Van Andel, T.R., Ruschel, A.R., Prieto, A., Rudas, A., Hoffman, B., Vela, C.I.A., Barbosa, E.M., Zent, E.L., Gonzales, G.P.G., Doza, H.P.D., Miranda, I.P.D.A., Guillaumet, J.L., Pinto, L.F.M., Bonates, L.C.D.M., Silva, N., Gómez, R.Z., Zent, S., Gonzales, T., Vos, V.A., Malhi, Y., Oliveira, A.A., Cano, A., Albuquerque, B.W., Vriesendorp, C., Correa, D.F., Torre, E.V., Van Der Heijden, G., Ramirez-Angulo, H., Ramos, J.F., Young, K.R., Rocha, M., Nascimento, M.T., Medina, M.N.U., Tirado, M., Wang, O., Sierra, R., Torres-Lezama, A., Mendoza, C., Ferreira, C., Baider, C., Villarroel, D., Balslev, H., Mesones, I., Giraldo, L.E.U., Casas, L.F., Reategui, M.A.A., Linares-Palomino, R., Zagt, R., Cárdenas, S., Farfan-Rios, W., Sampaio, A.F., Pauletto, D., Sandoval, E.H.V., Arevalo, F.R., Huamantupa-Chuquimaco, I., Garcia-Cabrera, K., Hernandez, L., Gamarra, L.V., Alexiades, M.N., Pansini, S., Cuenca, W.P., Milliken, W., Ricardo, J., Lopez-Gonzalez, G., Pos, E., Ter Steege, H., 2018. Species Distribution Modelling: Contrasting presence-only models with plot abundance data. Sci. Rep. https://doi.org/10.1038/s41598-017-18927-1

Goodwin, B.J., Fahrig, L., 2002. How does landscape structure influence landscape connectivity? Oikos. https://doi.org/10.1034/j.1600-0706.2002.11824.x

Guisan, A., Thuiller, W., 2005. Predicting species distribution: Offering more than simple habitat models. Ecol. Lett. https://doi.org/10.1111/j.1461-0248.2005.00792.x

Hameed, S., ud Din, J., Ali, H., Kabir, M., Younas, M., Hao, W., Bischof, R., Nawaz, M.A., 2020. Identifying priority landscapes for conservation of snow leopards in Pakistan. bioRxiv. https://doi.org/10.1101/2020.01.27.920975

Hirata, D., Mano, T., Abramov, A. V., Baryshnikov, G.F., Kosintsev, P.A., Vorobiev, A.A., Raichev, E.G., Tsunoda, H., Kaneko, Y., Murata, K., Fukui, D., Masuda, R., 2013. Molecular phylogeography of the brown bear (*ursus arctos*) in Northeastern Asia based on analyses of complete mitochondrial DNA sequences. Mol. Biol.

Evol. https://doi.org/10.1093/molbev/mst077

Huck, M., Jedrzejewski, W., Borowik, T., Miłosz-Cielma, M., Schmidt, K., Jedrzejewska, B., Nowak, S., Mysłajek, R.W., 2010. Habitat suitability, corridors and dispersal barriers for large carnivores in Poland. Acta Theriol. (Warsz). https://doi.org/10.4098/j.at.0001-7051.114.2009

Jacobose, J.P., 1993. Climatic records from Northern Areas of Pakistan. Culture Area Karakorum Newsletter 3, 13-17.

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2006. Estimating Snow Leopard Population Abundance Using Photography and Capture–Recapture Techniques. Wildl. Soc. Bull. https://doi.org/10.2193/0091-7648(2006)34[772:eslpau]2.0.co;2

Japan Bear Network, 2006. Understanding Asian Bears to Secure Their Future, Japan Bear Network.

Kabir, M., Hameed, S., Ali, H., Bosso, L., Din, J.U., Bischof, R., Redpath, S., Nawaz, M.A., 2017. Habitat suitability and movement corridors of grey wolf (*Canis lupus*) in Northern Pakistan. PLoS One. https://doi.org/10.1371/journal.pone.0187027

Keller, L.F., Waller, D.M., 2002. Inbreeding effects in wild populations. Trends Ecol. Evol. https://doi.org/10.1016/S0169-5347(02)02489-8

Koen, E.L., Bowman, J., Sadowski, C., Walpole, A.A., 2014. Landscape connectivity for wildlife: Development and validation of multispecies linkage maps. Methods Ecol. Evol. https://doi.org/10.1111/2041-210X.12197

Koen, E.L., Bowman, J., Walpole, A.A., 2012. The effect of cost surface parameterization on landscape resistance estimates. Mol. Ecol. Resour. https://doi.org/10.1111/j.1755-0998.2012.03123.x

Kramer-Schadt, S., Niedballa, J., Pilgrim, J.D., Schröder, B., Lindenborn, J., Reinfelder, V., Stillfried, M., Heckmann, I., Scharf, A.K., Augeri, D.M., Cheyne, S.M., Hearn, A.J., Ross, J., Macdonald, D.W., Mathai, J., Eaton, J., Marshall, A.J., Semiadi, G., Rustam, R., Bernard, H., Alfred, R., Samejima, H., Duckworth, J.W., Breitenmoser-Wuersten, C., Belant, J.L., Hofer, H., Wilting, A., 2013. The importance of correcting for sampling bias in MaxEnt species distribution models. Divers. Distrib. https://doi.org/10.1111/ddi.12096

Ma, B., Sun, J., 2018. Predicting the distribution of Stipa purpurea across the Tibetan Plateau via the MaxEnt model. BMC Ecol. https://doi.org/10.1186/s12898-018-0165-0

McLellan, B.N., Proctor, M.F., Huber, D., Michel, S., 2017. Ursus arctos (amended version of 2017 assessment), The IUCN Red List of Threatened Species. IUCN.

McRae, B.H., Beier, P., 2007. Circuit theory predicts gene flow in plant and animal populations. Proc. Natl. Acad. Sci. U. S. A. https://doi.org/10.1073/pnas.0706568104

McRae, B.H., Dickson, B.G., Keitt, T.H., Shah, V.B., 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89, 2712–2724.

McRae, B.H., Shah, V.B., 2009. Circuitscape user's guide. Univ. California, St. Barbar.

McRae BH, 2006. Isolation by resistance. Evolution (N. Y).

Merow, C., Silander, J.A., 2014. A comparison of Maxlike and Maxent for modelling species distributions. Methods Ecol. Evol. https://doi.org/10.1111/2041-210X.12152

Mirza, Z.B., 2003. Biological baseline study of Chitral Gol National Park. Report prepared for the Protected Areas Management Project, Chitral, Pakistan.

Mölg, N., Bolch, T., Rastner, P., Strozzi, T., Paul, F., 2018. A consistent glacier inventory for Karakoram and Pamir derived from Landsat data: Distribution of debris cover and mapping challenges. Earth Syst. Sci. Data. https://doi.org/10.5194/essd-10-1807-2018

Nawaz, M.A., 2007. Status of the brown bear in Pakistan. Ursus.

https://doi.org/10.2192/1537-6176(2007)18[89:SOTBBI]2.0.CO;2

Nawaz, M.A., Martin, J., Swenson, J.E., 2014. Identifying key habitats to conserve the threatened brown bear in the Himalaya. Biol. Conserv. https://doi.org/10.1016/j.biocon.2013.12.031

Nawaz, M.A., Swenson, J.E., Zakaria, V., 2008. Pragmatic management increases a flagship species, the Himalayan brown bears, in Pakistan's Deosai National Park. Biol. Conserv. https://doi.org/10.1016/j.biocon.2008.06.012

O'Grady, J.J., Brook, B.W., Reed, D.H., Ballou, J.D., Tonkyn, D.W., Frankham, R., 2006. Realistic levels of inbreeding depression strongly affect extinction risk in wild populations. Biol. Conserv. https://doi.org/10.1016/j.biocon.2006.05.016

Pearson, R.G., Thuiller, W., Araújo, M.B., Martinez-Meyer, E., Brotons, L., McClean, C., Miles, L., Segurado, P., Dawson, T.P., Lees, D.C., 2006. Model-based uncertainty in species range prediction. J. Biogeogr. 33, 1704–1711. https://doi.org/10.1111/j.1365-2699.2006.01460.x

Phillips, S., 2008. Transferability, sample selection bias and background data in presence-only modelling: a response to Peterson et al. (2007). Ecography (Cop.). 0, 080227084236895–0. https://doi.org/10.1111/j.2007.0906-7590.05378.x

Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Modell. 190, 231–259.

Phillips, S.J., Dudík, M., 2008. Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation. Ecography (Cop.). https://doi.org/10.1111/j.0906-7590.2008.5203.x

Pound, M.J., Salzmann, U., 2017. Heterogeneity in global vegetation and terrestrial climate change during the late Eocene to early Oligocene transition. Sci. Rep. https://doi.org/10.1038/srep43386

R Core Team, 2019. R: A language and environment for statistical computing. R Found. Stat. Comput.

Radosavljevic, A., Anderson, R.P., 2014. Making better Maxent models of species distributions: Complexity, overfitting and evaluation. J. Biogeogr. https://doi.org/10.1111/jbi.12227

Reddy, M.T., Begum, H., Sunil, N., Pandravada, S.R., Sivaraj, N., Kumar, S., 2015. Mapping the Climate Suitability Using MaxEnt Modeling Approach for Ceylon Spinach (*Basella alba L.*) Cultivation in India. J. Agric. Sci. 10, 87. https://doi.org/10.4038/jas.v10i2.8054

Roberts, T.J., d'Olanda.), B. (principe, 1977. The mammals of Pakistan.

Roscioni, F., Rebelo, H., Russo, D., Carranza, M.L., Di Febbraro, M., Loy, A., 2014. A modelling approach to infer the effects of wind farms on landscape connectivity for bats. Landsc. Ecol. https://doi.org/10.1007/s10980-014-0030-2

Roscioni, F., Russo, D., Di Febbraro, M., Frate, L., Carranza, M.L., Loy, A., 2013. Regional-scale modelling of the cumulative impact of wind farms on bats. Biodivers. Conserv. https://doi.org/10.1007/s10531-013-0515-3

Roura-Pascual, N., Brotons, L., Peterson, A.T., Thuiller, W., 2009. Consensual predictions of potential distributional areas for invasive species: A case study of Argentine ants in the Iberian Peninsula. Biol. Invasions. https://doi.org/10.1007/s10530-008-9313-3

Schaller, G.B., 1976. Mountain Mammals in Pakistan. Oryx. https://doi.org/10.1017/S0030605300014071

Servheen, C., Herrero, S., Peyton, B., 1999. Status Survey and Conservation Action Plan for Bears. IUCN/SSC Bear and Polar Bear Specialist Groups. Gland. Switz. Cambridge, UK.

Sheehan, K.L., Esswein, S.T., Dorr, B.S., Yarrow, G.K., Johnson, R.J., 2017. Using species distribution models to define nesting habitat of the eastern metapopulation of double-crested cormorants. Ecol. Evol. https://doi.org/10.1002/ece3.2620

Sheikh, K., Molur, S., 2005. Status and red list of Pakistan's mammals, based on conservation assessment and management plan for mammals. IUCN, Pakistan 344.

Smeraldo, S., Di Febbraro, M., Ćirović, D., Bosso, L., Trbojević, I., Russo, D., 2017. Species distribution models as a tool to predict range expansion after reintroduction: A case study on Eurasian beavers (*Castor fiber*). J. Nat. Conserv. https://doi.org/10.1016/j.jnc.2017.02.008

Su, J., Aryal, A., Hegab, I.M., Shrestha, U.B., Coogan, S.C.P., Sathyakumar, S., Dalannast, M., Dou, Z., Suo, Y., Dabu, X., Fu, H., Wu, L., Ji, W., 2018. Decreasing brown bear (*Ursus arctos*) habitat due to climate change in Central Asia and the Asian Highlands. Ecol. Evol. https://doi.org/10.1002/ece3.4645

Subba, S.A., Shrestha, A.K., Thapa, K., Malla, S., Thapa, G.J., Shrestha, Sujeet, Shrestha, Shrota, Subedi, N., Bhattarai, G.P., Ottvall, R., 2017. Distribution of grey wolves *Canis lupus lupus* in the Nepalese Himalaya: Implications for conservation management. ORYX. https://doi.org/10.1017/S0030605316000296

Summers, D.M., Bryan, B.A., Crossman, N.D., Meyer, W.S., 2012. Species vulnerability to climate change: Impacts on spatial conservation priorities and species representation. Glob. Chang. Biol. 18, 3268. https://doi.org/10.1111/j.1365-2486.2012.02771.x

Suryawanshi, K.R., Bhatnagar, Y.V., Mishra, C., 2012. Standardizing the double-observer survey method for estimating mountain ungulate prey of the endangered snow leopard. Oecologia. https://doi.org/10.1007/s00442-011-2237-0

Syfert, M.M., Smith, M.J., Coomes, D.A., 2013. The Effects of Sampling Bias and Model Complexity on the Predictive Performance of MaxEnt Species Distribution Models. PLoS One 8. https://doi.org/10.1371/journal.pone.0055158

Tischendorf, L., Fahrig, L., 2000. On the usage and measurement of landscape connectivity. Oikos. https://doi.org/10.1034/j.1600-0706.2000.900102.x

Tyre, A.J., Tenhumberg, B., Field, S.A., Niejalke, D., Parris, K., Possingham, H.P., 2003. Improving precision and reducing bias in biological surveys: Estimating false-negative error rates. Ecol. Appl. 13, 1790–1801. https://doi.org/10.1890/02-5078

Václavík, T., Meentemeyer, R.K., 2009. Invasive species distribution modeling (iSDM): Are absence data and dispersal constraints needed to predict actual distributions? Ecol. Modell. https://doi.org/10.1016/j.ecolmodel.2009.08.013

Vasudev, D., Fletcher, R.J., Goswami, V.R., Krishnadas, M., 2015. From dispersal constraints to landscape connectivity: Lessons from species distribution modeling. Ecography (Cop.). https://doi.org/10.1111/ecog.01306

Vedel-Sørensen, M., Tovaranonte, J., Bøcher, P.K., Balslev, H., Barfod, A.S., 2013. Spatial distribution and environmental preferences of 10 economically important forest palms in western South America. For. Ecol. Manage. https://doi.org/10.1016/j.foreco.2013.07.005

Walpole, A.A., Bowman, J., Murray, D.L., Wilson, P.J., 2012. Functional connectivity of lynx at their southern range periphery in Ontario, Canada. Landsc. Ecol. https://doi.org/10.1007/s10980-012-9728-1

Wang, F., McShea, W.J., Wang, D., Li, S., Zhao, Q., Wang, H., Lu, Z., 2014. Evaluating landscape options for corridor restoration between giant panda reserves. PLoS One. https://doi.org/10.1371/journal.pone.0105086

Wilting, A., Cord, A., Hearn, A.J., Hesse, D., Mohamed, A., Traeholdt, C., Cheyne, S.M., Sunarto, S., Jayasilan, M.A., Ross, J., Shapiro, A.C., Sebastian, A., Dech, S., Breitenmoser, C., Sanderson, J., Duckworth, J.W., Hofer, H., 2010. Modelling the species distribution of flat-headed cats (*Prionailurus planiceps*), an endangered South-East Asian small felid. PLoS One. https://doi.org/10.1371/journal.pone.0009612

Wolf, C., Ripple, W.J., 2016. Prey depletion as a threat to the world's large carnivores. R. Soc. Open Sci. https://doi.org/10.1098/rsos.160252

Yackulic, C.B., Chandler, R., Zipkin, E.F., Royle, J.A., Nichols, J.D., Campbell Grant, E.H., Veran, S., 2013. Presence-only modelling using MAXENT: When can we trust the inferences? Methods Ecol. Evol. 4, 236–243. https://doi.org/10.1111/2041-210x.12004

Zhang, Yu, Clauzel, C., Li, J., Xue, Y., Zhang, Yuguang, Wu, G., Giraudoux, P., Li, L., Li, D., 2019. Identifying refugia and corridors under climate change conditions for the Sichuan snub-nosed monkey (Rhinopithecus roxellana) in Hubei Province, China. Ecol. Evol. https://doi.org/10.1002/ece3.4815

APPENDIX 3.1

BEAR SIGHTING SHEET

Form Ref:____ ____ ___
(Block ID) (Team)

Block ID_____________Locality: ___________Date__________Time________________________

Team | A | B | Observer (s) ____________ Observation distance (m) ___________

N □□.□□□□□□ **E** □□.□□□□□□

Numbers Observed	**Size**			**Sex**						
	S	**M**	**L**	**M**	**F**	**Y**	**C1**	**C2**	**C3**	**U**

Pelage Color: ☐ Blonde ☐ Silver-tip ☐ Light brown ☐ Dark brown

White Patches

Present		Location of patch if present				
☐ Yes	☐ No	☐ Snout	☐ Ear tips	☐ Shoulder	☐ Neck	☐ other

Description of white patches, if present: ....

Activity on sighting: ☐ Grazing ☐ Digging ☐ Walking ☐ Resting
☐ Mating ☐ Nursing ☐ Other

Wind: ☐ Light ☐ Moderate ☐ Strong

Cloud cover: ☐ 0% ☐ 20% ☐ 50% ☐ ≥80%

Habitat: ☐ Marshy ☐ Grassy ☐ Stony ☐ Rocky

Identification and Group Relationships:
Comments:

Size: S = Small, M = Medium, L = Large

Sex: M = Male, F = Female, Y=Coy (Birth of this year), C1= 1 year old Cub, C2= 2 year old Cub, C3= 3 year old Cub, U = Unidentified

Ecology and Conflicts Dynamics of Apex Predators in Northern Pakistan

CHAPTER 4

Human Perceptions about the Himalayan Brown Bear and other Carnivores in Chitral district in the Hindu Kush Range, Pakistan

4 Human Perceptions about the Himalayan Brown Bear and other Carnivores in Chitral district in the Hindu Kush Range, Pakistan

ABSTRACT

The Himalayan brown bear (*Ursus arctos isabellinus*) historically occupied the vast mountain ranges of South and Central Asia. Their range has shrunken significantly in the past century and they currently live in small and isolated populations. Most of their range has not been surveyed; hence information on their distribution is largely based on anecdotal information and expert judgments. The present study investigated the species' current distribution in the Hindu Kush Range in Pakistan, gathering information on human-brown bear conflict along with other large carnivore species in the study area. Multiple survey techniques—questionnaire surveys, sign surveys and camera trapping—were used during the period 2008–2010 in five study blocks delineated on natural watersheds in Pakistan's Chitral district. Based on questionnaire surveys, sign surveys and direct sighting, Himalayan brown bear presence was confirmed only in the Yarkhun and Laspur valleys. Ninety-six respondents (59 from Laspur Valley and 37 from Broghil Valley) reported a total of 449 livestock losses (90 heads per year) to carnivore species—grey wolf (*Canis lupus*), snow leopard (*Panthera pardus*), Himalayan lynx (*Lynx lynx isabellinus*)—during the five-year (2005–2009) period, which translated into an economic loss of USD 34,297 (PKR 2,931,022); USD 357 (PKR 30,531) per household. Himalayan brown bear was not accounted for any livestock loss. Though the public was seen to be strongly against large carnivores, brown bear was considered 'less dangerous'. Despite limited conflict with humans, brown bear has lost a large part of its historical range in the Hindu Kush Range. The species is confined to the eastern valleys where it is maintaining connectivity with brown bear in Gilgit-Baltistan towards the east and with Afghan populations towards the west.

Keywords: Himalayan brown bear, *Ursus arctos isabellinus*, Grey wolf, Snow leopard, Himalayan lynx, Chitral, Conflict, Livestock loss, Perception, Carnivores.

4.1 INTRODUCTION

The Himalayan brown bear (*Ursus arctos isabellinus*) is a subspecies that represents an ancient lineage of the brown bear (Galbreath et al., 2007). The brown bear historically occupied the western Himalayas, Karakoram, Hindu Kush, Pamirs, western Kunlun Shan, and the Tian Shan ranges in South and Central Asia (Nawaz, 2008). In Pakistan, approximately 150–200 bears may survive in seven populations over approximately 150,000 km^2 across three provinces/states—Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and Azad Jammu and Kashmir (AJK) — (Nawaz, 2007). In KP, this species is distributed in Chitral, Kalam (Kohistan), Pallas Valley (Indus Kohistan) and Kaghan Valley (Nawaz, 2007; Roberts and d'Olanda), 1977). Chitral district, with an area of 14,850 km^2, provides the largest habitat in KP and marks the western extremity of the brown bear range in Pakistan. It is the high mountainous dry temperate area of the Hindu Kush Range that connects to brown bear habitat in Afghanistan towards the west (Nawaz, 2007), GB in the east, and a narrow strip of the Wakhan Corridor separating Chitral from Tajikistan in the North (Result, 2015). Brown bear presence has been reported from Trich Mir Valley (Schaller, 1976), Torkhow Valley and Yarkhun Valley in Chitral (Fulton, 1903; Nawaz, 2007; Schaller, 1976). However, the species is rare in the Hindu Kush Range (Nawaz, 2007) and extirpated from a large part of Chitral district. For example, it has been wiped out from Chitral Gol National Park and surrounding areas (Mirza, 2003).

Growing human population, expanding infrastructure, loss of habitat, increasing number of domestic animals, declines in food supply, climate change and increasing human dependence on natural resources are primary reasons contributing to a persistent decline in brown bear population in Pakistan. Unmanaged and growing tourism also contributes to population decline (Nawaz, 2007) by exposing pristine habitats to human movement, hoteling, camping and littering. Other threats include killing bears for their organs for regional or international trade in medicine, shooting out of excitement—people consider them harmful (Sheikh and Molur, 2005)—and capturing cubs to train for dancing and even bear-baiting (Roberts and d'Olanda), 1977). These threats exist throughout its distribution range in all three administrative divisions. The brown bear in Pakistan is, therefore, a Critically Endangered species in the Red List of Pakistan

Mammals (Sheikh and Molur, 2005) even though globally it is considered as Least Concern.

Human-carnivore conflict is a serious problem worldwide, and a primary driver of carnivore population declines (Broekhuis et al., 2017; Woodroffe et al., 2009). Various large carnivore species'—tiger (*Panthera tigris*), Mexican wolf (*Canis lupus baileyii*) and African lion (*Panthera leo*)—populations are decreasing due to such conflict (Michalski et al., 2006). Worldwide, human-carnivore conflict increases with the expansion of human populations (Naughton-Treves et al., 2003; Woodroffe, 2000), a dynamic that often results in local carnivore extinctions (Woodroffe, 2000). Human-carnivore conflict is complex and difficult to handle because of many factors, including livestock depredation and associated economic losses, religious values and the monetary value of wild animals' bones and body parts (Dickman, 2010).

Large carnivores constitute a naturally rare, ecologically important and increasingly threatened group of mammals (Estes et al., 2011; Ripple et al., 2014) that provide emotional, recreational and cultural benefits to society (Kellert et al., 1996). Facilitating coexistence between humans and carnivores is a global conservation and management challenge (Dickman et al., 2011; Treves et al., 2006). The complexity in resolving human-wildlife conflict arises from the presence of multi-predator systems—mitigation strategies tend to be species-specific. Documenting the nature and distribution of such conflicts is an important step towards ensuring that subsequent management and mitigation efforts are appropriately targeted (Morehouse and Boyce, 2017).

Conflict between humans and bears has drawn less attention than that of other large carnivores like felids (Macdonald et al., 2011) and canids (Macdonald and Sillero-Zubiri, 2004). Human-brown bear conflict occurs as a result of crop and beehive damage, livestock depredation and even human injuries and death and a gradually diminishing public tolerance for bears (Can et al., 2014; Qashqaei et al., 2014; Rigg et al., 2011). Human-brown bear conflicts are increasing in areas where bears are expanding into private lands bordering their areas of occurrence e.g. national parks, posing a threat to livestock and people.

Pastoral communities living near large carnivores tend to fall in the lowest income categories. Having to bear significant economic losses, people have a low tolerance for carnivores, their conservation, and the conservation of non-conflict species (Linkie et al., 2007). People's responses depend on tolerance levels (Frank et al., 2005) and they may resort to direct action using poison, hunting, or shooting.

Human-brown bear conflict is a significant issue in northern Pakistan, but there are very few studies describing such conflict despite wide prevalence. In Chitral district, for instance, no study has ever been conducted to gain an understanding of the nature and magnitude of human-bear conflict (or other human-carnivore connection) and develop suitable conservation plans. Brown bears have been reported from Chitral (Nawaz, 2007; Roberts and d'Olanda), 1977), but there have been no recorded scientific studies from Chitral to confirm bear occurrence, distribution, population trends and magnitude of conflict with humans as the area is remote and logistically challenging. This study was carried out in five valleys of Chitral district with two main objectives, i) updating brown bear distribution in the area and ii) evaluating the nature of human-brown bear conflict and the perceptions of local people. Alongside human bear conflict, we also documented human interaction with other carnivores of the study area.

4.2 MATERIAL AND METHODS

4.2.1 Study Area

Chitral Valley provides ideal growing conditions for at least 64 endemic plant species, 45 mammalian species, 195 bird species and 28 reptilian species (NWFP and IUCN Pakistan, 2004).The study area was selected based on the brown bear's potential distribution range in Chitral district and was divided into five blocks based on major watersheds viz., Chitral Gol National Park (CGNP) and surrounding areas (Tooshi Game Reserve (TGR), Koghozi Gol and Gaherate Gol), Mastuj Valley, Yarkhun Valley, Laspur Valley and Torkhow Valley, covering an area of 2504 km^2 (Figure 4.1). The weather in the study area is extremely harsh and cold in the winter but pleasant in the summer. Average summer temperatures range from 25 to 40°C but drop below 0°C in winter. The study area is outside the monsoon range and receives very little rainfall during summer. Winter precipitation occurs in the form of snow (Shah et al., 2013). The topography is represented by highly rugged and steep mountains that provide habitat for large numbers of flora and fauna. Dominant plant species include *Quercus baloot*, *Pinus gerardiana*, *Juniperus excelsa*, *Juniperus communis*, *Betula utilis*, *Salix spp.*, *Populus spp.*, *Ephedra spp.*, *Abies pindrow*, *Picea smithiana*, *Viburnum spp.*, *Tamarix* spp., *Rosa webbiana*, *Ephedra spp*., and *Artemisia spp.* (MACP, 2001). Mammalian species found in the study area are snow leopard (*Panthera uncia*), common leopard (*Panthera pardus*), Himalayan lynx (*Felis lynx isabellinus*), leopard cat (*Prionailurus bengalensis*), grey wolf (*Canis lupus*), red fox (*Vulpes vulpes*), Asiatic jackal (*Canis aureus*), Asiatic black bear (*Ursus thibetanus*), brown bear, stone marten (*Martes foina*), Kashmir flare-horned markhor (*Capra falconeri falconeri*), Siberian ibex (*Capra ibex sibirica*), Ladakh urial (*Ovis vignei vignei*), and the long-tailed marmot (*Marmota caudata*).

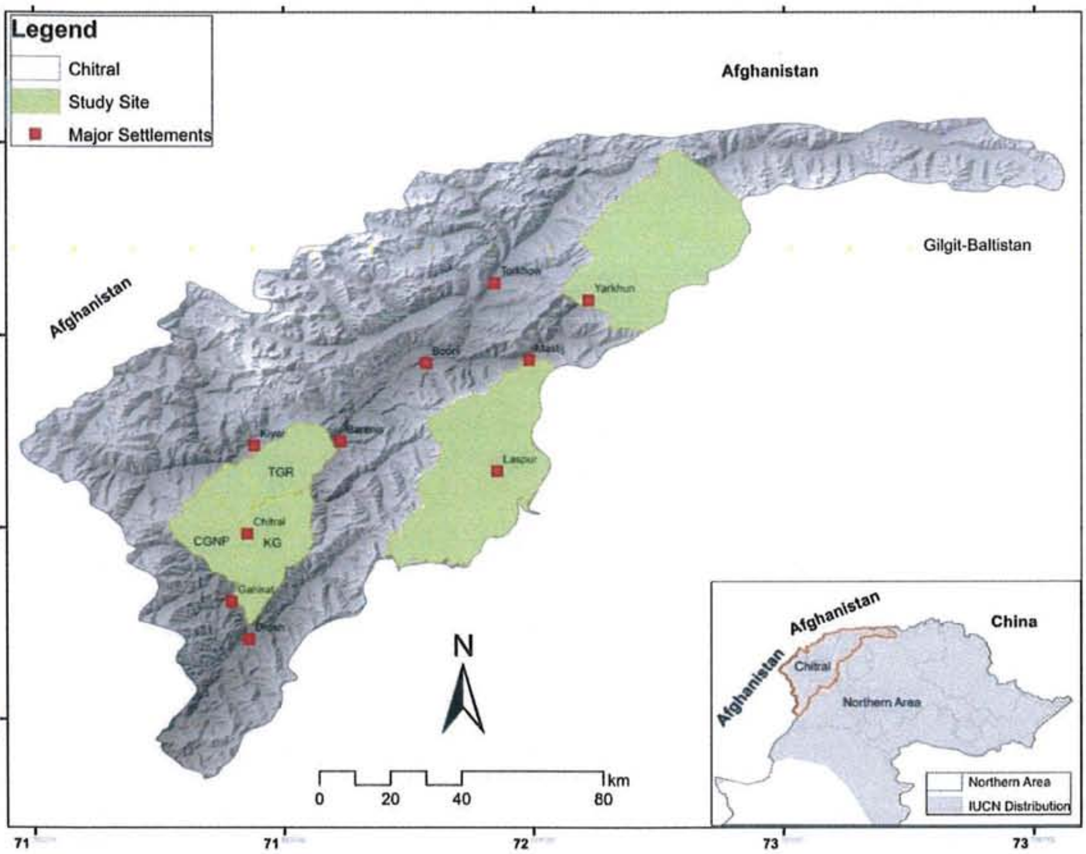

Figure 4.1. Map of Study Chitral showing study sites.

4.2.2 Survey Techniques

Multiple survey techniques were used during 2008–2010 to determine the brown bear's status and its conflict with locals in the study area.

4.2.2.1 Questionnaire Surveys

Human-carnivore conflict surveys were carried out in communities in Laspur Valley, Torkhow Valley, Yarkhun Valley, and Mastuj Valley during 2009–2010. Semi-structured questionnaire was used for interviews (Appendix 4.1). A total of 206 local people were interviewed about human-carnivore conflict (Table 4.1). The largest number (60) was interviewed in Mastuj Valley followed by 59 from three villages (Raman, Balim and Sor Laspur) in Laspur Valley, 37 from Rech and Ujnu villages in Torkhow Valley, 13 in Yarkhun Valley (various villages) and 37 in all the villages of Broghil.

Heads of households/adults were interviewed to gather information about the presence of brown bear and other carnivores, sightings, livestock depredation by carnivores, and perceptions about brown bear and other carnivores over the past five years (2005–2009). Questionnaire-based sighting reports were used to determine the presence-absence and human conflict between brown bears and other carnivores in the study area.

4.2.2.2 Sign Surveys

Sign surveys were conducted in potential brown bear habitat in Chitral. Seven sign surveys were conducted in six different areas of Chitral during the period September 2008–July 2010. These were conducted in three study blocks—CGNP and its surroundings (TGR, Koghozi Gol and Gaherate Gol), Laspur Valley and Yarkhun Valley (Table 4.1). In Yarkhun Valley, the sign surveys were carried out in 2010, while in Laspur Valley, sign surveys were conducted in both 2009 and 2010. Only Bashqar Gol was surveyed in the 2009 while the Phargram Gol, Bashqar Gol and Shandur areas of the valleys were surveyed in 2010. Random points were selected in the study area and a line transect of unequal length was walked at each sampling site. A total of 97 transects of 79.1 km were walked at different sampling sites (Table 4.1). The average length of the transect was 0.82 ±0.21 (SD) km and the length of the transect depended on topography and habitat type.

Information like GPS position, location, date, elevation and observer name were noted on transect survey forms at the starting point of each transect. Transects were walked slowly by 1-2 persons, searching for signs of brown bear on either side of the transect route. Whenever a sign was found, information like its location on GPS, type of sign (old or fresh) and substrate type was noted. Signs of other mammalian carnivore species found in the areas were also recorded. The above-mentioned information was noted on the survey form at the end point. Information about dominant topography of transect, primary habitat type, grazing status, ruggedness and overall aspect of the transect were also recorded.

4.2.2.3 Camera Trapping

Camera trapping is being used increasingly for the conservation and monitoring of elusive and rare wildlife species (Jackson et al., 2006). It is extensively used to investigate the abundance, density, diversity and habitat utilization of wildlife species (Soisalo and Cavalcanti, 2006). Camera trapping studies were conducted in different areas of Chitral district from September 2008 to July 2010 with the aim of obtaining a brown bear photo-capture record. The study area included CGNP, TGR, Laspur Valley and Yarkhun Valley (Table 4.1). A total of 134 motion-triggered cameras (6 Reconyx, 128 Cam Trakker™ Ranger, Wattkinsville, GA, USA) were installed for 164 days at different locations of the study area. Cameras were placed in rock piles or on metal poles approximately 45–50cm above the ground.

Camera traps were positioned along possible carnivore travelling routes, including sharp ridgelines, near scrapes, cliff bases, rock faces, and along animal trails and paths to maximize capture success. The camera direction was either faced directly up or down to anticipate travel in order to obtain close-up photographs of the face for quick identification. They generally faced north or south to avoid direct sunlight (Ahmad et al., 2016). All vegetation in front of cameras was removed to avoid false triggers. Cameras and infrared sensors were concealed and covered to protect against the weather (Jackson et al., 2006). This system can be set for delays of 20 seconds to 45 minutes between pictures, and for day, night, or continuous operation. All camera batteries and memory cards were checked, on weekly basis, and replaced as needed. The number of trap-days was calculated for each camera location from the time of mounting to the time of retrieval (Johnson et al., 2006).

Table 4.1. Summary of data collected using multiple methods in Chitral district, 2008–2010

Questionnaire Survey					
S.NO	*Study Area*	*No. of Household*	*Year*		
1	Laspur Valley	59	2009–10		
2	Torkhow Valley	37	2009		
3	Yarkhun Valley	13	2009		
4	Mastuj Valley	60	2009–10		
5	Broghil	37	2010		
Total	**5**	**206**			
Sign Survey					
S.NO	*Study Area*	*Study Site*	*Year*	*Total Transect Length (km)*	*Mean Transect Length (km)*
1	CGNP	21	2008–09	18.76	0.89
2	TGR	6	2008–09	5.09	0.84
3	Koghozi Gol	8	2008–09	7.39	0.92
4	Gahirait Gol	8	2008–09	10.38	1.29
5	Laspur Valley	32	2010	19	0.59
6	Laspur Valley	9	2009	8.06	0.89
7	Yarkhun Valley	13	2010	10.54	0.81
Total	*7*	*105*		*79.22*	*0.89*
Camera Trapping					
S.NO	*Study Area*	*Study Site*	*Year*	*Installed Camera Duration*	*Study Duration*
1	CGNP	40	2008	56	Sep–Oct 2008
2	CGNP	20	2009	28	Oct–Nov 2009
3	TGR	20	2009	28	Apr-09
4	TGR	20	2009	28	Dec-09
5	Laspur Valley	20	2010	30	May 24–June 22, 2010
6	Yarkhun Valley	14	2010	14	Jul-10
Total	*6*	*134*		*184*	

4.3 RESULTS

4.3.1 Distribution Pattern

Questionnaire surveys and sign surveys in different valleys of Chitral district confirmed brown bear presence in the eastern part of Chitral district only. Surveys conducted in CGNP and surrounding areas (TGR, Gaherate Gol and Koghozi Gol) did not provide any recent evidence of species occurrence. Based on questionnaire survey, only a single individual was reported brown bear presence in Torkhow Valley. Questionnaire surveys and sign surveys conducted in the other two study blocks—Laspur Valley and Yarkhun Valley (Broghil)—provided strong evidence of presence (Table 4.2).

Table 4.2 Evidence of brown bear presence in different valleys of the study area based on different types of survey techniques used in different parts of the study area, 2008–2010.

Study Site	*Type of Survey*	*Date and duration*	*Evidence of the brown bear presence*
Yarkhun Valley	Questionnaire survey	July 2010, 1 month	5 sightings
Laspur Valley	Questionnaire survey	2009–2010, 1year	17 sightings
Torkhow Valley	Questionnaire survey	July 2009, 3months	One sighting from the northern part of the valley
Yarkhun Valley	Sign survey	July 2010, 10days	Four scats, pugmarks, and one sighting
Laspur Valley	Sign survey	May–June 2010, 1month	Four scats, fresh tracks, pugmarks, and one sighting
Laspur Valley (Bashqar Gol)	Sign survey	August 2009	One old scat

4.3.2 Status in Laspur Valley

Based on questionnaire surveys in Laspur Valley, 29% (17) of local people confirmed brown bear sightings in the valley (Table 4.2). These sighting reported that adults were accompanied by cubs which was a sign of animal reproductive activity in the area.

Based on public sighting reports, two sign surveys were conducted at different sites of Laspur Valley to confirm brown bear presence. A sign survey was conducted in one sub-valley (Bashqar Gol) of Laspur Valley in August 2009. Line transects of unequal length were walked and brown bear signs were searched along the transects. Only one old brown bear scat was observed along 8.06 km transect length. Average length of the transect walked in Bashqar Gol during 2009 was 0.89 km (Table 4.2).

A second sign survey was conducted in June 2010 in Bashqar Gol, Phargram Gol and Shandur sub-valleys to obtain information about brown bears in the area. Only one fresh brown bear scat was recorded during 8 km transect walk in Bashqar Gol (Plate 4.1a). Moreover, a brown bear was directly sighted in the area (Plate 4.1b). No signs of brown bear were observed in 4.8 km transects (average length=0.59 km) in Phargram Gol (Table 4.1).

The third study site in Laspur Valley was Shandur where sign surveys were conducted in June 2010. Sixteen transects with 9.17 (average length=0.76 km) were walked (Table 4.1) and four scats (both fresh and old), two fresh tracks, and pugmarks of the brown bear were observed (Plate 4.1c and 4.1d). Local people recorded a mobile phone video of brown bears visiting garbage sites in Laspur Valley and the Shandur Plateau in 2019.

a.Brown bear scat in Bashqar Gol

b. Brown bear sighting in Laspur Valley (Bahqar Gol) on June 22, 2010 (photo by Shoaib Hameed)

c. Brown bear pugmark in Shandur

d. Brown bear pugmarks in Shandur

Plate 4.1. Photographs from filed surveys.

4.3.3 Status in Yarkhun Valley

Some 39% of local people (5) of Yarkhun Valley reported brown bear sightings in the past five years (Table 4.2). Sign surveys were conducted in Yarkhun Valley (Broghil) to confirm the public sighting reports. However, logistical constraints and poor weather did not allow us to conduct large-scale surveys—the presence was however, confirmed. The sign surveys revealed four scats (both fresh and old) and some fresh pugmarks of the brown bear. Brown bears were also observed through direct sighting in Broghil which supported local people's claims.

Many camera trapping studies were also carried out in all our study blocks except Torkhow Valley; however, no brown bear was photo-captured.

4.3.4 Human-Carnivore Conflict

4.3.4.1 Livestock Depredation and Economic Evaluation

Ninety-six (96) respondents—59 in Laspur Valley and 37 in Broghil Valley—reported 449 livestock losses (90 heads per year) to carnivore species in the area during the five-year period (2005–2009). The grey wolf was held responsible for 338 losses (68 heads per year/75%) while the snow leopard and lynx were blamed for 50 (10 heads per year/11%) and 41 (8 heads per year/9%), respectively. Respondents blamed 20 (4 heads per year/4%) losses on unknown predators. No brown bear-related livestock loss was reported (Figure 4.2). The most favorable prey species for grey wolves were sheep (45%), goat (42%), and cattle (13%). Snow leopard's prey species consisted of cattle (60%), sheep (22%), and goat (18%). Lynx prey species were goat (66%) and sheep (34%).

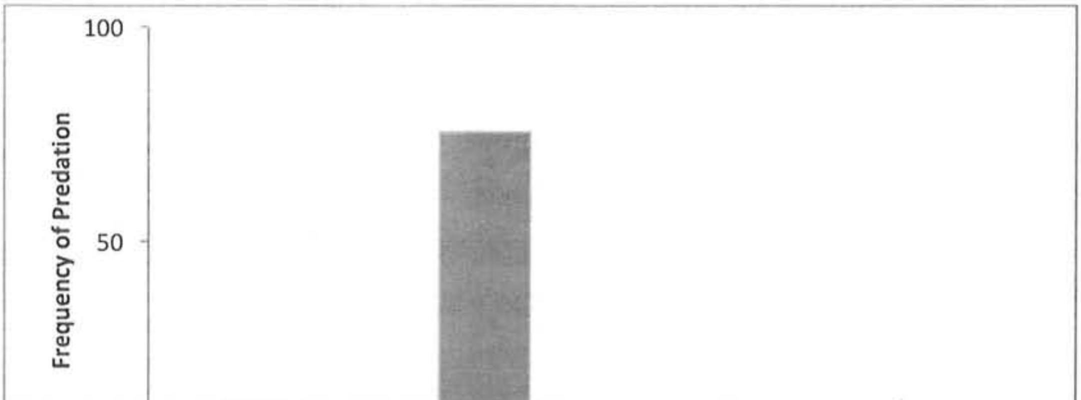

Figure 4.2. Livestock killed by carnivores in Laspur and Broghil valleys during 2005–2010.

The reported figure of 449 livestock losses in two valleys constituted an economic loss of PKR 2,931,022 or USD 34,297 (PKR 30,531/USD 357 per household). Of the total loss, grey wolves were blamed for USD 21,133 (USD 220 per household in five years) while snow leopards and lynx were held responsible for a loss of USD 8,074 (USD 84 per household) and USD 1,439 (USD 15 per household), respectively. A significant amount was also caused by unknown predators (Table 4.3).

Table 4.3. Economic loss [USD (number killed)] due to livestock depredation in Laspur and Broghil valleys, Chitral District, Pakistan, during 2005–2009.

Livestock	*Snow leopard*	*Wolf*	*Lynx*	*Unknown predators*	*Total economic loss*
Goat	316 (9)	4,985 (142)	948 (27)	211 (6)	6,460
Sheep	386 (11)	5,336 (152)	491 (14)	-	6,213
Cattle	7,372 (30)	10,812 (44)	-	3,440 (14)	21,624
Total loss	**8,074 (50)**	**21,133 (338)**	**1,439 (41)**	**3,651 (20)**	**34,297 (449)**
Average loss/HH	**84**	**220**	**15**	38	**357**

The numbers in parenthesis represent the number of livestock killed, PKR 85.46 = 1 USD, the exchange rate of PKR to USD pertains to 2005-2009 (Average).

4.3.4.2 Local People's Perceptions about Carnivores

People were asked about their perceptions of brown bears and other large carnivores during the questionnaire surveys. Perceptions were categorized into four groups—increase, maintain (positive view), decrease and eliminate (negative view).

In the study area, about 30% of respondents wanted to increase the brown bear population, 17% wanted to maintain its current population status, 2% wanted to decrease, and 13% wanted complete elimination from the area. Other respondents (39%) did not state a preference. A significant number (49%) wanted an increase in the numbers of snow leopards in the area. Greater percentages (53%) of local people possessed negative perceptions about the grey wolf and wanted a decrease in numbers or complete elimination from the area (Figure 4.3).

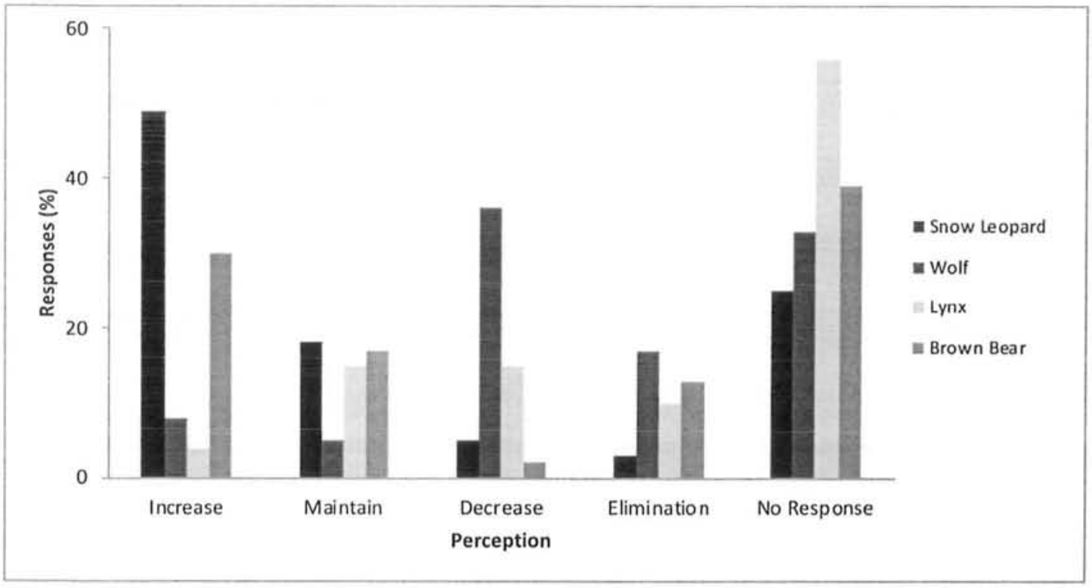

Figure 4.3. Public perceptions on carnivores' existence in Laspur and Broghil valleys during questionnaire surveys conducted in 2009–2010.

4.3.4.3 Public Attitude towardsCarnivores

The perceived danger of carnivores for livestock was categorized into four levels (1–4) depending on the intensity of danger perceived by local people. Category 1 was assigned to the most dangerous carnivore and category 4 to the least. Communities were asked to rank four carnivore species—snow leopard, wolf, lynx and brown bear—by their perceived level of danger. A large number of local people (85%) considered brown bears to be the least dangerous animal in the area followed by lynx (73%) and snow leopard (44%). A greater percentage (56%) considered the wolf as the most dangerous carnivore species for livestock (Figure 4.4).

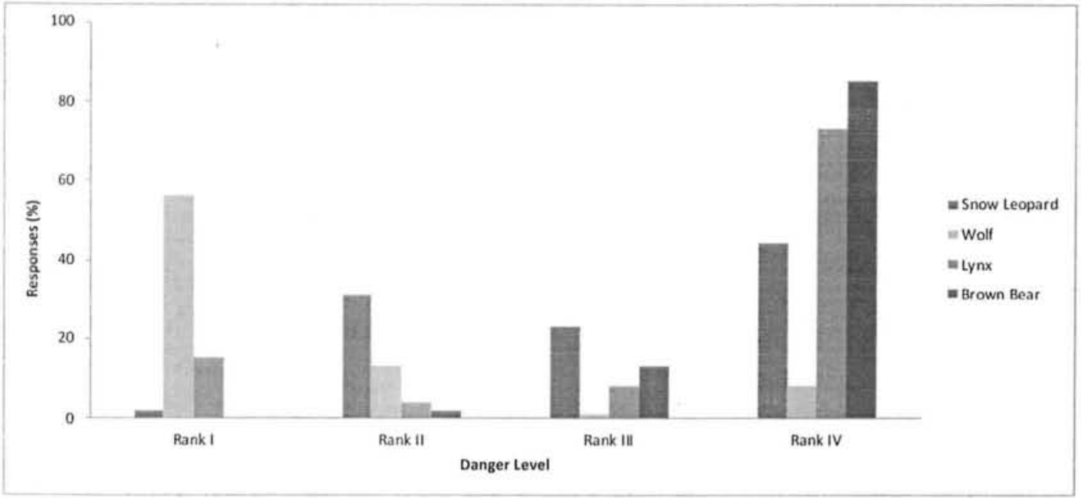

Figure 4.4. Community perceptions on threats from carnivores in Laspur and Broghil valleys during questionnaire surveys conducted in 2009–2010.

4.4 DISCUSSION

Brown bear presence in the western part of its distribution range has been indicated in the past (Nawaz, 2007; Roberts and d'Olanda, 1977). Multiple techniques—questionnaire surveys, sign surveys, and camera trapping surveys—were used during this study to obtain reliable information about the target species. Surveys were also conducted in areas where species was believed to be extinct like CGNP (Mirza, 2003; Schaller, 1976) and its surrounding areas. Only sign surveys and camera trapping methods were used in these areas to obtain solid evidence about presence, but none could be found.

Parts of Chitral district where brown bear presence had been claimed in the past included Torkhow Valley, Yarkhun Valley (Fulton, 1903; Schaller, 1976) and the border area between KP and GB (Nawaz, 2007). Questionnaire surveys in Torkhow Valley did not reveal any strong evidence of brown bears—only one respondent claimed a sighting of a Himalayan brown bear which could not be confirmed through sign surveys. Public sightings in Yarkhun Valley (Broghil) were confirmed by sign surveys and direct sightings. Himalayan brown bear presence in Laspur Valley bordering the Chitral district of KP with GB on one side and Swat district on the other—as previously claimed by Nawaz (2007)—was also confirmed by questionnaire surveys, sign surveys, and direct sighting.

The presence of the brown bear in two of our four study blocks—Yarkhun Valley and Laspur Valley—was confirmed by questionnaire surveys and sign surveys, but not by camera trapping. Camera trapping in Yarkhun Valley (Broghil) was short-termed and could not be extended due to poor weather and floods in the valley. However, one specimen in Laspur Valley arrived at a camera station and pulled the camera out of the ground.

Increased livestock depredation by large carnivores in the Himalayas and Hindu Kush mountains has been attributed to increasing livestock populations (Hussain, 2003). The 96 respondents of the Yarkhun and Laspur valleys reported 449 livestock losses (90 per year) between 2005 to 2009. Grey wolves account for the highest predation followed by snow leopard, lynx, and unknown predators. The Himalayan brown bear did not account for any livestock depredation due to two possible reasons; 1) due to its rarity in the study area as shown by our results, 2) Himalayan brown bear is predominantly vegetarian, and study conducted by Nawaz et al. (2019) in Deosai National Park shows that 70% of analyzed scats were composed of plant residue—with very low dietary meat. Our study shows that carnivores prefer goats and sheep to cattle. This is due primarily to the significantly higher number of goats and sheep in the area as compared to other livestock. In addition, goats and sheep are more vulnerable to predation because larger-sized carnivores can drag them to safe places (Ahmad et al., 2016; Kabir et al., 2014; Rehman et al., 2021). Another study in Chitral reported annual livestock losses of 27 (Din and Nawaz, 2010) and 261 (Din et al., 2013). The highest depredation of livestock in the study area can be attributed to thin natural prey and the presence of multiple large-sized carnivore species.

The reported figure of 449 livestock losses in two valleys constituted an economic loss of USD 34,297 or PKR 2,931,022 (PKR 30,531or USD 357 per household). The grey wolf was a major culprit in both valleys of the study area. The major economic loss reported by local people was in the form of cattle depredation, although a smaller number of cattle were killed by carnivores as compared to goats and sheep but the market value of cattle is much higher than that of goats and sheep.

Human-carnivore conflict can be particularly controversial when the resources concerned have economic value (livestock) and the predators involved have a high conservation profile (Graham et al., 2005). Attitudes are commonly seen as people's evaluation of some object or animal (e.g., carnivore) that range from positive to negative (Ajzen, 2001). For example, attitudes towards carnivores can be positive when they are associated with tourist revenue (Dickman et al., 2011), but negative when carnivores are perceived as threats to livestock or human life (Dickman, 2008). Community perception about brown bears in our study is very positive and most people wanted to increase or maintain populations. It was also found that there was no direct conflict between people and the brown bear. Brown bears did not account for any livestock losses in the reported period—a strong reason for local people's positive perceptions. Still, a small percentage (13%) of local people said they wanted to eliminate the species from the area, which may be due to its large size, which can frighten people.

A large percentage of local people also possess a positive perception of snow leopards despite heavy livestock losses because it is seen as a sign of bravery and beauty—children are often named after the snow leopard in this region (Ahmad et al., 2016). On the other hand, most of local people have highly negative perceptions about grey wolf and lynx and wanted to decrease their numbers or completely eliminate them from the area (due to large economic losses). The likely reason for negative perception about lynx is due it threats to poultry which is one of the major source of livelihood for these local communities, although no incidents of lynx predating on poultry was reported in this study. Similarly, a low percentage of locals possess negative perception about brown bear owing to the fear of crop damage which result huge economic loss (Ahmad et al., 2016) but no crop damage was reported in this study.

4.4.1 Conclusion

Our study concludes that within the study area, the Himalayan brown bear is present only in Yarkhun and Laspur valleys, and probably lives in a small population. This marks a drastic reduction in historically reported range in the Hindu Kush. The species no longer exists in the western and southern parts of the district and appears to be confined to eastern valleys adjacent to GB where brown bear lives in several valleys (Nawaz, 2007). The Yarkhun Valley is connected to the Wakhan corridor in Afghanistan to the north-west where brown bears do exist (Mishra and Fitzherbert, 2004). Thus, remaining brown bear populations maintain connectivity with other populations towards the north-east of GB. The absence of brown bear from the rest of Chitral district is likely due to the unsuitable terrain in the south-western Chitral which has steeper topography and small patches of alpine plateaus which is considered suitable habitat for brown bear (Nawaz et al., 2014). Furthermore, human densities which have increased in the past few decades in these areas have increased the pressure on natural habitats. Climate change is also a factor and southern areas are getting warmer. For example, snow leopard population has declined in southern Chitral and common leopards from the south are occupying these areas. Finally, historical information from some of these areas is no longer considered accurate.

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4.6 REFERENCES

Ahmad, S., Hameed, S., Ali, H., Khan, T.U., Mehmood, T., Nawaz, M.A., 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-016-1029-6

Ajzen, I., 2001. Nature and operation of attitudes. Annu. Rev. Psychol. https://doi.org/10.1146/annurev.psych.52.1.27

Broekhuis, F., Cushman, S.A., Elliot, N.B., 2017. Identification of human–carnivore conflict hotspots to prioritize mitigation efforts. Ecol. Evol. https://doi.org/10.1002/ece3.3565

Can, Ö.E., D'Cruze, N., Garshelis, D.L., Beecham, J., Macdonald, D.W., 2014. Resolving Human-Bear Conflict: A Global Survey of Countries, Experts, and Key

Factors. Conserv. Lett. https://doi.org/10.1111/conl.12117

Dickman, A.J., 2010. Complexities of conflict: The importance of considering social factors for effectively resolving human-wildlife conflict. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2010.00368.x

Dickman, A.J., 2008. Key determinants of conflict between people and wildlife, particularly large carnivores, around Ruaha National Park, Tanzania. Univ. Coll. London.

Dickman, A.J., Macdonald, E.A., Macdonald, D.W., 2011. A review of financial instruments to pay for predator conservation and encourage human-carnivore coexistence. Proc. Natl. Acad. Sci. U. S. A. https://doi.org/10.1073/pnas.1012972108

Din, J.U., Hameed, S., Shah, K.A., Khan, M.A., Khan, S., Ali, M., Nawaz, M.A., 2013. Assessment of canid abundance and conflict with humans in the Hindu Kush Mountain Range of Pakistan. Wildl. Biol. Pract. https://doi.org/10.2461/wbp.2013.9.5

Din, J.U., Nawaz, M.A., 2010. Status of the Himalayan lynx in district Chitral, NWFP, Pakistan. J. Anim. Plant Sci.

Estes, J.A., Terborgh, J., Brashares, J.S., Power, M.E., Berger, J., Bond, W.J., Carpenter, S.R., Essington, T.E., Holt, R.D., Jackson, J.B.C., Marquis, R.J., Oksanen, L., Oksanen, T., Paine, R.T., Pikitch, E.K., Ripple, W.J., Sandin, S.A., Scheffer, M., Schoener, T.W., Shurin, J.B., Sinclair, A.R.E., Soulé, M.E., Virtanen, R., Wardle, D.A., 2011. Trophic downgrading of planet earth. Science (80-.). https://doi.org/10.1126/science.1205106

Frank, K.T., Petrie, B., Choi, J.S., Leggett, W.C., 2005. Ecology: Trophic cascades in a formerly cod-dominated ecosystem. Science (80-.). https://doi.org/10.1126/science.1113075

Fulton, C.H., 1903. Rough notes on the mammalia of Chitral. J. Bombay Nat. Hist. Soc. 14, 758–759.

Galbreath, G.J., Groves, C.P., Waits, L.P., 2007. Genetic resolution of composition and phylogenetic placement of the Isabelline Bear. Ursus. https://doi.org/10.2192/1537-6176(2007)18[129:GROCAP]2.0.CO;2

Graham, K., Beckerman, A.P., Thirgood, S., 2005. Human-predator-prey conflicts: Ecological correlates, prey losses and patterns of management. Biol. Conserv. https://doi.org/10.1016/j.biocon.2004.06.006

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2006. Estimating Snow Leopard Population Abundance Using Photography and Capture–Recapture Techniques. Wildl. Soc. Bull. https://doi.org/10.2193/0091-7648(2006)34[772:eslpau]2.0.co;2

Johnson, A., Vongkhamheng, C., Hedemark, M., Saithongdam, T., 2006. Effects of human-carnivore conflict on tiger (Panthera tigris) and prey populations in Lao PDR. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2006.00049.x

Kabir, M., Ghoddousi, A., Awan, M.S., Awan, M.N., 2014. Assessment of human-leopard conflict in Machiara National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-013-0782-z

Kellert, S.R., Black, M., Rush, C.R., Bath, A.J., 1996. Human Culture and Large Carnivore Conservation in North America. Conserv. Biol. https://doi.org/10.1046/j.1523-1739.1996.10040977.x

Linkie, M., Dinata, Y., Nofrianto, A., Leader-Williams, N., 2007. Patterns and perceptions of wildlife crop raiding in and around Kerinci Seblat National Park, Sumatra. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2006.00083.x

Macdonald, D.W., Sillero-Zubiri, C., 2004. Wild canids - an introduction and dramatis personae, in: The Biology and Conservation of Wild Canids.

Macdonald, D.W., Loveridge, A., Rabinowitz, A., 2011. Felid futures: Crossing disciplines, borders, and generations. Macdonald and, D.W. and Loveridge, A., editors. Oxford University Press, Oxford.

Michalski, F., Boulhosa, R.L.P., Faria, A., Peres, C.A., 2006. Human-wildlife conflicts in a fragmented Amazonian forest landscape: Determinants of large felid depredation on livestock. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2006.00025.x

Mirza, Z.B., 2003. Biological baseline study of Chitral Gol National Park. Report prepared for the Protected Areas Management Project, Chitral, Pakistan.

Mishra, C., Fitzherbert, A., 2004. War and wildlife: A post-conflict assessment of Afghanistan's Wakhan Corridor. ORYX. https://doi.org/10.1017/S0030605304000158

Morehouse, A.T., Boyce, M.S., 2017. Troublemaking carnivores: Conflicts with humans in a diverse assemblage of large carnivores. Ecol. Soc. https://doi.org/10.5751/ES-09415-220304

Mountain Areas Conservancy Project (MACP) NWFP-Chitral., 2001. Livestock enumeration report of Laspur Valley. Unpublished report.

Naughton-Treves, L., Grossberg, R., Treves, A., 2003. Paying for tolerance: The impact of livestock depredation and compensation payments on rural citizens' attitudes toward wolves. Conserv. Biol.

Nawaz, M.A., 2008. Ecology, genetics and conservation of Himalayan brown bears. Ecol. Nat. Resour. Manag.

Nawaz, M.A., 2007. Status of the brown bear in Pakistan. Ursus. https://doi.org/10.2192/1537-6176(2007)18[89:SOTBBI]2.0.CO;2

Nawaz, M.A., Martin, J., Swenson, J.E., 2014. Identifying key habitats to conserve the threatened brown bear in the Himalaya. Biol. Conserv. https://doi.org/10.1016/j.biocon.2013.12.031

Nawaz, M.A., Valentini, A., Khan, N.K., Miquel, C., Taberlet, P., Swenson, J.E., 2019. Diet of the brown bear in Himalaya: Combining classical and molecular genetic techniques. PLoS One. https://doi.org/10.1371/journal.pone.0225698

NWFP, IUCN Pakistan., 2004. Chitral -An integrated development vision (Chitral Conservation Strategy). IUCN Pakistan and NWFP, Karachi, Pakistan. xiv+103 pp.

Qashqaei, A.T., Karami, M., Etemad, V., 2014. Wildlife conflicts between humans and Brown Bears, Ursus arctos, in the Central Zagros, Iran. Zool. Middle East. https://doi.org/10.1080/09397140.2014.914711

Rehman, E.U., Din, J.U., Ahmad, S., Hameed, S., Shah, K.A., Mehmood, T., Nawaz, M.A., 2021. Insight into occupancy determinants and conflict dynamics of grey wolf (*Canis lupus*) in the dry temperate zone of Hindukush Range. Glob. Ecol. Conserv. https://doi.org/10.1016/j.gecco.2020.e01402

Result, E.P., 2015. District profile Swat. AASA Consult.

Rigg, R., Findo, S., Wechselberger, M., Gorman, M.L., Sillero-Zubiri, C., MacDonald, D.W., 2011. Mitigating carnivore-livestock conflict in Europe: Lessons from Slovakia. ORYX. https://doi.org/10.1017/S0030605310000074

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., Schmitz, O.J., Smith, D.W., Wallach, A.D., Wirsing, A.J., 2014. Status and ecological effects of the world's largest carnivores. Science (80-.). https://doi.org/10.1126/science.1241484

Roberts, T.J., d'Olanda.), B. (principe, 1977. The mammals of Pakistan.

Schaller, G.B., 1976. Mountain Mammals in Pakistan. Oryx. https://doi.org/10.1017/S0030605300014071

Shah, S.M., Hussain, F., Khan, M., 2013. Growth behaviour, sex ratio and fruit output of Juniperus excelsa in Mastuj valley, District Chitral, Khyber Pakhtunkhawa, Pakistan. Int. J. Biosci. https://doi.org/10.12692/ijb/3.2.146-151

Sheikh, K., Molur, S., 2005. Status and red list of Pakistan's mammals, based on conservation assessment and management plan for mammals. IUCN, Pakistan 344.

Soisalo, M.K., Cavalcanti, S.M.C., 2006. Estimating the density of a jaguar population in the Brazilian Pantanal using camera-traps and capture-recapture sampling in combination with GPS radio-telemetry. Biol. Conserv. https://doi.org/10.1016/j.biocon.2005.11.023

Treves, A., Wallace, R.B., Naughton-Treves, L., Morales, A., 2006. Co-managing human–wildlife conflicts: A review. Hum. Dimens. Wildl. https://doi.org/10.1080/10871200600984265

Woodroffe, R., 2000. Predators and people: Using human densities to interpret declines of large carnivores. Anim. Conserv. https://doi.org/10.1017/S136794300000086X

Woodroffe, R., Thirgood, S., Rabinowitz, A., 2009. The impact of human–wildlife conflict on natural systems, in: People and Wildlife. https://doi.org/10.1017/cbo9780511614774.002

APPENDIX 4.1. HOUSEHOLD LEVEL HUMAN-CARNIVORE INTERACTION SURVEY

Enumerator Name_______________________________Date ______________________________

Respondent Name ______________________________ Village Name __________________

Education______________________________________ Age_____________________________

Ethnic background______________________________Occupation_______________________

How many earning members are there in the household? __________________________

Home much agricultural land your family own? _______________ HH Size ___________

Predators Status:

Did you sight any of following species in past 1 year (Jan-Dec 2013)?

	Snow Leopard	Common Leopard	Wolf	Brown Bear	Black Bear	Lynx
Numbers						
Status (Common/Rare/Absent						

Population of which species you wish to increase/maintain/reduce /eliminate from your area:

↑ / → / ↓/x

Snow Leopard	Wolf	Brown Bear	Lynx

Which one is most dangerous for livestock, rate 1-4 (from low to high):

Snow Leopard	Wolf	Brown Bear	Lynx

Livestock

How many livestock your family own?

Livestock	Goats	Sheep	Cattle	Yak	Other
Number					
Vaccinated					

Mortality due to Disease in 1 year (January – December 2013):

Livestock	Goats	Sheep	Cattle	Yak	Other
Number					

Livestock sold in 1 year:

Livestock	Goats	Sheep	Cattle	Yak	Other
Number					
Total Income in Rs					
Slaughtered for domestic consumption					

Predation Losses

Crop damage by wildlife in past 1 year (estimated economic loss):

Species	Winter	Spring	Summer	Autumn

Any other Damage by wildlife: ____________________

Predation in 1 year:

Predator	Season/ month	Location	Prey type	Prey sex	Prey Age	Guarded (Y/N)	Circumstances

Seasons: Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug), Autumn (Sep-Nov)

Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

CHAPTER 5

Population of Snow Leopards in Khunjerab National Park and its Surroundings

5 Population of Snow Leopards in Khunjerab National Park and its Surroundings

ABSTRACT

Understanding the population dynamics and abundance numbers of rare species like snow leopards is of crucial importance for their conservation. Population monitoring is a challenge as they are shy, cryptic, highly camouflaged and live in harsh terrains. With the advent of technologies and modern statistical understanding, it has become possible to devise new techniques of studying these species. Camera trapping and new spatial capture-recapture (SCR) models generate reliable population numbers, keeping in view the statistical assumptions and ecological behaviour of the species. We used SCR models to estimate the population and density of snow leopards in Shimshal and Khunjerab using camera trapping data. We set a total of 122 camera stations in both areas, which were active for 1,243 trap days. A total of 19 individuals were identified from all comparable photographs of snow leopards. The SCR model estimated a total of 55 individuals in the area of 5,764 km^2 comprising both the Khunjerab and Shimshal areas. The base encounter rate was 0.008, and the spatial scale of detected movement in all activity centres was calculated as 6.726 ± 1.23. The density calculated was about 1 animal per 100 km with an upper confidence limit of 1.8 individuals/100 km^2, and lower confidence limit of 0.5 individuals/100 km^2. SCR models are promising estimators, but our study faced limitations like harsh weather and low accessibility in high potential areas. It is recommended to further study these hotspot areas with a standardized approach of species home range-specific camera trap spacing and configuration. There is an urgent need of refining the sampling strategy of such camera traps and using these models in all potential distribution areas of snow leopards in Pakistan.

Keywords: snow leopard, camera trap, capture recapture, encounter, population.

5.1 INTRODUCTION

The snow leopard is native to the mountain ranges of Central and southern Asia, some of the world's most rugged landscapes (McCarthy et al., 2017; McCarthy and Chapron, 2003). It occurs in the Altai, Sayan, Tien Shan, Kunlun, Pamir, Hindu Kush, Karakoram, and outer Himalayan ranges, and in smaller isolated mountains in the Gobi region (Hussain, 2003; Nowell and Jackson, 1996; Schaller, 1976). The wide range in estimates of global range size varies from 1.2 million to 3 million km^2 (Network, 2014) and populations are highly threatened throughout the range. A recent study estimated the area of snow leopard-occupied range to be about 2.8 million km^2 (McCarthy et al., 2016a). Its range extends to 12 countries, namely Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan, and Uzbekistan (Fox, 1994; Jackson and Hunter, 1996; Maheshwari, 2013). A small area of potential range occurs in northern Myanmar, but recent snow leopard presence has not been confirmed (Network, 2014).

Population monitoring is a vital tool for the conservation of a species. Without knowing about the population and habitat of a target species, it is not possible to judge the usefulness of conservation action to it. So far, reliable baseline information is lacking upon which informed decisions can be made (Jackson et al., 2005). If conservationists are to ensure that populations of large predators like the tiger and snow leopard persist, they need to know far more about each species' distributional pattern and population trends over manageable time periods (Chapron and McCarthy, 2003). Population monitoring is also important for the verification of conservation action, and it has a positive impact when the action is done in order to a known number of target species.

There are no robust estimates of snow leopard population across the world. The total snow leopard population is estimated, from various figures as guesses, to be between 4,000 and 7,500 (Jackson et al., 2010; McCarthy and Chapron, 2003; Sharma et al., 2019; Snow Leopard Working Secretariat, 2013). The species has recently been classified as Near Threatened in the IUCN Red List of Threatened Species (McCarthy et al., 2017). The status change may have been biased due to several reasons. A lack of reliable overall population estimates and standardized methodologies are the key challenges that are yet to be overcome before we are sure about the population trends of snow leopards. In earlier times, it was a general practice to conduct interviews and sign surveys for studying snow leopards. Many studies have conducted interviews, reports, and questionnaires, i.e. Schaller et al. (1988) and Grachev and Ata (1977), but none have relied on just these for estimating any population figure for snow leopards, because dishonesty, inconsistent answers, issues in understanding and interpreting questions, and a lack of appropriate way to analyse interviews data, are the main problems (Henschel and Ray, 2003). Many studies, including the above-mentioned ones, have reported population or density based on signs (Ale and Brown, 2009; Fox et al., 1991; Grachev and Ata, 1977; Jiang, 2006; Ma et al., 2011; Schaller et al., 1988; Xu et al., 2008). The problem with sign surveys is that obtaining absolute densities from signs/unit area is biased in many ways. The identification of individuals from signs and tracks has limited success and mostly untested. This limitation hinders this approach and is questioned by Karanth et al. (2003) in India for tigers, and so is true for snow leopards in other areas as well. Accumulations of signs over time in a region and washed out signs due to weather conditions like snow cover, are also major constraints in obtaining sign densities. Tracks, pugmarks, and other signs analysis are dependent on many complex assumptions, like no sign from any unique individual is counted twice. The individual species are native to the area and are not transients. Signs are accurately identified, and efforts in searching for signs are uniform throughout the study area. There is no reliable or practical way to fully account for these assumptions and test if they are fulfilled. The failure of these assumptions can potentially affect estimates, and there may be no predictable relation of the estimate with the true population size of the species (Karanth et al., 2003). Thus, we can say that sign surveys for snow leopards are not reliable indicators of conservation success (Nyhus et al., 2016). Both sign densities and prey availability may be indices of predator abundance. The snow leopard information management system (SLIMS) incorporates prey biomass calculations in its analysis. Snow leopards are numbered based on sign density and prey biomass (Ale et al., 2007; Din et al., 2017; Feng et al., 2011; Hameed, 2010; Khatiwada et al., 2007; McCarthy et al., 2008; Mcgregor and Newell, 2007). This approach has certain drawbacks as well. All signs-related issues are the same with prey species as well. The age and quality of the prey are important information, which in turn represent the true quality of total biomass energy. It is difficult to assess this information through signs. Also, prey density in an area does not necessarily determine the available food for predators like snow leopards (Bertram, 1973). Other competing predators may share the same energy biomass. Scavengers constrain the predation and energy gain of large carnivores (Gittleman, 1989; Yang and Lee, 2013). Another important component is the spatial distribution of prey species in an area. SLIMS generally does not account for the spatial variation in prey availability. Whether the prey species are transient, migratory, sedentary, or renewed at some internal are important considerations and have critical consequences for predator movements, home ranges, and other behaviours (Gittleman, 1989; Houston and Davies, 1985). All of these factors may also influence the density and abundance estimates of predators in the region, and SLIMS is not robust enough to account for all of them. The genetic identification of individuals from scat samples of such species is gaining popularity. The technique is quite expensive, and very few studies have been conducted to date for snow leopards using genetics. Even fewer studies have attempted estimating densities from genetically identified individuals. The major portion of the snow leopard's distribution range has not been studied with genetic tools, and identifications through signs and manual visuals are questionable. The methodologies used in population or density estimation in genetic studies are mostly non-spatial and lack the consideration of the spatial variation of study areas. Aryal et al. (2014), Ferretti et al. (2014), Janecka et al. (2008), Karmacharya et al. (2011), and Suryawanshi et al. (2017) have reported either minimum snow leopard individuals, or have derived their densities using non-spatial estimators.

Estimating densities from camera trap data are the most common and widespread practice for large-ranging species. This method utilizes conventional capture-recapture closed population models. The models are fitted to the capture-recapture history of identified individuals to gain abundance, and then the effective study area is calculated to obtain a density estimate (Janečka et al., 2011; Ma and Xu, 2006; McCarthy et al., 2008, 2010; Sharma et al., 2014; Zhou et al., 2017). There are many issues related to these conventual capture-recapture studies. They cannot account for the detection variability induced by the spatial distribution of animals. The fairly new spatially explicit capture-recapture models (SECR) do not need to calculate effective area for density estimation and are quite robust, taking into consideration the spatial aspect of the area (Efford and Fewster, 2013; Royle et al., 2014). SECR models are not assumption-free, and it is generally assumed that populations under study are geographically closed, the activity centres of individuals are fixed and independent of each other during survey periods, and the capture detection probability is inversely related to the distance from the trap (Royle and Chandler, 2014). The design of spatial studies varies from survey to survey according to the nature of target species, and these models perform rather well for studying large-ranging animals (Sollmann et al., 2012).

In Pakistan, the snow leopard is found throughout the mountain ranges of the north—the Hindu Kush, Karakorams and Himalayas, in Chitral, Dir, Swat, and Kohistan districts of Khyber Pakhtunkhwa (KP), in all districts of Gilgit-Baltistan (GB), and in the northern part of Neelum Valley in Azad Jammu and Kashmir (AJK) (Ahmad et al., 2016; Hussain, 2003; Nowell and Jackson, 1996; Schaller, 1976). Based on surveys undertaken in the early 1970s, Schaller (1979) estimated the total population of snow leopards in Pakistan to be around 104–130 animals. Surveys undertaken in the Skardu and Ghanche districts of GB resulted in an estimate of 90–120 animals in that area, and 300–420 animals throughout Pakistan (Hussain, 2003). However, these reported figures and numbers are not based on standardized approaches, keeping in view all statistical assumptions, snow leopard ecology, and the risks of extrapolating results over large spatial landscapes. This study focused on Khunjerab National Park (KNP) and its surroundings to obtain a robust population estimate using motion sensor camera traps and spatial capture-recapture (SCR) models. The main objectives of the study were a) to test the effectiveness of such methods in Pakistan and, b) to obtain a reliable estimate of snow leopard population in KNP and its surroundings.

5.2 MATERIALS AND METHODS

5.2.1 Study Area

Established in 1975, KNP is situated to the extreme north of the country in Hunza district of GB between the coordinates 74° 55' E to 75° 57' E and 36° 01' N to 37° 02' N. It covers an area of 6,150 km^2 (Figure 5.1). It is one of the highest parks in the world, existing above 4,000 m above sea level (Shafiq and Ali, 1998). KNP extends from Zero point; the Chinese border to the Shimshal area. It also borders Central Karakoram National Park (CKNP) at its northeast side. The main river flowing inside the park is the Khunjerab River, while many tributaries join it at different locations on the way. KNP borders China on one side, while Shimshal, the Khujerab Villager Organisation (KVO) area and Shimshal border the other sides. The different *nullahs* in

Khunjerab valley include Dhee, Karchanai, Toghroqin, Furzindur, Barkhun, Perpek, Arbobkuk, Gozkil, Padekishk, Koksil, and Kooz (Qureshi et al., 2011).

KNP's wildlife is composed of a blend of Palearctic and Indo-Malayan elements containing taxa of the Ethiopian region that makes the park's biodiversity very interesting and diverse (Qureshi et al., 2011). Prominent fauna includes the snow leopard, brown bear, wolf, ibex, Marco Polo sheep, red fox, cape hare, stone marten, weasel, pika, golden marmot, snow cock, and numerous bird species. Four types of vegetation zones are recognized, including dry alpine scrub, moist alpine pastures, dry alpine plateau pastures, and sub-alpine scrub and birch forests. Dominant species include *Artemisia spp., Juniperus excelsa, Rosa webbiana, Myricaria germanica, Hippophae rhamnoides, Populus nepalensis, Salix spp., Betula utilis, Potentilla desertorum, Gentiana spp., Anemone spp., Plantago lanceolata, Saxifraga sibirica, Poa bulbosa, Poa sinaica, Primula spp., Lonicera quinquilocularis, Artemisia spp., Setaria spp., Phleum spp., Carex spp.*, and *Potentilla spp.* (Qureshi et al., 2010).

5.2.2 Camera Trapping

A total of 122 passive infrared cameras (Reconyx, HC500, PC800) were set up in KNP and Shimshal for 10–15 days in December 2010–January 2011. The system would be triggered when a moving animal with a higher body temperature than the ambient temperature crossed the camera detection zone. This system was set for continuous operation, day and night, with a one-second delay between pictures to obtain maximum captures.

To maximize the possibility of capture success, camera traps were placed strategically along possible carnivore travelling routes, including sharp ridgelines, near scrapes, cliff bases, rock faces, stream confluences, and game trails. Cameras were generally faced towards the north or south to avoid erroneous pictures caused by direct sunlight. Cameras were placed on metal stakes approximately 45–50 cm above the ground. The camera sensors were placed in such a position that there was no vegetation in the foreground that could trigger the cameras (Jackson et al., 2006). The number of trap-days was calculated for each camera location from the time of mounting to the time of retrieval (Johnson et al., 2006). Trap cameras were distributed across the core zone of the study area, and all of the trap stations were spaced about one kilometre apart. At the end of the trapping period, cameras were retrieved, and data on SD cards was saved.

Individual animals were identified based on their distinct pelage patterns according to guidelines provided by Jackson et al. (2006) for identification from photographs. The photo rate was calculated by dividing the number of individual photo events by the total number of trap nights. The criteria set by McCarthy et al. (2008) was used to consider a photo or set of photos to a single photo event. The capture rate was very low, and a capture-mark-recapture model could not be applied due to the low density of cats in the area.

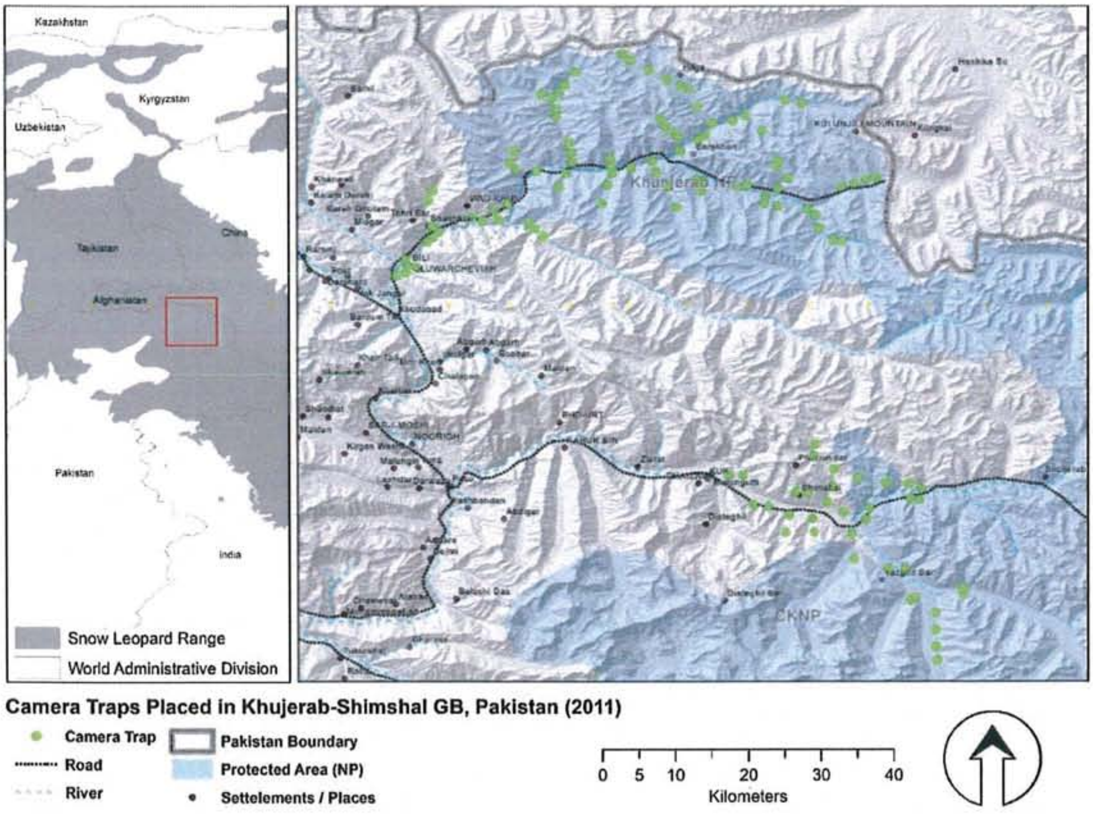

Figure 5.1. Study area map showing camera trap locations.

5.2.3 SCR Models

SCR explains the distribution of individual detection probabilities and estimate densities, keeping in view the spatial aspect of animal encounter histories. The lack of consideration of spatially induced capture heterogeneity was the major deficiency of old classical capture-recapture models, which was highlighted by authors like Dice

(1938) and Hayne (1950), but addressed only recently (Efford, 2004). SCR models have assumed that, (i) every individual in the area during the survey has its activity centre or home range centre, and (ii) the capture probability of an animal during any survey occasion is inversely related to the distance between its activity centre and the trap. The estimated density in SCRs is invariant to the state-space size and thus considered advantageous over the old capture-mark-recapture models (Royle et al., 2013).

5.2.4 Analysis Input Files

In these models, detection probability in space is a function of the distance between camera traps and individuals' activity centres (Borchers and Efford, 2008; Royle and Young, 2008). These models function with two components. The first is the state space, which is a meshwork of all the potential activity centres of the animal in the area. It is considered a point process model, which are unknown random effects generated throughout the potential area of a study. The second component is the observations of animals in the region, i.e. the capture history.

Table 5.1 Sample of a detector layout file

Detector	*X*	*Y*	*1*	*2*	*3*
1	482385.7	4050523	0	1	1
2	479169.6	4050229	0	0	0
3	483856.5	4048003	0	1	1
4	471723.8	4045542	1	0	0

The capture data file holds a record of all detections of animals. One detection per row is kept, and multiple columns define the session ID, animal ID, trap ID, and occasion number. The trap ID column in capture data matches the trap ID in the detector layout file, and thus, the location of each detection event is read by the scrFrame. A sample of a capture data file is shown in Table 5.2. Column 1 in the table defines the trapping session; the second and third columns define the unique individual captured and their capture occasions, respectively. The last column is a detector identifier which links the detection data to trap data.

Table 5.2 Capture data input format.

Session	*ID*	*Occasion*	*Detector*
1	1	2	1
1	1	3	1
2	1	1	3
2	2	2	4

A schematic view of a three-dimensional scrFrame is shown in Figure 5.2.

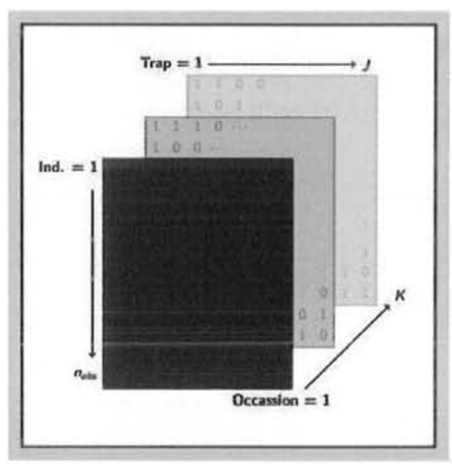

Figure 5.2. Framework of scrFrame visualizing all the trap locations, occasion and individual data. It is an array with dimensions n (individual) × J (trap locations) × K (occasion).

Another object required for SCR models is the state-space data frame 'ssDF', which specifies all potential activity centres of all possibly detectable animal individuals in the study area (Figure 5.1). We created a habitat mask to create state space. A habitat mask is a two-columned X and Y coordinate spatial data frame imported into an R environment. Every X and respective Y coordinate in this spatial points data frame represented a suitable habitat pixel.

5.2.5 Data analysis

Having readied both of the files for detector layout and capture data of both sessions of camera trapping, we used 'make.scrFrame' in R syntax to create the main data object. The complete code was:

<- make.scrFrame (caphist, traps, indCovs, trapCovs, trapOperation, type = “scr”)

where ‘caphist’ is the capture data input, and ‘traps’ is the detector layout. ‘trapCovs’ defines the trap station site covariates, e.g., elevation. Trap covariates can be added to the detector layout file in subsequent columns to occasions separated by ‘/’. ‘indCovs’ specifies animal-related covariates like sex and can be added to a capture data file for sex- or age-specific models. Traps and individual covariates were not used in our analysis. ‘trapOperation’ denotes whether a camera was functional or not on an occasion, and assigns a binary matrix. ‘type’ keeps the data in SCR format (Sutherland, 2016). Two independent observers evaluated and finalized unique snow leopard individuals’ data and analysis sheets. For state-space, a 15-kilometre buffer was taken around all camera traps. The state-space total area was 5,764 km^2, and all of the area was considered as suitable because of very low human disturbance and high potency of snow leopard presence across the entire region. A null model (d0 ~ 1, p0 ~ 1, g ~ 1) was run to calculate the baseline density, detection probability, and sigma parameters.

5.3 RESULTS

All 122 camera stations captured a total of 17,608 photos, of which 1,181 were of snow leopards. The average number of photos per camera was 144. Camera stations were set collectively for a total of 1,243 trap-days. Of 122 stations, snow leopards were captured at 22. A total of 19 individuals were identified from all comparable photographs of snow leopards. Snow leopards were captured on 29 independent events comprising 12 spatially distinct recaptures. Some of the photos of uniquely identified snow leopard individuals from their pelage pattern are shown in Plate 5.1.

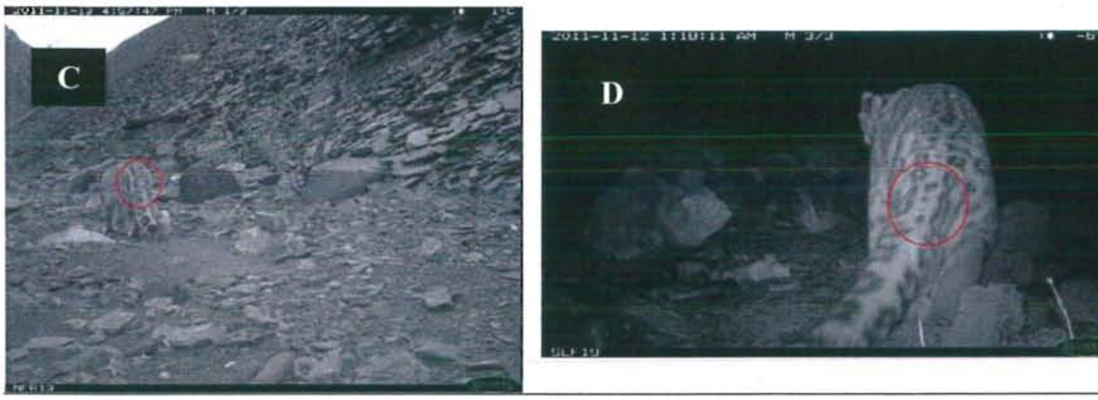

Plate 5.1 Photographs A–B show one individual from different camera traps, identified based on a pattern on a front limb. Photographs C–D show another individual identified by its tail pattern.

Snow leopard activity was detected mostly during dawn and dust, and almost complete inactivity was seen during the middle of the day. Figures 5.3 and 5.4, for Shimshal and Khunjerab show the highest number of photos captured during the circadian circle (labelled as frequency of images).

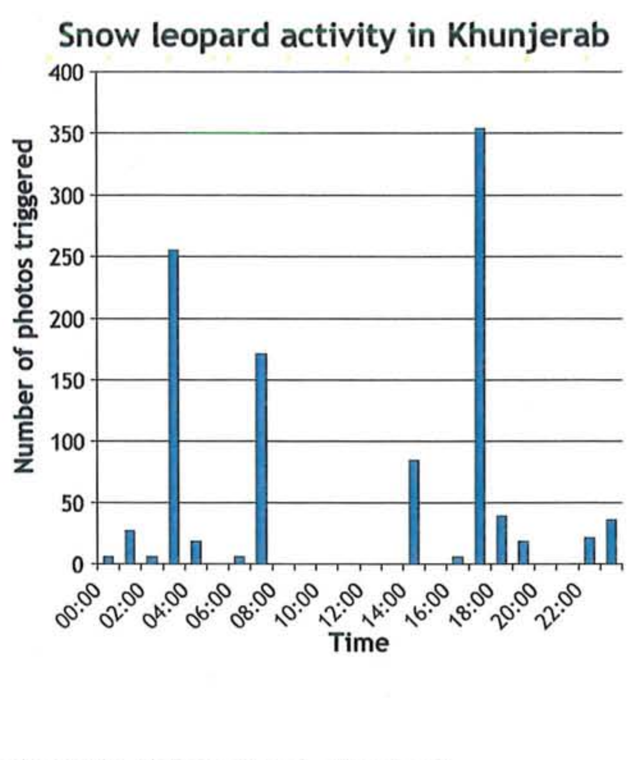

Figure 5.3. Snow leopard activity pattern in Khunjerab

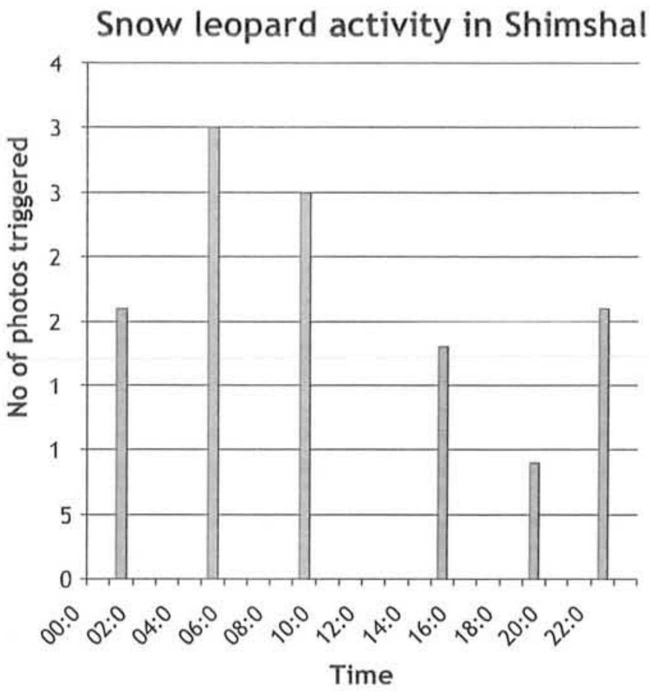

Figure 5.4. Snow leopard activity pattern in Shimshal.

Other than snow leopards, the camera traps were triggered by 16 different species, including humans and livestock. All of the triggers collectively resulted in a total of 312 independent trigger events of the traps. Details of all species captured in both Khunjerab and Shimshal are shown in Table 5.3.

Table 5.3. Record and events of all species captured in the study.

Species	*Independent trigger events*
Blue sheep	1
Brown bear	2
Cape hare	32
Chukor partridge	2
Common leopard	1
Domestic dog	2
Grey wolf	2
Human	119
Ibex	28
Livestock	13

Pika	11
Red fox	60
Small mammal	1
Snowcock	1
Snow leopard	22
Stone marten	11
Weasel	4
Grand total	**312**

The SCR model run on the snow leopard detection data and histories estimated a total of 55 individuals in an area of 5,764 km^2 comprising both the Khunjerab and Shimshal areas. The coefficients of all parameters and real-time values of estimated densities are shown in Table 5.4 and 5.5, respectively. The base encounter rate was 0.008, and the spatial scale of detected movement in all activity centres was calculated as 6.726 ± 1.23.

Table 5.4. Coefficients of model.

Parameter	*Estimate*	*SE*	*z*	*P(>|z|)*
p0.(Intercept)	-4.829	0.416	-11.603	0
sig.(Intercept)	1.906	0.209	9.097	0
d0.(Intercept)	-3.265	0.326	-10.025	0

Table 5.5. Real-time density estimates of model.

Area (km^2)	*Density*	*Upper*	*Lower*
Pixel (4)	0.038	0.072	0.020
100	0.955	1.809	0.504
5764	55.042	104.277	29.053

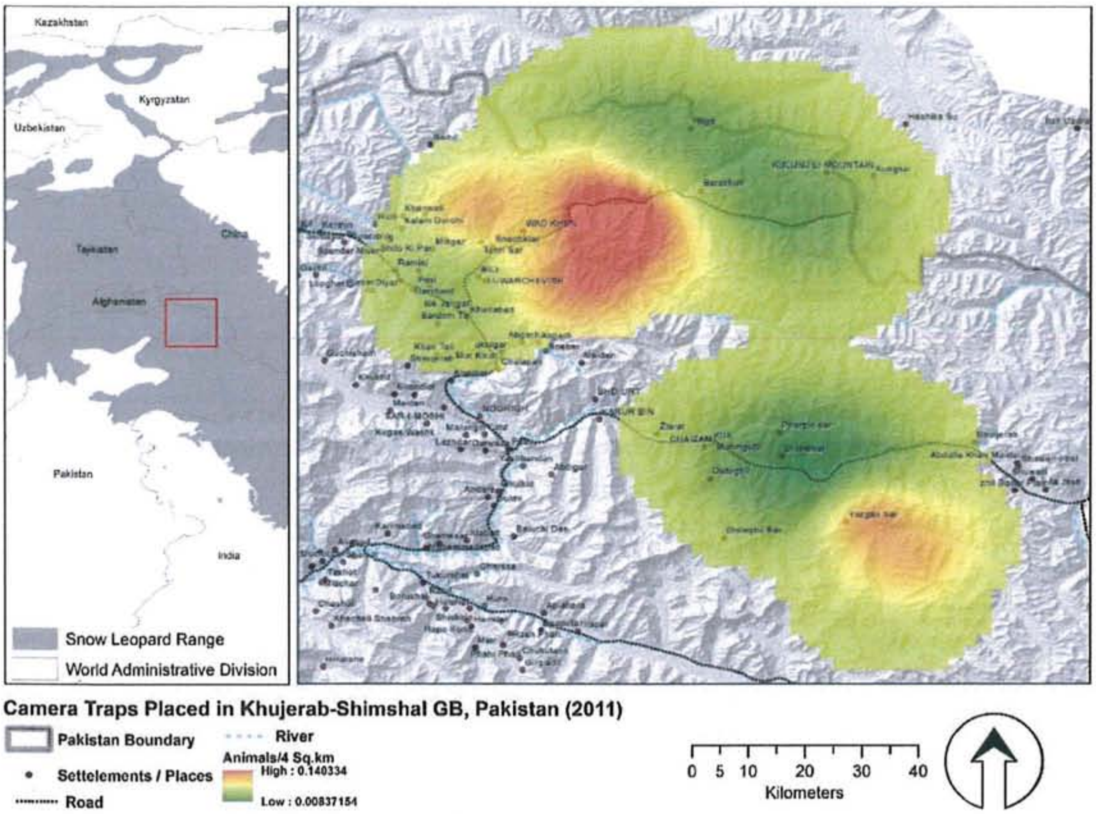

Figure 5.5. Density surface from null model.

5.4 DISCUSSION

The reliable estimation of abundance is a vital parameter in conservation and management planning (Araujo and Chiarello, 2013; Williams et al., 2012). Population density is an estimate that is usually reported in species capture-recapture studies but is rarely looked at for its reliability, keeping in view the sampling and statistical approach for such studies (Keiter et al., 2017). Density estimation may be compromised if statistical assumptions are not taken into account in highly patchy distributed populations of rare and elusive species like snow leopards. The sampling design and analysis of the data needs to be robust and relevant to the nature of the species under study and its habitat. Such concerns have prevailed in ecological literature; ecological studies on iconic species like snow leopards are no exception. The fact that snow leopards are long-ranging, rare, dwell in harsh, logistically inaccessible, spatially and temporally dynamic areas, having low encounter probabilities, minimal densities and small obtained sample sizes, make it extremely hard to count their numbers. Understanding snow leopard population and distribution in various parts of its range has been a priority of conservationists and researchers. The earliest investigation dates to 1972 when Anonymous (1972) provided an initial baseline for snow leopard studies. There have been several attempts (Fox et al., 1991; McCarthy et al., 2016b; Schaller, 1977) to update and refine the baseline. Initial studies were based largely on reviews, expert judgements, and on the expanse of potential habitat. Researchers started validating this information through interviews, site visits, and sign surveys (Ale and Brown, 2009; Fox et al., 1991; Grachev and Ata, 1977; Jiang, 2006; Ma et al., 2011; Schaller et al., 1988; Xu et al., 2008). It was soon learnt that snow leopard markings in the field are distinctive (Sunquist, 2016), which can be used to establish species presence. This led to the development of a sign-based protocol to assess the abundance of snow leopards—SLIMS (Jackson et al., 1997). Snow leopard biologists relied on indirect methods for abundance estimation until the advent of technology in the past decade in the form of trail cameras and molecular genetics, which allow for actual individual detection. Trail cameras were first tested for snow leopards in 2002 in Zanskar, Jammu and Kashmir, India. (Spearing, 2002). However, their use in abundance estimation has seen an increase in the past ten years.

In Pakistan, very few studies have been conducted using camera trapping, and even fewer have been published, keeping in view modern statistical and species behavioural aspects. This study applied the SCR approach, which is distinct from conventional capture-recapture in the sense that it does take into consideration the spatial aspect of the study area which may affect the detection probability of a species at a particular trap location (Efford, 2011). Traditional models induce spatial bias and do not account for the effect a trap location may have on the encounter rate of snow leopards. The total trapping duration resulted in 29 independent events of captures and 12 recaptures of the same individuals. There were 12 spatially distinct recaptures. Covariates and other environmental variables were not considered in the analysis since the sample size was obtained using uniform effort in the area. In addition, the camera trap locations shared the same climate, topography, and snowy terrain. The sample size contained a total of 19 unique individuals, and the density calculated was about 1 animal per 100 km^2 with an upper confidence limit of 1.8 individuals/100 km^2, and a lower confidence limit of 0.5 individuals/100 km^2. The total study area considered for the possible existence of snow leopard activity centres under these statistical models resulted in a total population of 55 (95% Cl: 29–104) individuals. The species is known to be highly elusive, and the model yielded the same behaviour via an encounter rate of 0.008, which matches the findings of Sharma et al. (2014) and Chetri et al. (2019). The vast landscape of 5,764 km^2, including Khunjerab and Shimshal, meant that these individuals move long distances. The sigma, a spatial scale of movement in the study area, was calculated as 6.73 and confirmed that snow leopards live in extremely low densities in rugged terrains across massive landscapes (Alexander et al., 2016, 2015; Chetri et al., 2019). In SCR models, the sigma is linearly considered as the home range estimate under the assumption of normal activity patterns. Sigma size considered as home range will, however, remain inferior information as compared to that of data from telemetry (Efford et al., 2016). The density map (Figure 5.5) shows that most of the activity centres fall inside the central core zones of the study area with higher distribution. Despite the similar climatic, anthropogenic, and topographic conditions of camera traps, the model density maps predicted slight avoidance of areas near the Pakistan-China boundary, possibly due to fencing that could hinder snow leopard movement, and areas near major villages like Shimshal. The SCR analysis and results presented here may suffer from some limitations as well—the estimates obtained had high confidence intervals and large margins of error (Table 5.4 and 5.5). The camera trapping array size and configuration deployment as per the behaviour and home ranges were not entirely possible due to scarce resources and harsh weather conditions. Studies such as Keiter et al. (2017) and Ponchon et al. (2018) have stressed keeping trap spacing according to animals' movement behaviours. Sollmann et al. (2012) simulated different designs and reported SCR models to be good estimators if the trap array was not smaller than the sigma of the species. Another limitation of the study was the linear coverage of the study area—it was not possible due to inaccessible terrain and an insufficient number of camera traps. It is generally recommended, in case of insufficient camera traps, that two designs be followed (Karanth and Nichols, 2017). Either the central area of the study should be covered uniformly (which we did, but still had to leave some holes in the region), or a second approach, a cluster design, where traps in small clusters are placed uniformly for maximizing spatial recaptures and clusters, be spread over a larger area to maximize the sample. This approach can be evaluated in future along with simulations of the study area prior to actual fieldwork. Sun et al. (2014) simulated different sampling schemes for capture-recapture studies and described cluster sampling to be more appropriate and field implementable as compared to the uniform spread of cameras in all areas under study. However, the performance of cluster design was not significantly different when the study area size increased in accordance with the species' home range. It is suggested, therefore, that further studies be conducted with standardized approaches of species home ranges, with relevant camera trap spacing and configuration.

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5.6 REFERENCES

Ahmad, S., Hameed, S., Ali, H., Khan, T.U., Mehmood, T., Nawaz, M.A., 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-016-1029-6

Ale, S.B., Brown, J.S., 2009. Prey Behavior Leads to Predator: A Case Study of the Himalayan Tahr and the Snow Leopard in Sagarmatha (Mt. Everest) National Park, Nepal. Isr. J. Ecol. Evol. 55, 315–327. https://doi.org/10.1560/IJEE.55.4.315

Ale, S.B., Yonzon, P., Thapa, K., 2007. Recovery of snow leopard Uncia uncia in Sagarmatha (Mount Everest) National Park, Nepal. Oryx 41, 89–92. https://doi.org/10.1017/S0030605307001585

Alexander, J.S., Gopalaswamy, A.M., Shi, K., Riordan, P., Margalida, A., 2015. Face value: Towards robust estimates of snow leopard densities. PLoS One 10. https://doi.org/10.1371/journal.pone.0134815

Alexander, J.S., Zhang, C., Shi, K., Riordan, P., 2016. A granular view of a snow leopard population using camera traps in Central China. Biol. Conserv. 197, 27–31. https://doi.org/10.1016/j.biocon.2016.02.023

Anonymous, 1972. The snow leopard in Pakistan. Animals 14, 256–259.

Aryal, A., Brunton, D., Ji, W., Karmacharya, D., McCarthy, T.O.M., Bencini, R., Raubenheimer, D., 2014. Multipronged strategy including genetic analysis for assessing conservation options for the snow leopard in the central Himalaya. J. Mammal., 95, 871–881. https://doi.org/10.1644/13-MAMM-A-243

Bertram, B.C.R., 1973. Lion population regulation. Afr. J. Ecol. https://doi.org/10.1111/j.1365-2028.1973.tb00088.x

Borchers, D.L., Efford, M.G., 2008. Spatially explicit maximum likelihood methods for capture-recapture studies. Biometrics 64, 377–385. https://doi.org/10.1111/j.1541-0420.2007.00927.x

Chapron, G., McCarthy, T.M., 2003. Snow leopard survival strategy.

Chetri, M., Odden, M., Sharma, K., Flagstad, Ø., Wegge, P., 2019. Estimating snow leopard density using fecal DNA in a large landscape in north-central Nepal. Glob. Ecol. Conserv. 17, e00548. https://doi.org/10.1016/j.gecco.2019.e00548

Dice, L.R., 1938. Some Census Methods for Mammals. J. Wildl. Manage. https://doi.org/10.2307/3796432

Din, U.J., Ali, H., Ali, A., Younus, M., Mehmood, T., Norma-Rashid, Y., Ali Nawaz, M., 2017. Pastoralist-predator interaction at the roof of the world: Conflict dynamics and implications for conservation. Ecol. Soc. https://doi.org/10.5751/ES-09348-220232

Efford, M., 2004. Density estimation in live-trapping studies. Oikos 106, 598–610. https://doi.org/10.1111/j.0030-1299.2004.13043.x

Efford, M. G., 2011. Estimation of population density by spatially explicit capture-recapture analysis of data from area searches. Ecology 92, 2202–2207. https://doi.org/10.1890/11-0332.1

Efford, M.G., Dawson, D.K., Jhala, Y. V, Qureshi, Q., 2016. Density-dependent home-range size revealed by spatially explicit capture–recapture. Ecography (Cop.). 39, 676–688. https://doi.org/10.1111/ecog.01511

Efford, M.G., Fewster, R.M., 2013. Estimating population size by spatially explicit capture-recapture. Oikos 122, 918–928. https://doi.org/10.1111/j.1600-0706.2012.20440.x

Feng, X., Ming, M., Yiqun, W., 2011. Population density of snow leopards (Panthera uncia) in Tomur National Nature Reserve of Xinjiang, China. Acta Theriol. Sin. 31, 205–210.

Ferretti, F., Lovari, S., Minder, I., Pellizzi, B., 2014. Recovery of the snow leopard in Sagarmatha (Mt. Everest) National Park: Effects on main prey. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-014-0810-7

Fox, J., 1994. Snow leopard conservation in the wild-a comprehensive perspective on a low density and highly fragmented population. In: Fox JL and Du JZ (eds), Proc. Seventh Int. Snow Leopard Symp., International Snow Leopard Trust, Seattle, WA, USA, 3–15.

Fox, J.L., Sinha, S.P., Chundawat, R.S., Das, P.K., 1991. Status of the snow leopard *Panthera uncia* in Northwest India. Biol. Conserv. 55, 283–298. https://doi.org/10.1016/0006-3207(91)90033-6

Gittleman, J.L., 1989. Carnivore Group Living: Comparative Trends. In: Gittleman J.L. (eds) Carnivore Behavior, Ecology, and Evolution. Springer, Boston, MA. https://doi.org/10.1007/978-1-4757-4716-4_8.

Grachev, U.A., Ata, A., 1977. Distribution and Numbers of Snow Leopard in Kazakhstan. Sci. York 1962–1964.

Hameed, S., 2010. Population Status of Snow Leopard (*Uncia Uncia*) in Laspur Valley, Chitral. Thesis submitted in the partial fulfillment of degree in M. Phil Wildlife Management. PMAS-Arid Agriculture University Rawalpindi.

Hayne, D.W., 1950. Apparent home range of Microtus in relation to distance between traps. J. Mammal., 31(1), pp.26-39.

Henschel, P., Ray, J., 2003. Leopards in African Rainforests : Survey and Monitoring

Techniques. Wcs 33, 54. https://doi.org/http://www.carnivoreconservation.org/largecatsurvey/

Houston, A.I., Davies, N.B., 1985. The evolution of cooperation and life history in the dunnock, *Prunella modularis*, in: Behavioural Ecology: Ecological Consequences of Adaptive Behaviour. https://doi.org/10.1111/j.1863-2378.2009.01268.x

Hussain, S., 2003. The status of the snow leopard in Pakistan and its conflict with local farmers. Oryx 37, 26–33. https://doi.org/10.1017/S0030605303000085

Jackson, R., Hunter, D.O., Emmerich, C., 1997. SLIMS: an information management system for promoting the conservation of snow leopards and biodiversity in the mountains of Central Asia. Proc. Int. Snow Leopard Symp. 8, 75-91 ST-SLIMS: an information management syste.

Jackson, R.M., Hunter, D.O., 1996. Snow leopard survey and conservation handbook. International Snow Leopard Trust.

Jackson, R.M., Mishra, C., McCarthy, T.M., Ale, S.B., 2010. Snow leopards: conflict and conservation. Biol. Conserv. wild felids 417–430. https://doi.org/10.1111/1365-2664.12061

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2006. Estimating snow leopard population abundance using photography and capture-recapture techniques. Wildl. Soc. Bull. 34, 772–781.

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2005. Camera-Trapping of Snow Leopards. Cat News.

Janečka, J.E., Jackson, R., Yuquang, Z., Diqiang, L., Munkhtsog, B., Buckley-Beason, V., Murphy, W.J., 2008. Population monitoring of snow leopards using noninvasive collection of scat samples: A pilot study. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2008.00195.x

Janečka, J.E., Munkhtsog, B., Jackson, R.M., Naranbaatar, G., Mallon, D.P., Murphy, W.J., 2011. Comparison of noninvasive genetic and camera-trapping techniques for surveying snow leopards. J. Mammal. https://doi.org/10.1644/10-MAMM-A-036.1

Jiang, Z., 2006. Snow leopards in the Dulan International Hunting Ground, Qinghai, China . Report submitted to ISLT. pp1-8..

Karanth, K.U., Nichols, J.D., 2017. Methods for monitoring tiger and prey populations. Springer Singapore. Vol., 01, 303pages.. https://doi.org/10.1007/978-981-10-5436-5

Karanth, K.U., Nichols, J.D., Seidensticker, J., Dinerstein, E., Smith, J.L.D., McDougal, C., Johnsingh, A.J.T., Chundawat, R.S., Thapar, V., 2003. Science deficiency in conservation practice: The monitoring of tiger populations in India. Anim. Conserv. 6, 141–146. https://doi.org/10.1017/S1367943003003184

Karmacharya, D.B., Thapa, K., Shrestha, R., Dhakal, M., Janecka, J.E., 2011. Noninvasive genetic population survey of snow leopards (Panthera uncia) in Kangchenjunga conservation area, Shey Phoksundo National Park and surrounding buffer zones of Nepal. BMC Res. Notes. https://doi.org/10.1186/1756-0500-4-516

Keiter, D.A., Davis, A.J., Rhodes, O.E., Cunningham, F.L., Kilgo, J.C., Pepin, K.M., Beasley, J.C., 2017. Effects of scale of movement, detection probability, and true population density on common methods of estimating population density. Sci. Rep. 7. https://doi.org/10.1038/s41598-017-09746-5

Khatiwada, J.R., Chalise, M.K., Kyes, R.C., 2007. Survey of Snow Leopard (Uncia uncia) and Blue Sheep (Pseudois nayaur) populations in the Kangchenjunga Conservation Area (KCA), Nepal 12.

Ma, M., Xu, F., 2006. Successful camera trapping on snow leopard in the Muzat Valley Tomur Feng Nature Reserve, Xinjiang, P. R. China (in mandarin). Arid L. Geogr. 29, 307–308.

Ma, M., Xu, F., Munkhtsog, B., Wu, Y., McCarthy, T., McCarthy, K., 2011. Monitoring of population density of snow leopard in Xinjiang. J. Ecol. Rural Environ. 27, 79–

83.

Maheshwari, A., 2013. Snow leopard (Panthera uncia) surveys in the Western Himalayas, India. J. Ecol. Nat. Environ. 5, 303–309. https://doi.org/10.5897/jene2013.0382

Malik, M.M., 1997. Status and Conservation of Snow Leopard in Pakistan. In: R. Jackson and A. Ahmad (eds.). Proceedings of the 8th International Snow Leopard Symposium, Islamabad, November 1995. International Snow Leopard Trust, Seattle and WWF-Pakistan, Lahore, pp11-20.

McCarthy, K.P., Fuller, T.K., Ming, M., McCarthy, T.M., Waits, L., Jumabaev, K., 2008. Assessing Estimators of Snow Leopard Abundance. J. Wildl. Manage. 72, 1826–1833. https://doi.org/10.2193/2008-040

McCarthy, T., Mallon, D., Jackson, R., Zahler, P., McCarthy, K., 2017. IUCN Red List Assessment: Panthera uncia, Snow Leopard 8235, 27. https://doi.org/10.2305/IUCN.UK.2017-2.RLTS.T22732A50664030.en

McCarthy, T., Mallon, D., Sanderson, E.W., Zahler, P., Fisher, K., 2016a. What is a Snow Leopard? Biogeography and Status Overview, Snow Leopards: Biodiversity of the World: Conservation from Genes to Landscapes. Elsevier Inc. https://doi.org/10.1016/B978-0-12-802213-9.00003-1

McCarthy, T., Mallon, D., Sanderson, E.W., Zahler, P., Fisher, K., 2016b. What is a snow leopard? Biographical and status overview, Snow Leopards. Biodiversity of the World: Conservation from Genes to Landscapes. Elsevier Inc. https://doi.org/10.1016/B978-0-12-802213-9/00003-1

McCarthy, T., Murray, K., Sharma, K., Johansson, O., 2010. Preliminary results of a long-term study of snow leopards in South Gobi, Mongolia. Cat News 53, 15–19.

McCarthy, T.M., Chapron, G., 2003. Snow leopard survival strategy. Snow Leopard Netw. (2014). Snow Leopard Surviv. Strateg. Revis. 2014 Version Snow Leopard Network, Seattle, Washington, USA.

Mcgregor, T., Newell, C., 2007. Expedition report Surveying snow leopards and other animals in the mountains of the Altai Republic , central Asia Резюме.

Network, S.L., 2014. Snow leopard survival strategy. Seattle, Washington, USA 1–145.

Nowell, K., Jackson, P., 1996. Wild cats: status survey and conservation action plan. IUCN Gland.

Ponchon, A., Choquet, R., Tornos, J., Mccoy, K.D., Tveraa, T., Boulinier, T., 2018. Survival estimates strongly depend on capture-recapture designs in a disturbed environment inducing dispersal. Ecography (Cop.). 1–12. https://doi.org/10.1111/ecog.03334

Qureshi, R., Khan, W.A., Bhatti, G., Khan, B., Iqbal, S., Ahmad, M.S., Abid, M., Yaqub, A., 2011. First report on the biodiversity of Khunjerab National Park, Pakistan. Pakistan J. Bot. 43, 849–861.

Qureshi, R., Raza Bhatti, G., Memon, R.A., 2010. Ethnomedicinal uses of herbs from northern part of Nara desert, pakistan. Pakistan J. Bot. 42, 839–851.

Royle, J.A., Chandler, R.B., 2014. Spatial Capture-Recapture. Spat. Capture-recapture iii. https://doi.org/10.1016/B978-0-12-405939-9.00022-0

Royle, J.A., Chandler, R.B., Sollmann, R., Gardner, B., 2014. Spatial Capture-Recapture. https://doi.org/10.1016/B978-0-12-405939-9.00020-7

Royle, J.A., Chandler, R.B., Sollmann, R., Gardner, B., 2013. Spatial capture-recapture. Academic Press.

Royle, J.A., Young, K. V., 2008. A hierarchical model for spatial capture recapture data. Ecology 89, 2281–2289. https://doi.org/10.1890/07-0601.1

Schaller, G.B., 1979. Mountain monarchs. wild sheep and goats of the himalaya. The University of Chicago Press, Chicago and London, xviii + 425 pp., illus., 1977. J. Mammal. 60, 240–241. https://doi.org/10.2307/1379791

Schaller, G.B., 1977. Mountain monarchs. Wild sheep and goats of the Himalaya, Mountain monarchs. Wild sheep and goats of the Himalaya. https://doi.org/10.1086/410940

Schaller, G.B., 1976. Mountain Mammals in Pakistan. Oryx. https://doi.org/10.1017/S0030605300014071

Schaller, G.B., Junrang, R., Mingjiang, Q., 1988. Status of the snow Leopard Panthera uncia in Qinghai and Gansu Provinces, China. Biol. Conserv. 45, 179–194. https://doi.org/10.1016/0006-3207(88)90138-3

Sharma, K., Bayrakcismith, R., Tumursukh, L., Johansson, O., Sevger, P., McCarthy, T., Mishra, C., 2014. Vigorous dynamics underlie a stable population of the endangered snow leopard Panthera uncia in Tost Mountains, South Gobi, Mongolia. PLoS One 9. https://doi.org/10.1371/journal.pone.0101319

Sharma, K., Borchers, D., Mackenzie, D., Durbach, I., Sutherland, C., Nichols, J.D., Lovari, S., Zhi, L., Khan, A.A., Modaqiq, W., McCarthy, T.M., Alexander, J.S., Mishra, C., 2019. Guidelines for estimating snow leopard abundance and distribution using a combination of spatial capture-recapture and occupancy models. Submitted to the Steering Committee of the Global Snow Leopard and Ecosystem Protection Program; with financial suppor.

Snow Leopard Working Secretariat, 2013. Global Snow Leopard and Ecosystem Protection Program Bishkek, Kyrgyz Republic. Kyrg. Repub. 92.

Sollmann, R., Gardner, B., Belant, J.L., 2012. How does spatial study design influence density estimates from spatial capture-recapture models? PLoS One 7. https://doi.org/10.1371/journal.pone.0034575

Spearing, a, 2002. The snow leopard in Zanskar, Jammu & Kashmir, NW India. Contrib. Pap. to Snow Leopard Surviv. Strateg. Summit 175–187.

Srbek-Araujo, A.C., Chiarello, A.G., 2013. Influence of camera-trap sampling design on mammal species capture rates and community structures in southeastern Brazil. Biota Neotrop. 13, 51–62. https://doi.org/10.1590/S1676-06032013000200005

Sun, C.C., Fuller, A.K., Andrew Royle, J., 2014. Trap configuration and spacing influences parameter estimates in spatial capture-recapture models. PLoS One 9. https://doi.org/10.1371/journal.pone.0088025

Sunquist, F., 2016. Snow leopards, International Wildlife. Elsevier. https://doi.org/10.1016/B978-0-12-802213-9/00068-7

Suryawanshi, K.R., Redpath, S.M., Bhatnagar, Y.V., Ramakrishnan, U., Chaturvedi, V., Smout, S.C., Mishra, C., 2017. Impact of wild prey availability on livestock predation by snow leopards. R. Soc. Open Sci. https://doi.org/10.1098/rsos.170026

Sutherland, C., 2016. oSCR - an R package for SCR analyses.

Williams, B.K., Nichols, J.D., Conroy, M.J., 2012. Analysis and management of animal populations, Uma ética para quantos? https://doi.org/10.1007/s13398-014-0173-7.2

Xu, A., Jiang, Z., Li, C., Guo, J., Da, S., Cui, Q., Yu, S., Wu, G., 2008. Status and conservation of the snow leopard Panthera uncia in the Gouli Region, Kunlun Mountains, China. Oryx 42, 460–463. https://doi.org/10.1017/S0030605308000252

Yang, T.H., Lee, W.P., 2013. A service-oriented approach with neural networks and knowledge ontologies for robot control. Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics) 8227 LNCS, 473–483. https://doi.org/10.1007/978-3-642-42042-9_59

Zhou, X., Chong, J., Yang, X., Li, W., Guo, X., 2017. Ocean Surface Wind Retrieval Using SMAP L-Band SAR. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 10, 65–74. https://doi.org/10.1109/JSTARS.2016.2630919

Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

CHAPTER 6

Population Estimation of Brown Bear in Deosai National Park

6 Population estimation of Brown Bear in Deosai National Park

ABSTRACT

The Himalayan brown bear (*Ursus arctos isabellinus*) is a subspecies of the brown bear and represents an ancient lineage distributed over the great Himalayan region. Its overall population status throughout its distribution range has not been estimated. This study was carried out in Deosai National Park (DNP) and its buffer areas in 2012 with the objective to evaluate the effectiveness of camera trapping and double-observer techniques for brown bear population estimation. A double-observer survey was conducted in DNP. The park was divided into 45 unequal watershed-based blocks. A double-observer survey was conducted in 27 blocks due to accessibility issues and logistical constraints. A direct count survey using a single observer was carried out in some watersheds, including in the buffer areas. A camera trapping study was carried out in both DNP and its buffer areas. The study area was divided into 5 × 5 km grids. A total of 116 ReconyxTM camera stations were established at different locations in different grids of the study area. Brown bears were sighted in 9 of 27 watersheds through the double-observer method, and 30 bears were sighted in 19 sighting events, excluding double counts. They were photo-captured at nine camera stations with few recaptures, which restricted our ability to perform any population estimation analysis. The double-observer data were analyzed using a Huggins Closed Capture model in Program MARK. The analysis showed an averaged capture probability (p) 0.48 ± 0.11SE with 0.28-0.69 (95% CI) and recapture probability (c) 0.48 ± 0.11SE with 0.29-0.68 (95% CI). The averaged population size (N) was 44.64 ± 12.66SE with 19.84 - 69.45 (95% CI) within DNP's boundary. The percentage of variation attributable to the model was 19.63%. In addition to this, 11 brown bears were counted using the single-observer method but were not included in the analysis (but were kept separately for the record). This study showed that the double-observer method is the most effective method for the population estimation and monitoring of brown bears in the plain areas of DNP and other similar areas of High Asia because it increases opportunities to easily observe the species in its habitat. It also creates a capture-mark-recapture history based on individuals' unique morphological characteristics. We recommend that bear

population surveys in DNP and other similar areas throughout their distribution range in High Asia be conducted through the double-observer technique.

Keywords: Himalayan brown bear, *Ursus arctos isabellinus*, Deosai National Park, double observer, camera trapping, population estimation, High Asia

6.1 INTRODUCTION

The Himalayan brown bear *(Ursus arctos isabellinus)* is a subspecies of the brown bear *(Ursus arctos)* and represents an ancient lineage that has likely been long-isolated in the mountains of Central Asia (Galbreath et al., 2007). The brown bear's historical distribution range spreads from the Karakorams, Hindu Kush, western Himalayas, western Kunlun Shah, Pamirs, and Tian Shan range in Southern Asia (Nawaz, 2007; Roberts, 1977). In Pakistan, the brown bear is distributed over an area of about 150,000 km^2 in the country's northern parts (Haq et al., 2012; Nawaz, 2007). Its overall population status throughout its distribution range has not yet been determined, although estimates do exist for certain populations. For example, in China, brown bears exist in poorly defined populations in the west and northeast, with population estimates of 6,000 and 1,000, respectively. In India, the estimated population range is 500–750 individuals (Japan Bear Network, 2006), while in Pakistan, information about brown bear distribution and population status is patchy, but approximately 150–200 bears may exist in seven populations over three major mountain ranges—the Himalayas, Karakorams, and Hindu Kush. Connectivity among these seven populations is limited, and some are completely isolated (Nawaz, 2007). All of these populations are small and decreasing, except for the Deosai population, which is growing (Nawaz et al., 2008).

Many populations of brown bears are now isolated and of conservation concern, particularly in the southern parts of their distribution range (McLellan et al., 2017). The brown bear's phylogeography has been studied comprehensively in many parts of its distribution range (Hirata et al., 2013), but information about its population status in Central Asia is minimal—many populations are further fragmented into several smaller populations and listed as critically endangered by IUCN (McLellan et al., 2017). Two subspecies of brown bear, the Tibetan brown bear *(Uusus arctos pruinosus)* and Himalayan brown bear, occupy the southern Tibetan Plateau and northwestern Himalayas, respectively (Aryal et al., 2012; Nawaz, 2007). Phylogenetic analyses based on mitochondrial DNA suggest that the Himalayan brown bear, which is genetically distinct from the Tibetan brown bear, may represent a more ancient lineage (Galbreath et al., 2007), while the Tibetan brown bear might be a relict population of the Eurasian brown bear (Hirata et al., 2013). Habitat fragmentation, the main factor leading to the isolation of populations and individuals, has negative genetic and demographic effects (Boitani, 2012). The slight genetic difference between geographically distant populations of brown bear in Central Asia suggests substantial range expansion during the late Pleistocene-Holocene period (Galbreath et al., 2007). Once abundant in northern Pakistan, the Himalayan brown bear has been eliminated from most of its former distribution range. This decline may imply a decrease in genetic diversity, compromising population survival. The northern Pakistani brown bear population may have endured an estimated 200–300-fold decrease during the last thousand years, possibly due to glaciations and growing human populations. However, in spite of the presence of a bottleneck genetic signature, the population in northern Pakistan has a moderate level of genetic diversity and is not at immediate risk of inbreeding depression. Gene flow may exist with adjacent populations (Bellemain et al., 2007).

In southern Asia, isolated brown bear populations inhabit rugged and remote mountainous areas (Servheen et al., 1999). Himalayan brown bears in northern Pakistan (Deosai) avoid steeper slopes and higher elevations, instead selecting grassy, marshy, and stony vegetation. Marshy vegetation is the most preferred habitat, probably because it has the highest forage production and density of golden marmots *(Marmota caudata)*. Brown bears tolerate human infrastructures like roads and camps but generally avoid grazing areas with high livestock density (Nawaz et al., 2014). The Himalayan brown bear is predominantly herbivorous, as indicated by diet composition in Pakistan and India (Nawaz et al., 2019). In Pakistan, its diet consists of plant matter (64%) and animal matter (36%). Eight plant families, Apiaceae, Asteraceae, Caryophyllaceae, Cyperaceae, Lamiaceae, Poaceae, Polygonaceae, and Rubiaceae and golden marmots are brown bears' main source of meat. Males are generally more carnivorous than females, probably because of their larger size and the higher energy demand for hunting marmots (Nawaz et al., 2019).

Many techniques are used for monitoring animal populations. Among these, camera trapping is one of the most reliable (Agha et al., 2018; Swann and Perkins, 2014). The use of camera trapping technology has a long history, beginning in wildlife photography more than 100 years ago. It is now a universal tool in ecology and conservation—scientific studies using them are published regularly (Wearn and Glover-Kapfer, 2017). They include camera trapping in diverse and challenging environments like deserts (Alqamy, 2010), high mountain ranges (Jackson et al., 2006), dense forests (Ahmad et al., 2016), and savannahs (Balme et al., 2010). Camera trap studies can be used for multiple ecological investigations, including population size and density (Noss et al., 2012), species presence (Ahmad et al., 2016), habitat use (Rich et al., 2013), and demographic structure (Karanth et al., 2011). Although, there are some limitations like low capture rate, unrecognizable individual etc., for low density species in challenging terrain and especially where individual markings are not proven approaches to recognize individuals. Still Camera trapping is more convincing tool, as compared to older methods such as line transects, fixing traps, track surveys, and human interviews, for detecting elusive and nocturnal species (Hossain et al., 2016).

The double-observer technique for population estimation was originally developed to estimate the detection probabilities of aerial surveys of various taxonomic groups (Cook and Jacobson, 1979; Graham and Bell, 1989). It has been found to be applicable to birds (Nichols et al., 2000), bats (Duchamp et al., 2006), ungulates (Jenkins and Manly, 2008), and rodents (Corlatti et al., 2015). In general, the technique involves two observers searching for and counting animals simultaneously while ensuring they do not cue each other on the locations of the animals (Suryawanshi et al., 2012). It was initially standardized by Forsyth and Hickling (1997) to estimate the abundance of Himalayan tahr *(Hemitragus jemlahicus)* in New Zealand. This survey technique was further modified and applied to estimate mountain ungulate populations, e.g., bharal *(Pseudois nayaur)* and ibex *(Capra sibirica)* (Suryawanshi et al., 2012).

The double-observer survey method is based on the principles of mark-recapture theory (Forsyth and Hickling, 1997). A capture history can be built for each observed individual, and data can be analyzed in a capture-mark-recapture-like fashion (Williams et al., 2002). The method is usually implemented for ungulate species population estimation but has also been used in some form for brown bear population estimation (Quang and Becker, 1997; Walsh et al., 2010).

Habitat utilization by Himalayan brown bears is quite different from that of other brown bear populations. They generally inhabit open, high-elevation plateau in Pakistan, India, China, and Central Asia. This habitat uniqueness offers different types of opportunities and challenges for monitoring bears. In this study, we tested two different approaches—camera trapping and the double-observer method in Deosai

National Park (DNP). The aims were to assess their effectiveness for brown bear population estimation in an open area, and develop recommendations for monitoring Asian brown bear populations across their entire distribution range.

6.2 MATERIALS AND METHODS

6.2.1 Study area

This study was conducted in DNP (Figure 6.1) and its surrounding areas—it is a continuation of previous studies by Nawaz (2008, 2007). DNP (75° 27' N, 35° 00' E) is 1,800 km^2 of alpine plateau east of Nanga Parbat (peak) in northern Pakistan. It is a relatively flat area between narrow valleys and steep mountains, close to the Line of Control (military control line) with India. The Deosai plateau was designated a national park in 1993 to protect the largest remnant population of brown bears in Pakistan (Nawaz et al., 2008). Elevations range from 3,500 m to 5,200 m, with about 60% of the area between 4,000 m and 4,500 m. Mean daily temperatures are in the range -20–12° C. There are four kinds of habitats in the park: marshy, grassy, stony, and rocky. The brown bear is DNP's flagship species. Other important mammalian species in the park territory include the Tibetan wolf *(Canis lupus chanco),* Himalayan ibex *(Capra ibex sibrica),* Tibetan red fox *(Vulpes vulpesmontana),* golden marmot *(Marmota caudata),* and 17 other small mammal species (Nawaz et al., 2008).

DNP is a typical highlands ecosystem characterized by low atmospheric pressure, low temperatures, aridity, low oxygen and carbon dioxide levels, intense insolation, rapid radiation, and high ultraviolet radiation (Mani, 1990). The park is covered by snow most of the year (October–May, depending on the weather). Therefore, brown bears, who usually den in the surrounding valleys, move into DNP in June and leave in early October when the snow returns.

6.2.2 Survey methods

Three different survey techniques were used to determine the study area's brown bear population size. We sought to assess the effectiveness of the methods in obtaining data for the population estimation of brown bears in DNP.

6.2.2.1 Visual count by double observers

Deosai's treeless vegetation and relatively gentle terrain allow good visibility. This makes it possible to locate and follow bears from a distance of 2–3 km without any major technology, and directly count them—a method that was used in an annual census of DNP bears during the period 1994–2006 (Nawaz et al., 2008). Bears' markings make them recognizable, which helps avoid double-counting. In Deosai brown bears are morphologically recognizable (Nawaz et al., 2008) due to following factors:

- Color variation: Four pelage colors were identifiable; blonde, silvertip, light brown and dark brown. Individuals generally darkened with age, and females were usually lighter than males.
- White patches: Many individuals had characteristic white patches. These patches are variable; some individuals had a white snout, others white ear tips. White oval patches on the shoulders were relatively common, but their sizes are variable.
- Size: Brown bears are sexually size dimorphic, adult females in Deosai have a mass of 60-80 kg, adult males 120-150 kg, and sub-adult males 50-60 kg.

A direct count using a double-observer survey was conducted in DNP in summer season from 25-August to 01-September, 2012. This was the best time as Park area is open and accessible as well as the bears are usually more active at this time. The method (Suryawanshi et al., 2012) was implemented by dividing the park into 45 blocks based on major watersheds and roads (Figure 6.1). Brown bear counting was carried out in 27 of the 45 watersheds. Two teams of observers searched each block. Both teams searched the block simultaneously and were separated by 1–2 km. Both observers recorded sightings along with other relevant information about brown bear size, sex, habitat, and disturbance. On return from the survey, both teams tallied their observations and developed capture-recaptured histories. Captures and recaptures were marked as '1s' and '0s' on the datasheet, respectively. Animals sighted by both observers were marked as '11'. They were marked as '10' or '01' if missed by either observer.

6.2.2.2 *Visual count by a single observer*

The direct count survey by a single observer was conducted Autumn season, from 04-25 September 2012, in some of DNP's remaining areas where the double-observer survey was not possible due to logistical constraints. Single-observer counts were also extended to some of the peripheral valleys. Those sites were searched by a single observer only, and these data were used to estimate the minimum number of bears in that area.

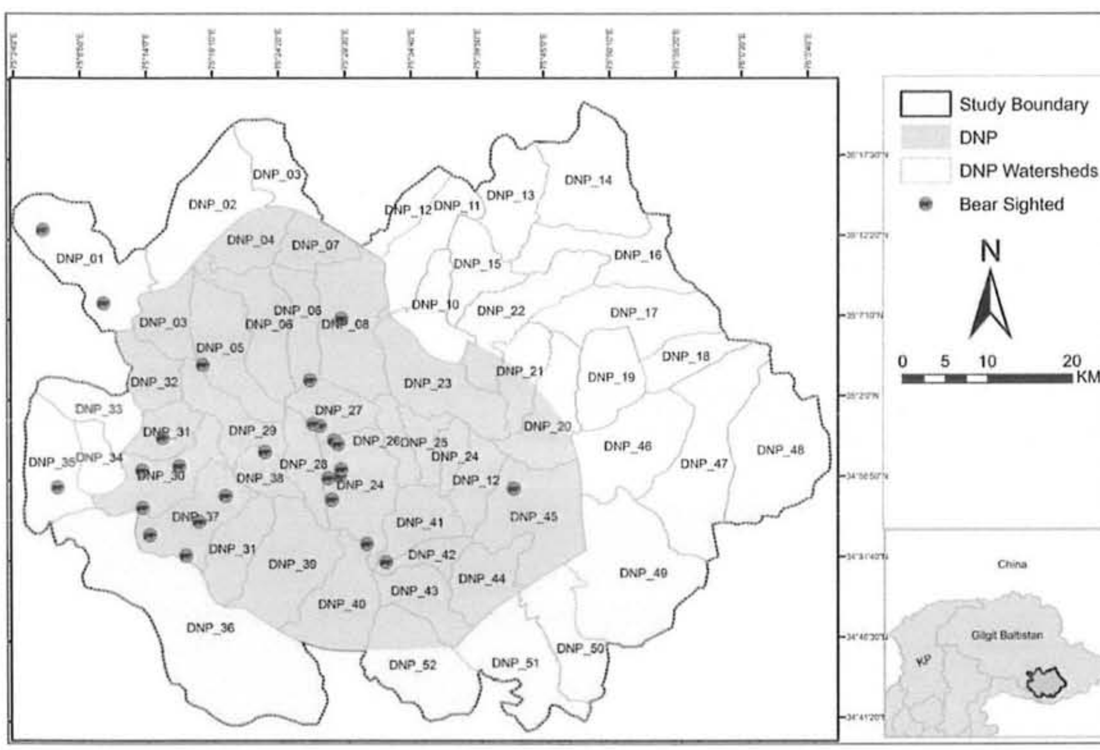


Figure 6.1. Watershed-based division of study area and locations of brown bears sighted in DNP and buffer areas during double- and single-observer surveys in 2012.

6.2.2.3 *Camera trapping*

Camera trapping was conducted in DNP and its buffer areas in 2012 to assess the population status of brown bears in the park. The park was divided into 5 × 5 km grids (Figure 6.2). A total of 116 ReconyxTM (HC500 HyperfireTM and PC900 HyperfireTM; Reconyx, Holmen, Wisconsin, USA) camera stations were established in different grids. Each camera remained functional in the field for 15–20 days. The camera trapping study was completed in two rounds. In the first round, 58 cameras were installed. We relocated these cameras to the buffer areas during the second round to increase the number of sampling units (Li et al., 2018; Sasidhran et al., 2016).

No more than two camera stations were set up in a grid to cover the park. Cameras were set up at least 1 km apart to decrease overestimation. Shooting when changes in ambient temperature are detected, these cameras were set for a one-second delay between photos, three photos per trigger, and high sensitivity options. Camera station sites were selected based on signs and animals' specific travel routes. Two types of lures were used—fish oil on plaster tablets and castor (Bischof et al., 2014). Camera trapping photos were used to confirm the presence of brown bears in several blocks.

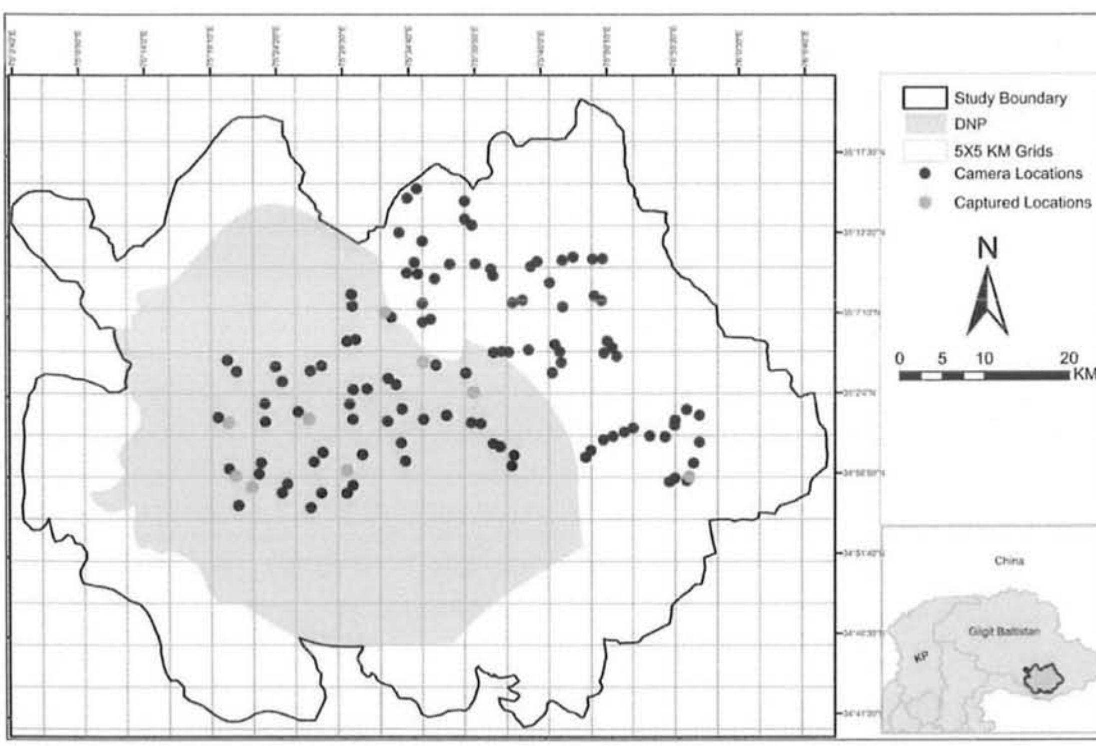


Figure 6.2. Study area map showing 5 × 5 km grids, installed camera locations, and brown bear capture locations.

6.2.3 Statistical analysis

The double observer data were analyzed in Program MARK (White and Burnham, 1999) using the Huggins Closed Captures option (Huggins, 1991, 1989). Huggins Closed Capture models provide estimates of capture and recapture probability (denoted by p and c, respectively), and permit the inclusion of individual covariates (Evan Cooch and White, 2013; Huggins, 1991, 1989). Capture-recapture histories were made, and different factors such as sex, body size, habitat, and grazing pressure were included as individual covariates. Several models were tested (Burnham and Anderson, 2002) to estimate the capture probability (p), recapture probability (c), and population size (N), which was a derived parameter—because it also estimates the number of animals not captured.

The number of brown bear individuals counted using a direct count by a single observer was not added to the population estimated using the double-observer technique. There was not enough camera trap data to apply capture and recapture analysis, so the data were used only to confirm brown bear presence in several grids.

6.3 RESULTS

6.3.1 Brown bear population estimation

6.3.1.1 Double-observer counts

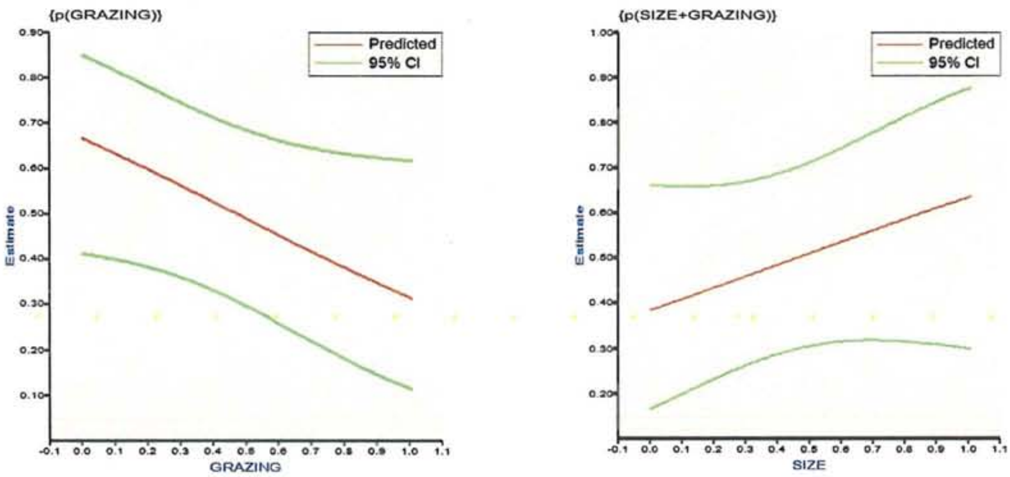
Brown bears were sighted in 9 of 27 surveyed watersheds during the double-observer survey. A total of 30 bears were sighted in 19 sightings, excluding double counts (Table 6.1) (Figure 6.1). Using Huggins Closed Capture in Program MARK, different models (Burnham and Anderson, 2002) were run to find estimates and the effect of individual covariates (Table 2). No single model supported the data adequately. Model averaging was, therefore, used to estimate capture probability (p), recapture probability (c), and population size (N). Averaged capture probability (p) was 0.48 ± 0.11SE with 0.28-0.69 (95% CI) and recapture probability (c) was 0.48 ± 0.11SE with 0.29-0.68 (95% CI). Averaged population size (N) was 44.64 ± 12.66SE with 19.84-69.45 (95% CI). The percentage of variation attributable to the model was 19.63%.

Table 6.1. Sex and age distribution of brown bears during the survey in DNP and its buffer areas.

Method	*Male*	*Female*	*Coy*	*Cub*	*Unknown*	*Total*
Double-observer counts (DNP)	10	9	4	7	0	***30***

Single-observer counts (buffer areas)	3	4	0	4	0	***11***
Camera traps	5	3	0	2	1	***11***
Total	***18***	***16***	***4***	***13***	***1***	***52***

Individual covariates were also tested. It was found that brown bear population sightings were very low in areas grazed by livestock—brown bears were detected mainly in undisturbed areas (Figure 6.3a). It was also observed that sighting probability increased with body size (Figure 6.3b).



a: **b**:

Figure 6.3. a) Effect of grazing pressure on brown bear sightings, b) Effect of body size on brown bear sightings

Table 6.2. Models used and their AICc values, likelihood, number of parameters and deviances

Model	*AICc*	*Delta AICc*	*AICc Weights*	*Model likelihood*	*Num. par*	*Deviance*
{p(grazing)}	66.79	0.00	0.23	1.00	2.00	62.58
{p(size+grazing)}	67.81	1.02	0.14	0.60	3.00	61.38
{Mo}	67.99	1.20	0.12	0.55	1.00	65.91

{p(sex+grazing)}	68.76	1.98	0.08	0.37	3.00	62.34
{p(habitat+grazing)}	68.99	2.21	0.07	0.33	3.00	62.57
{p(size)}	69.83	3.04	0.05	0.22	2.00	65.62
{p(sex)}	69.83	3.04	0.05	0.22	2.00	65.62
{p(size+grazing+sex)}	69.95	3.16	0.05	0.21	4.00	61.22
{p(habitat)}	69.98	3.19	0.05	0.20	2.00	65.77
{p(size+grazing+habitat)}	70.11	3.32	0.04	0.19	4.00	61.38
{Mb}	70.13	3.34	0.04	0.19	2.00	65.92
{Mt}	70.13	3.34	0.04	0.19	2.00	65.92
{p(size+sex)}	71.81	5.01	0.01	0.09	3.00	65.38
{p(size+habitat)}	71.92	5.14	0.02	0.08	3.00	65.50

6.3.2 Single observer counts

Brown bear sightings were also recorded by direct counts conducted by a single observer in the areas where double-observer surveys were not possible. A total of 11 bears were sighted in 7 sighting events (Table 6.1).

6.3.3 Photo-capture record

Brown bears were photo-captured at 9 of 116 camera stations set up during the study period. A total of 11 animals were captured, including five males, three females, two cubs, and one unidentified adult individual (Table 6.1). Brown bears disturbed some of our cameras—two were fully displaced from their positions. Photo-captured bears appeared to be different individuals based on size and physical features (Plate 6.1). Only one block had two captures. The recapture rate was low in camera trappings, which meant population estimation using the capture-mark-recapture method was not possible. Other carnivore species like wolves and foxes were also photo-captured at various camera stations.

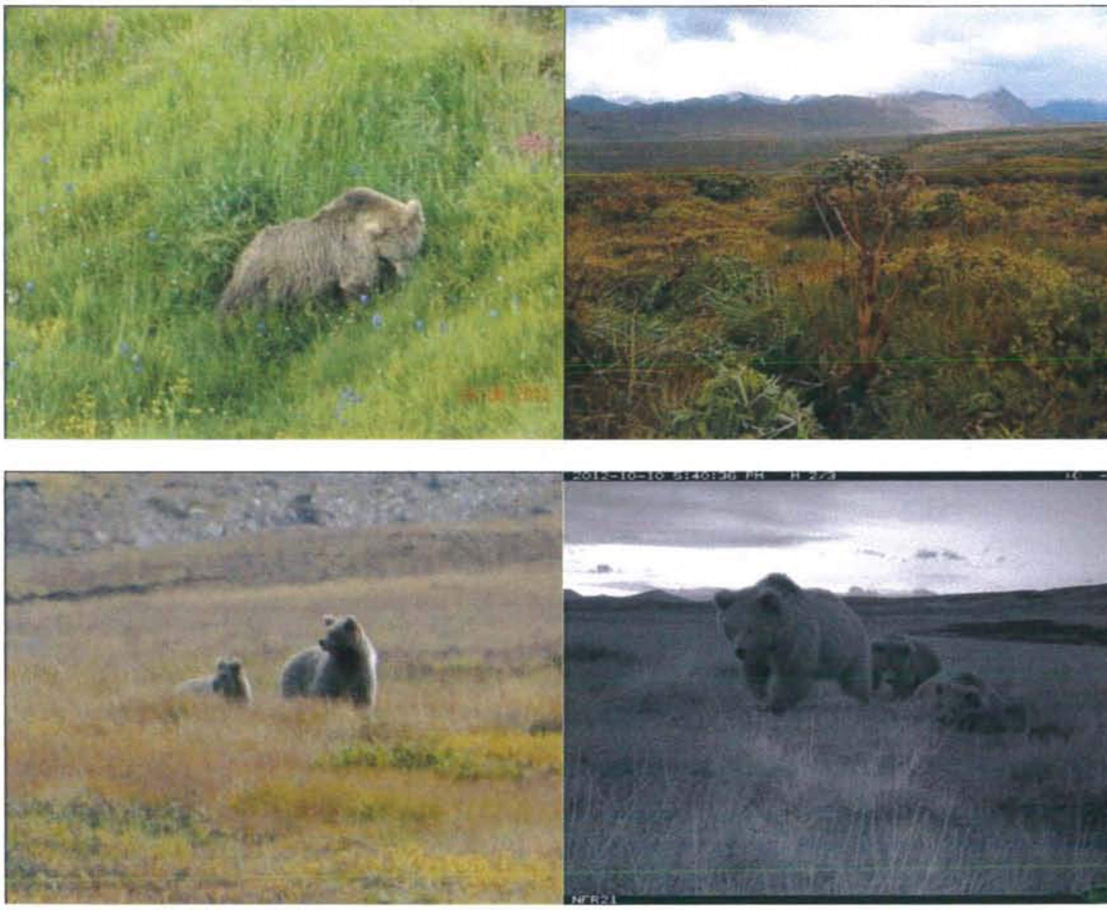


Plate 6.1. Brown bears and associated habitat photo-captured in the study area during the double-observer survey and camera trapping studies.

6.4 DISCUSSION

We tested camera trapping and the double-observer survey technique for brown bear population estimation in DNP and its buffer areas. We concluded that the direct count using the double-observer method was the most effective technique as compared to camera trapping and long term monitoring in an open area like DNP—the park is open and relatively flat, allowing long-distance sightings. Brown bears were photo-captured at 9 of 116 camera stations, while direct sightings occurred on 26 occasions in a number of watersheds. The photo-capture record indicated a low capture history of brown bears in the study area. The main reason for this was the terrain. The study showed that camera trapping surveys are likely to be less efficient in habitats with open spaces (deserts, grasslands, and wetlands) compared to more 'restricted' areas like forests and mountains where animal movement is relatively limited. Open habitats often lack obvious trails or places that animals are likely to visit, making other methods like direct observation sometimes more effective (Silveira et al., 2003; Wearn and Glover-

Kapfer, 2017). The same problem was faced during the current camera trapping study because the study area is a plateau without defined trails—which are usually ideal for camera installation (Goulart et al., 2009; Harmsen et al., 2010; Melo et al., 2012). Open and flat plateau like DNP allow animals to move freely. This makes camera site selection difficult. Camera trapping studies conducted by the Snow Leopard Foundation (SLF) throughout the brown bear's distribution range in northern Pakistan show low capture rates for brown bears. In these studies, over 800 cameras were installed in 25 different study sites for more than 20,000 trap-days. Brown bears were photo-captured in just 36 events at 28 camera stations, which illustrates their ineffectiveness in studying brown bears (SLF, unpublished data).

Another disadvantage of camera trapping specific to DNP is the terrain. Past research (Nawaz, 2008) indicates that brown bears prefer marshy areas in DNP where setting cameras up was particularly difficult due to tall grass and loose substrate. Brown bears were also found to be aggressive or playful with cameras, often dislodging them. Combined, the aforementioned factors contributed to a low photo-capture record, making capture-recapture analysis impossible. The direct-count method (single observer) is an effective technique for counting brown bears. However, direct counting by double-observer is more effective as it creates capture-recapture histories (Suryawanshi et al., 2012) based on individuals' unique markings, pelage color, body size, and sex (Nawaz, 2008), which can be used for population estimation using the program MARK. Repeating these surveys every summer season in the areas like DNP will be helpful to measure population dynamics of the brown bear over the time.

There are numerous problems associated with large carnivore conservation and management (Wilson and Delahay, 2001). Large carnivores' position at the top of food webs and their potential impact on human communities makes them significant in conservation and management actions (Moore et al., 1999). Globally, there is concern about their distribution and population status. Monitoring the populations of rare and elusive wildlife species is necessary for effective management (Thompson, 2004). In Pakistan, DNP has long been recognized as the main stronghold of brown bears in the country (Nawaz, 2007; Roberts and d'Olanda, 1977; Schaller, 1976). Population surveys in 1993 revealed that there were no more than 20 individuals in DNP (Nawaz, 2008). The Deosai plateau was declared a national park the same year to protect this small population. A conservation program was initiated to protect the species and its habitat to allow population recovery. The population size was set as an indicator of the park's success and monitored during 1994–2006. An annual census was conducted using a direct count method. The park and buffer areas population increased to 43 in 2006—an estimated annual increase of five percent (Nawaz et al., 2008). This survey continued past monitoring programs using a more reliable survey technique and modern analytical tools. Based on the findings of double observer technique, a population of about 44.64 ± 12.66SE brown bears exists in DNP. The current brown bear population in the study area is evidence of a slow annual increase (Nawaz, 2008). The brown bear reproductive rate in northern Pakistan is considered low compared to other documented populations. It is due to the late age of first reproduction (8.25 years), a long reproductive interval (5.7 years), and small litter size (1.33). The family association (4.2 years) is the longest reported for brown bears and may contribute to the higher survival of young (Nawaz et al., 2014). Poor habitat quality, low-quality food, high seasonality, and extreme weather conditions likely explain poor reproductive performance (Nawaz, 2008). The increasing population trend is also due to the dedicated efforts of the Gilgit-Baltistan Forest and Wildlife Department, particularly its strict control over poaching.

6.4.1 Conclusion and Recommendations

This study concludes that the double-observer method is the most reliable method for brown bear population estimation in the plain area of DNP and other such areas in High Asia. Other methods, such as camera trapping and direct counts by a single observer, are less effective. Plain areas with not preferred rout like DNP are not suited to camera trapping, but the double-observer method increases sighting chances and creates a capture-mark-recapture history based on individuals' unique appearance. This study showed a slow population increase rate in DNP and its buffer areas. An annual census of brown bear should be conducted in summer season to monitor population rate over the time. If annual census is not possible, population surveys must be conducted once in five years for future comparison. It is recommended that future bear population surveys in DNP and other similar areas in High Asia be conducted using the double-observer technique.

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6.6 REFERENCES

Agha, M., Batter, T., Bolas, E.C., Collins, A.C., Gomes da Rocha, D., Monteza-Moreno, C.M., Preckler-Quisquater, S., Sollmann, R., 2018. A review of wildlife camera trapping trends across Africa. Afr. J. Ecol. https://doi.org/10.1111/aje.12565

Ahmad, S., Hameed, S., Ali, H., Khan, T.U., Mehmood, T., Nawaz, M.A., 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-016-1029-6

Alqamy, H.E., 2010. Mammals of Dubai Desert Conservation Reserve: Initial Assessment and Baseline Data. using camera-traps.

Aryal, A., Raubenheimer, D., Sathyakumar, S., Poudel, B.S., Ji, W., Kunwar, K.J., Kok, J., Kohshima, S., Brunton, D., 2012. Conservation strategy for brown bear and its habitat in Nepal. Diversity. https://doi.org/10.3390/d4030301

Balme, G.A., Slotow, R., Hunter, L.T.B., 2010. Edge effects and the impact of non-protected areas in carnivore conservation: Leopards in the Phinda-Mkhuze Complex, South Africa. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2009.00342.x

Bellemain, E., Nawaz, M.A., Valentini, A., Swenson, J.E., Taberlet, P., 2007. Genetic tracking of the brown bear in northern Pakistan and implications for conservation. Biol. Conserv. https://doi.org/10.1016/j.biocon.2006.09.004

Bischof, R., Ali, H., Kabir, M., Hameed, S., Nawaz, M.A., 2014. Being the underdog: An elusive small carnivore uses space with prey and time without enemies. J. Zool. https://doi.org/10.1111/jzo.12100

Boitani, L., 2012. Carnivore Ecology and Conservation: A Handbook of Techniques. Vasa.

Burnham, K.P., Anderson, D.R., 2002. A Practical Information-Theoretic Approach, Model Selection and Inference.

Cook, R.D., Jacobson, J.O., 1979. A Design for Estimating Visibility Bias in Aerial Surveys. Biometrics. https://doi.org/10.2307/2530104

Corlatti, L., Fattorini, L., Nelli, L., 2015. The use of block counts, mark-resight and distance sampling to estimate population size of a mountain-dwelling ungulate. Popul. Ecol. https://doi.org/10.1007/s10144-015-0481-6

DUCHAMP, J.E., YATES, M., MUZIKA, R.-M., SWIHART, R.K., 2006. Estimating Probabilities of Detection for Bat Echolocation Calls: An Application of the Double-Observer Method. Wildl. Soc. Bull. https://doi.org/10.2193/0091-7648(2006)34[408:epodfb]2.0.co;2

Evan Cooch, White, G., 2013. Program MARK: A Gentle Introduction. Extrem. Program. https://doi.org/10.1111/1467-9973.00225

Forsyth, D.M., Hickling, G.J., 1997. An improved technique for indexing abundance of Himalayan thar. N. Z. J. Ecol.

Galbreath, G.J., Groves, C.P., Waits, L.P., 2007. Genetic resolution of composition and phylogenetic placement of the Isabelline Bear. Ursus. https://doi.org/10.2192/1537-6176(2007)18[129:GROCAP]2.0.CO;2

Goulart, F.V.B., Cáceres, N.C., Graipel, M.E., Tortato, M.A., Ghizoni, I.R., Oliveira-

Santos, L.G.R., 2009. Habitat selection by large mammals in a southern Brazilian Atlantic Forest. Mamm. Biol. https://doi.org/10.1016/j.mambio.2009.02.006

Graham, A., Bell, R., 1989. Investigating Observer Bias in Aerial Survey by Simultaneous Double-Counts. J. Wildl. Manage. https://doi.org/10.2307/3809603

Haq, F., Rahatullah, H., 2012. Diversity and population status of Ursus arctos in Pakistan. Int. J. Biosci.

Harmsen, B.J., Foster, R.J., Silver, S., Ostro, L., Doncaster, C.P., 2010. Differential use of trails by forest mammals and the implications for camera-trap studies: A case study from Belize. Biotropica. https://doi.org/10.1111/j.1744-7429.2009.00544.x

Hirata, D., Mano, T., Abramov, A. V., Baryshnikov, G.F., Kosintsev, P.A., Vorobiev, A.A., Raichev, E.G., Tsunoda, H., Kaneko, Y., Murata, K., Fukui, D., Masuda, R., 2013. Molecular phylogeography of the brown bear (ursus arctos) in Northeastern Asia based on analyses of complete mitochondrial DNA sequences. Mol. Biol. Evol. https://doi.org/10.1093/molbev/mst077

Hossain, A.N.M., Barlow, A., Barlow, C.G., Lynam, A.J., Chakma, S., Savini, T., 2016. Assessing the efficacy of camera trapping as a tool for increasing detection rates of wildlife crime in tropical protected areas. Biol. Conserv. https://doi.org/10.1016/j.biocon.2016.07.023

Huggins, R.M., 1991. Some Practical Aspects of a Conditional Likelihood Approach to Capture Experiments. Biometrics. https://doi.org/10.2307/2532158

Huggins, R.M., 1989. On the Statistical Analysis of Capture Experiments. Biometrika. https://doi.org/10.2307/2336377

Jackson, R.M., Roe, J.D., Wangchuk, R., Hunter, D.O., 2006. Estimating Snow Leopard Population Abundance Using Photography and Capture–Recapture Techniques. Wildl. Soc. Bull. https://doi.org/10.2193/0091-7648(2006)34[772:eslpau]2.0.co;2

Japan Bear Network, 2006. Understanding Asian Bears to Secure Their Future, Japan

Bear Network.

Jenkins, K.J., Manly, B.F.J., 2008. A double-observer method for reducing bias in faecal pellet surveys of forest ungulates. J. Appl. Ecol. https://doi.org/10.1111/j.1365-2664.2008.01512.x

Karanth, K.U., Nichols, J.D., Kumar, N.S., Jathanna, D., 2011. Estimation of demographic parameters in a tiger population from long-term camera trap data, in: Camera Traps in Animal Ecology: Methods and Analyses. https://doi.org/10.1007/978-4-431-99495-4_9

Li, X., Bleisch, W. V., Jiang, X., 2018. Unveiling a wildlife haven: occupancy and activity patterns of mammals at a Tibetan sacred mountain. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-018-1213-y

Mani, M.S., 1990. Fundamentals of high altitude biology. Aspect Publications Ltd., London.

McLellan, B.N., Proctor, M.F., Huber, D., Michel, S., 2017. Ursus arctos (amended version of 2017 assessment), The IUCN Red List of Threatened Species. IUCN.

Melo, G.L., Sponchiado, J., Cáceres, N.C., 2012. Use of camera-traps in natural trails and shelters for the mammalian survey in the Atlantic Forest. Iheringia. Série Zool. https://doi.org/10.1590/s0073-47212012000100012

Moore, N., Whiterow, A., Kelly, P., Garthwaite, D., Bishop, J., Langton, S., Cheeseman, C., 1999. Survey of badger Meles meles damage to agriculture in England and Wales. J. Appl. Ecol. https://doi.org/10.1046/j.1365-2664.1999.00454.x

Nawaz, M.A., 2008. Ecology, genetics and conservation of Himalayan brown bears. Ecol. Nat. Resour. Manag.

Nawaz, M.A., 2007. Status of the brown bear in Pakistan. Ursus. https://doi.org/10.2192/1537-6176(2007)18[89:SOTBBI]2.0.CO;2

Nawaz, M.A., Martin, J., Swenson, J.E., 2014. Identifying key habitats to conserve the threatened brown bear in the Himalaya. Biol. Conserv. https://doi.org/10.1016/j.biocon.2013.12.031

Nawaz, M.A., Swenson, J.E., Zakaria, V., 2008. Pragmatic management increases a flagship species, the Himalayan brown bears, in Pakistan's Deosai National Park. Biol. Conserv. https://doi.org/10.1016/j.biocon.2008.06.012

Nawaz, M.A., Valentini, A., Khan, N.K., Miquel, C., Taberlet, P., Swenson, J.E., 2019. Diet of the brown bear in Himalaya: Combining classical and molecular genetic techniques. PLoS One. https://doi.org/10.1371/journal.pone.0225698

Nichols, J.D., Hines, J.E., Sauer, J.R., Fallon, F.W., Fallon, J.E., Heglund, P.J., 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk. https://doi.org/10.2307/4089721

Noss, A.J., Gardner, B., Maffei, L., Cuéllar, E., Montaño, R., Romero-Muñoz, A., O'Connell, A.F., 2012. Comparison of density estimation methods for mammal populations with camera traps in the K aa-I ya del G ran C haco landscape. Anim. Conserv. 15, 527–535.

Quang, P.X., Becker, E.F., 1997. Combining Line Transect and Double Count Sampling Techniques for Aerial Surveys. J. Agric. Biol. Environ. Stat. https://doi.org/10.2307/1400405

Rich, L.N., Russell, R.E., Glenn, E.M., Mitchell, M.S., Gude, J.A., Podruzny, K.M., Sime, C.A., Laudon, K., Ausband, D.E., Nichols, J.D., 2013. Estimating occupancy and predicting numbers of gray wolf packs in Montana using hunter surveys. J. Wildl. Manage. https://doi.org/10.1002/jwmg.562

Roberts, T.J., d'Olanda.), B. (principe, 1977. The mammals of Pakistan.

Sasidhran, S., Adila, N., Hamdan, M.S., Samantha, L.D., Aziz, N., Kamarudin, N., Puan, C.L., Turner, E., Azhar, B., 2016. Habitat occupancy patterns and activity rate of native mammals in tropical fragmented peat swamp reserves in Peninsular Malaysia. For. Ecol. Manage. https://doi.org/10.1016/j.foreco.2015.12.037

Schaller, G.B., 1976. Mountain Mammals in Pakistan. Oryx. https://doi.org/10.1017/S0030605300014071

Servheen, C., Herrero, S., Peyton, B., 1999. Status Survey and Conservation Action Plan for Bears. IUCN/SSC Bear and Polar Bear Specialist Groups. Gland. Switz. Cambridge, UK.

Silveira, L., Jácomo, A.T.A., Diniz-Filho, J.A.F., 2003. Camera trap, line transect census and track surveys: A comparative evaluation. Biol. Conserv. https://doi.org/10.1016/S0006-3207(03)00063-6

Suryawanshi, K.R., Bhatnagar, Y.V., Mishra, C., 2012. Standardizing the double-observer survey method for estimating mountain ungulate prey of the endangered snow leopard. Oecologia. https://doi.org/10.1007/s00442-011-2237-0

Swann, D., Perkins, N., 2014. Camera Trapping for animal monitoring and management: a review of applications. Camera Trapp. Wildl. Manag. Res.

Thompson, W.L., 2004. Sampling rare or elusive species: concepts, designs, and techniques for estimating population parameters. Popul. English Ed.

Walsh, P., Reynolds, J., Collins, G., Russell, B., Winfree, M., Denton, J., 2010. Application of a double-observer aerial line-transect method to estimate brown bear population density in Southwestern Alaska. J. Fish Wildl. Manag. https://doi.org/10.3996/JFWM-006

Wearn, R., Glover-Kapfer, P., 2017. Camera-trapping for conservation: a guide to best-practices, WWF Conservation Technology Series 1(1).

White, G.C., Burnham, K.P., 1999. Program mark: Survival estimation from populations of marked animals. Bird Study. https://doi.org/10.1080/00063659909477239

Williams, B.K., Nichols, J.D., Conroy, M.J., 2002. Analysis and management of animal populations : modeling, estimation, and decision making, Academic Press San Diego California USA.

Wilson, G.J., Delahay, R.J., 2001. A review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. Wildl. Res. https://doi.org/10.1071/WR00033

Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

CHAPTER 7

Growing Threats to the Recovering Brown Bear Population in Deosai National Park, Pakistan

7 Growing Threats to the Recovering Brown Bear Population in Deosai National Park, Pakistan

ABSTRACT

The Himalayan brown bear (*Ursus arctos isabellinus*) is a subspecies of the brown bear. In Pakistan, seven populations of brown bear may exist in the Himalayan, Karakoram, and Hindu Kush ranges. All of these are small and declining, except for the Deosai Plains population, which is growing. This study was conducted in Deosai National Park (DNP) and its buffer area with the aim of identifying threats to the recovering brown bear population. A human-carnivore interaction survey was conducted in the communities around DNP in 2012. Some 139 local people were interviewed about household size, number of heads of livestock owned, sightings of large carnivores, cases of livestock depredation by carnivores in the last five years (2007–2011), and community perceptions and attitudes about large carnivores. A structured questionnaire and park map was used to identify the park resources used by different stallholders. The respondents reported 1,526 livestock losses with an economic loss of USD 167,720 (PKR 16,772,000) due to large carnivores and disease. Of the reported figure, carnivores—snow leopards, brown bears, wolves, and Himalayan lynx—were held responsible for 468 livestock losses (94 per year) which translated into USD 49,250 (USD 70.9 per household per year), while disease accounted for 1,058 losses (212 per year). Brown bears were blamed for 35 livestock losses (7 heads per year) with an economic cost of USD 6,560 (USD 1,312 per year and USD 9.4 per household). Local people also reported crop damage due to brown bears in the Shilla and Dhappa valleys, with an estimated annual economic loss of USD 111 (USD 1.11 per household). However, while they were strongly against the presence of wolves and snow leopards in the area, they wanted to maintain the current brown bear population. A park resource-use survey showed that there were 28 camps in DNP—15 nomad (gujjar) livestock camps, 5 local livestock camps, 3 contractor camps, 2 hotels, 2 military posts, and 1 metrological station. This study conclude that livestock is the major threat to brown bear habitat, with a total of 13,876 heads of livestock reported by gujjars and local people within park territory. There has been a substantial expansion in grazing land, particularly in the northern and southwestern areas, compared to 2006. This study highlights the threats to recovering bear population in DNP. Based on finding of this study it is highly recommended that brown bear habitat be protected by restricting gujjar livestock to a distant area.

Keywords: Himalayan brown bear, Pakistan, Deosai National Park, livestock, threats

7.1 INTRODUCTION

Large carnivores play an important role at the top of the food web due to their large body size (Edwards, 2014; Meyer, 2011; Ripple and Beschta, 2012). They alter the structure and function of the entire ecosystem by potentially limiting the number of their prey (Terborgh et al., 2001; Treves and Karanth, 2003). Moreover, top predators with large spatial requirements play vital roles in biodiversity maintenance (Terborgh, 1992). Decreases or complete elimination of top predators may provoke an imbalance at several levels of the ecosystem. Conservation strategies for existing populations of large carnivores and restoration programmes for diminishing populations can help maintain ecosystem balance and foster positive human perceptions of nature (Palazón, 2017). Populations of large carnivores are typically at low densities and with low reproductive potential, partly because of their large spatial requirements and vulnerability to habitat destruction (Noss et al., 1996; Rosenblatt et al., 2013). This feature makes populations of large carnivores especially vulnerable to catastrophic events or continued declines, from which they recover slowly (Edwards, 2014).

Human-wildlife conflict is one of the most serious problems for carnivore conservation. Rooted in human history, it has intensified over time. Due to this conflict, many species, especially large carnivores, have become extinct or threatened, or their populations are rapidly decreasing in most parts of the world (Jamtsho and Katel, 2019; Ripple et al., 2014). Human-carnivore conflict is an important aspect of human-wildlife conflict and occurs when carnivores prey on livestock or cause human injury or even death (Thorn et al., 2012; Treves and Karanth, 2003).

Human-carnivore conflict occurs across the world and involves many different carnivore species. For example, snow leopards *(Panthera uncia)* often prey on livestock in the mountainous areas of Central Asia (Bagchi and Mishra, 2006), hyenas *(Crocuta crocuta)* and lions *(Panthera leo)* are responsible for large livestock depredation in Africa (Kissui, 2008; Kolowski and Holekamp, 2006), grey wolves *(Canis lupus)* prey on livestock in North America (Musiani et al., 2003), brown bears *(Ursus arctos)* attack humans in the Tibetan Plateau of northwest China (Worthy and Foggin, 2008), and dingoes *(Canis lupus dingo)* are responsible for the depredation of sheep and beef cattle in Australia (Allen and Sparkes, 2001).

People living in and around carnivore habitats suffer from livestock losses, and sometimes even fatal attacks on humans (Can et al., 2014; Lodhi, 2007). As a result of these losses, humans sometimes take direct action against these carnivores using poisons, or hunting and shooting them. Such actions depend on people's tolerance of damaging species (Frank et al., 2005). Worldwide, the conflict between humans and bears appears to have drawn less attention than conflict with other large carnivores such as felids (Macdonald et al., 2010) and canids (Macdonald and Sillero-Zubiri, 2004). Human-brown bear conflicts occur as a result of crop and beehive damage, livestock depredation, and diminishing public tolerance of bears (Qashqaei et al., 2014; Rigg et al., 2011). This conflict has consequences for both bears and local communities.

The Himalayan brown bear *(Ursus arctos isabellinus)* is a subspecies of the brown bear *(Ursus arctos)* and represents an ancient lineage that has probably been long-isolated in the mountains of Central Asia (Galbreath et al., 2007). In Pakistan, the brown bear is distributed over an area of about 150,000 km^2 in the northern parts of the country (Nawaz, 2007). However, information about brown bear distribution and population status is sparse—approximately 150–200 bears may be surviving in seven populations in the Himalayas, Karakorams, and Hindu Kush. All of these populations are small and decreasing, except for the Deosai population, which is growing (Nawaz et al., 2008). In Pakistan, the Deosai National Park (DNP) has long been recognized as the country's main brown bear stronghold (Nawaz, 2007). Population surveys in 1993 revealed that there were no more than 20 individuals in DNP (Nawaz, 2008). The Deosai Plateau was declared a national park in 1993 to protect this small population. A conservation programme was initiated to protect the population and its habitat to allow population recovery. Population size was monitored during 1994–2006 and increased to 43 individuals in the DNP and its buffer area, with an estimated annual increase of five percent (Nawaz et al., 2008).

The brown bear in northern Pakistan is facing a number of threats, e.g., growing human population, expanding infrastructure, increasing livestock, increasing dependency on natural resources, poaching, and growing and unmanaged tourism (Nawaz, 2007). Human-brown bear conflict is a little-studied topic. Thus, the main objective of this study was to determine key threats in DNP and surrounding areas that play a major role in hindering brown bear population recovery and hamper human-carnivore co-existence in the study area.

7.2 MATERIALS AND METHODS

7.2.1 Study Area

The study was conducted in DNP and its buffer area (Figure 7.1). The Deosai Plateau is situated between two of the world's major mountain ranges—the Karakorams and Himalayas. DNP is a plateau in the alpine ecological zone encompassing about 20,000 km^2. It is situated 30 km south of Skardu and 80 km east of Nanga Parbat (mountain) (Bellemain et al., 2007). Elevations range from 3,500 m to 5,200 m, with about 60% of the area between 4,000 m and 4,500 m (Bellemain et al., 2007).

DNP's documented biota includes 342 species of plants, 18 of mammals, 208 of birds, 3 of fish, 1 of amphibian, and 2 of reptiles (Woods, 1997). Most of the plant species are herbaceous perennials—cushion-forming and tufted plants are common. The plains present a mosaic of plant communities according to water availability. The low-lying areas usually consist of bogs and pools dominated by grasses, sedges, and plants like *Saxifraga hircus, Swetiaper foliata,* and *Aconitum violaceum* (Bellemain et al., 2007). Mammalian species include the brown bear, Tibetan red fox *(Vulpes vulpesmontana),*Tibetan wolf *(Canis lupus chanco),* golden marmot *(Marmota caudata),* Himalayan ibex *(Capra ibex sibirica),* and 17 other smaller species (Nawaz et al., 2008).

7.2.2 Survey Methods

Two different survey techniques were used to determine the magnitude of human-carnivore interaction and park resource use by local people and nomads alias *gujjars.*

7.2.2.1 Human-carnivore interaction survey

A human-carnivore interaction survey was conducted in DNP's communities in 2012 (Figure 7.1). Standardized human-carnivore conflict surveys were conducted at the household level by experienced Snow Leopard Foundation (SLF) field staff in the adjacent valleys/sub-valleys of DNP—Kharmang, Monthoka, Dhappa, Shilla, and

Sadpara. A total of 139 people were interviewed by selecting household heads or other adults. Questionnaires, interviews, and sighting reports by local communities were used to document animal distribution and conflict with humans (Henke and Knowlton, 1995; Hussain, 2003; Mishra et al., 2006).

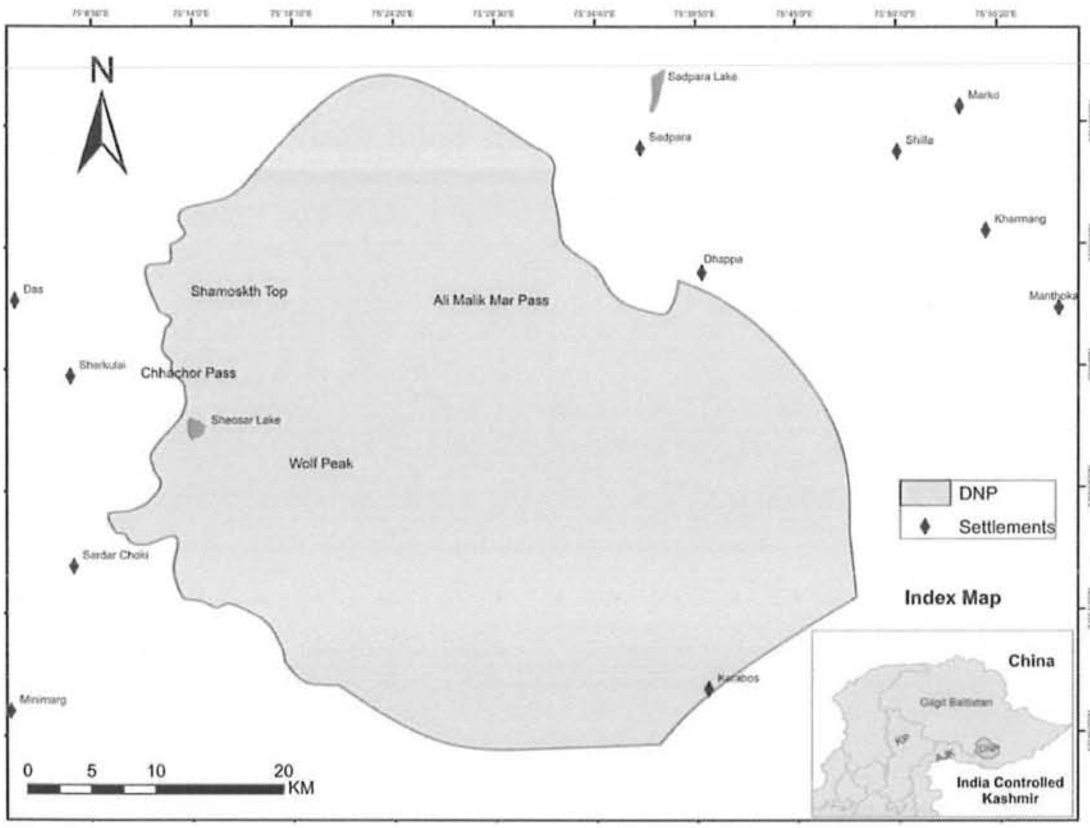

Figure 7.1. Questionnaire survey sites in DNP's buffer area.

Information collected included household size, bear/large carnivore sightings, number of heads of livestock, and livestock killed by carnivores in the last five years (2007–2011). Additional information like community perceptions of carnivores—especially bears—and attitudes towards carnivore species were noted. Sighting reports were confirmed by asking species-specific questions on appearance, size, and behaviour.

7.2.2.2 Park resource-use survey

A park resource-use survey (Appendix 7.1) was conducted in 2012 to identify and quantify resources used by humans and their livestock within the park. Livestock herders/*gujjars* are seasonal park visitors, usually arriving in June and leaving in September depending on weather conditions. A structured questionnaire and park maps were used to mark areas used by different stakeholders. Intensity of use was also noted.

7.2.3 Statistical Analysis

Human-carnivore interaction data were analysed in MS Excel using average, percentage and plot functions while park resource utilization data were analysed in ArcGIS 10 using Spatial Analyst Tool.

7.3 RESULTS

7.3.1 Livestock demography and associated livelihoods

The livelihood system in the study area is predominantly agro-pastoral, where livestock plays a crucial role. Surveyed households (n = 139) reared a total of 2,589 heads of livestock with an average herd size of 19 animals per household. Goats accounted for the largest percentage of livestock (55%), followed by sheep (27%) and cattle (18%). In the last year, 139 respondents reported selling of 266 heads of livestock for USD 42,248 (PKR 4,224,800) which yielded an average annual income of USD 304 (PKR 30,394) per household.

7.3.2 Average annual sightings

A total of 139 persons were interviewed about large carnivore sightings during the past five years (2007–2011) in DNP's surrounding valleys. The average annual sighting rate per respondent for the brown bear (1.0) was greater than that of other predators like the wolf (0.5), snow leopard (0.1), and lynx (0.1), which may indicates a higher abundance of brown bears in the study area.

7.3.3 Livestock depredation and economic loss

The 139 respondents of the study area reported 1,526 livestock losses to depredation and disease during the past five years. Carnivores were held responsible for 468 livestock losses (94 per year) while diseases accounted for 1,058 losses (212 per year). Wolves were blamed for the highest livestock loss (61%), followed by snow leopards (22%), brown bears (15%), and lynx (2%). The most favoured species of prey was the goat which accounted for 67.5% of total depredation. This was followed by sheep (27.6%) and cattle (4.9%).

Table 7.1. Livestock depredation and economic loss (USD) due to carnivores in the study area, 2007–2012

Livestock	*Lynx*	*Wolf*	*Brown bear*	*Snow leopard*	*Total predation loss*	*Disease loss*	*Total*
Goat	90 (1)	20,700 (230)	1,620 (18)	6,030 (67)	28,440 (316)	65,700 (730)	94,140 (1046)
Sheep	90 (1)	8550 (95)	540 (6)	2,430 (27)	11,610 (129)	22,770 (253)	34,380 (382)
Cattle	0	2,800 (7)	4,400 (11)	2,000 (5)	9,200 (23)	30,000 (75)	39,200 (98)
Total loss	**180 (2)**	**32,050 (332)**	**6,560 (35)**	**10,460 (99)**	**49,250 (468)**	**118,470 (1058)**	**167,720 (1,526)**
Annual loss	36	6,410	1,312	2,092	9,850	23,694	33,544
per household	0.3	46.1	9.4	15.1	70.9	170.5	241.3

USD 1 = PKR 100. Numbers in parentheses represent livestock losses

The reported figure of 1,526 livestock losses constituted an economic loss of USD 167,720 or PKR 16,772,000 (USD 241.3 or PKR 24,132 per household per year) to 139 households. Of the total loss, carnivores were blamed for an annual economic loss of USD 49,250 (USD 70.9 per household per year) while disease contributed an annual loss of USD 118,470 (USD 170.5 per household per year) (Table 7.1). Crop damage was also reported, but only in the Shilla and Dhappa valleys, with an estimated annual economic loss of USD 111 or PKR 154.29 (USD 1.11 or PKR 111 per household).

7.3.4 Human acceptance and perceived danger

Questions were asked on people's perceptions of brown bears and other carnivore species. Public responses about brown bears were categorized as positive (maintain = 1 and increase = 2) and negative (eliminate = 3, decrease = 4). Local people's perceptions of brown bears were mixed—though unhappy, they did not want to eliminate the animal. A greater percentage (51%) of the respondents was willing to maintain the current population. In comparison, 46% of the respondents possessed a negative attitude towards brown bears.

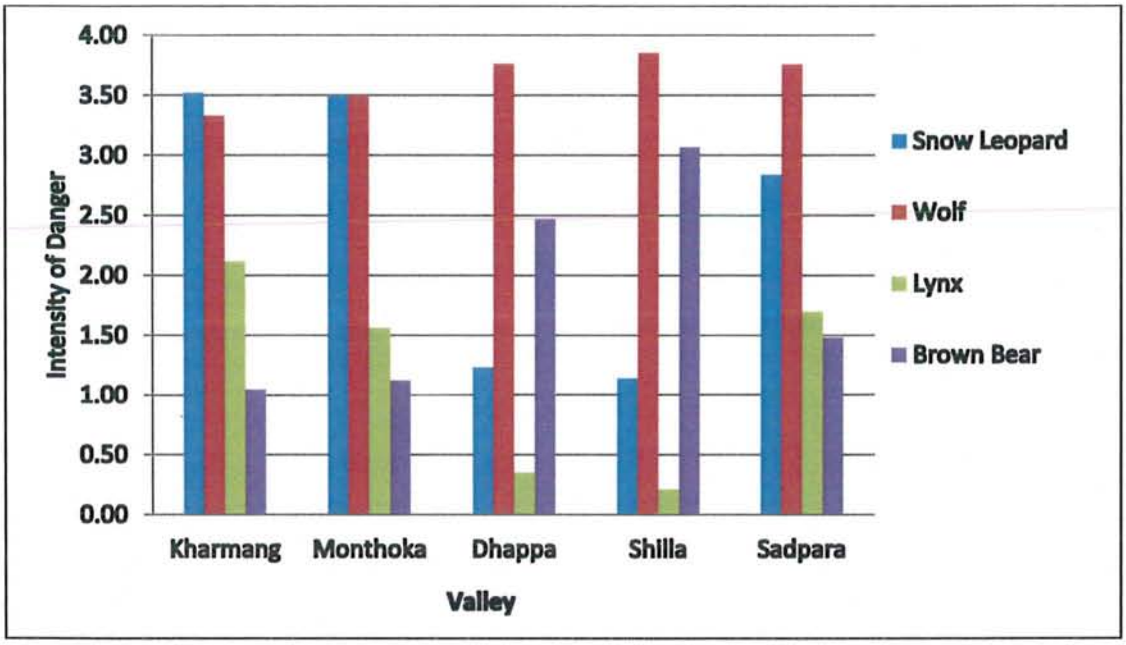

Figure 7.2. Perceived danger from various carnivores

People also perceived brown bears as the least dangerous among all predators in Kharmang, Monthoka, and Sadpara. By contrast, people in Dhappa and Shilla considered brown bears the most dangerous predators after wolves. The wolf was considered the most dangerous predator throughout the study area, while perceptions of snow leopards and lynx varied (Figure 7.2).

7.3.5 Park resource use

The park resource-use survey showed that there were 28 human occupations in DNP; 15 nomad *(gujjar)* livestock camps, 5 local livestock camps, 3 contractor camps, 2 hotels, 2 military posts, and 1 metrological station. Livestock is the major threat to brown bear habitat, and *gujjars* and local people reported the presence of 13,876 heads of livestock in park territory. Of these, *gujjars* reported 6,000 heads of livestock—the rest belonged to local communities and contractors. Compared with 2006, we documented a substantial expansion of grazing land, particularly in the park's northern areas. Expansion was also visible in the southwestern areas (Figure 7.3).

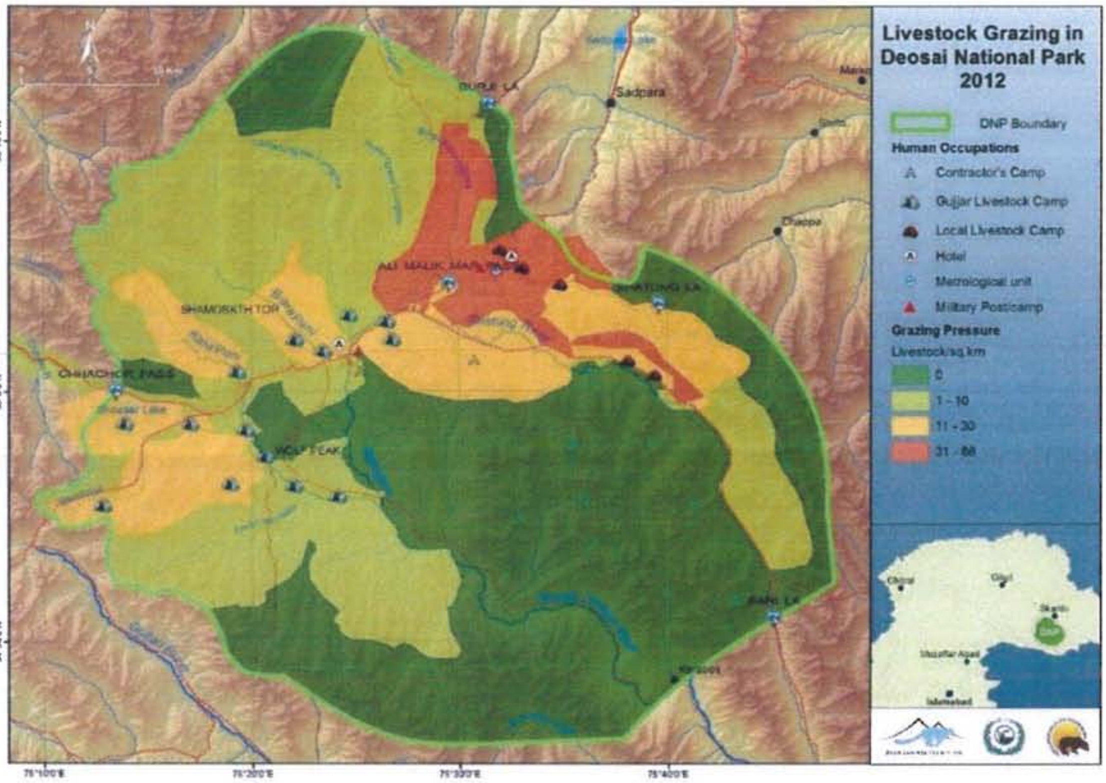

Figure 7.3. Spatial pattern of livestock grazing in Deosai National Park in 2012

7.4 DISCUSSION

The questionnaire-based survey showed that diseases in the study area were the main cause of economic loss in the form of livestock mortality. Disease is the main factor responsible for livestock losses in various other regions despite the fact that globally it is rarely reported in scientific literature relating to human-wildlife conflict, and challenges the notion that predators are always responsible for livestock losses (Ahmad et al., 2016; Dar et al., 2009; Soto-Shoender and Giuliano, 2011). This study showed that disease caused more than twice the economic loss of depredation by carnivores.

Most large carnivore species are in global decline due to conflict with humans, particularly over depredation of small and large livestock (Distefano, 2005; Michalski et al., 2006). In the Himalayan and Hindu Kush mountains, increased livestock depredation by large carnivores has been attributed to increasing livestock populations (Hussain, 2003; Mishra, 1997; Suryawanshi, 2013). Respondents in this study reported a total of 468 livestock losses (94 per year) with an economic loss of USD 49,250 (USD

71 per household) to different carnivore species inhabiting park territory and surrounding areas. The largest numbers of livestock were killed by the grey wolf and snow leopard. The lynx and brown bear were responsible for lower numbers. A recent study by Nawaz et al. (2019) on DNP brown bear diet analysis showed that the species was predominantly vegetarian; 70% of analysed scats were composed of plant residue—with very low dietary meat. This could explain the small number of livestock attacked by brown bears. The study showed that small-sized livestock such as goats and sheep were killed in greater numbers as compared to cattle. First, this is due perhaps to the greater number of goats and sheep owned by local people. Second, carnivores usually target medium-sized livestock (25–45 kg) such as goats and sheep because they can be easily killed and dragged to safety (Ahmad et al., 2016; Dar et al., 2009). Livestock losses due to wolves and snow leopards could also be attributed to thin natural prey, attracting carnivores to livestock instead that have no anti-predatory strategies, making them easier to kill (Vos, 2000). The 35 reported heads of livestock killed by brown bears during the study period caused an annual economic loss of USD 1,312 (USD 9.4 per household), which is much lower than the annual economic loss USD 6,285 (USD 42 per household) caused by this species in the area adjacent to DNP (Ahmad et al., 2016).

Public attitudes toward individual carnivore species were different. Local people have highly negative perceptions of wolves—followed by snow leopards—due to considerable economic losses in the form of livestock depredation. These negative perceptions are related to predation rates (Xu et al., 2015). Livestock depredation by carnivores causes large economic losses in a short time, thus negatively influencing livestock owners' opinions (Din et al., 2019). Brown bears and lynx were considered the least dangerous carnivores for livestock, although the former were held responsible for crop damage of USD 111 (USD 1.11 per household). Economic losses due to crop damage by brown bears in DNP were lower than corresponding losses (USD 6 per household) in DNP (Ahmad et al., 2016). Combined with restrictions on the use of natural resources, such losses are likely to generate an aggressive attitude towards conservation and may provoke retaliatory action by farmers (Conforti and De Azevedo, 2003). Communities consider wolves and snow leopards to be the most dangerous carnivore species for livestock, while brown bears were considered relatively less dangerous and [communities] were willing to tolerate their current population size.

Local people, particularly in Dhappa and Shilla, were concerned about crop damage by bears in addition to occasional depredation. It is noteworthy that crop damage at high elevations, however minimal, makes life difficult for farmers in harsh weather.

Growing livestock numbers (an estimated 35% increase from 2006 to 2012), increasing grazing camps, and expanded park grazing are the key factors that require immediate attention from management authorities. Grazing has been particularly expanded in the northern and south-eastern parts of the park. *Gujjars* are mainly responsible for expanded grazing via invasion into deeper habitat, thereby violating an initial understanding with park management. Local communities have increased grazing intensity, but not expanded their grazing areas.

7.4.1 Conclusion and Recommendations

The questionnaire study showed that an intense level of conflict existed between carnivore species and humans in the study area due to considerable livestock depredation by large carnivores and crop damage by brown bears. Based on this study, it is recommended that livestock numbers in DNP be monitored carefully and *gujjar* livestock be reassessed. Discussions need to be initiated with *gujjars* in the context of their recent invasion of additional park areas. A clear demarcation of their grazing areas, as practised before 2006, must be done, and their livestock should be restricted to those areas. Their camps should also be restricted to designated areas.

The Gilgit-Baltistan Parks and Wildlife Department should consider building proper huts for park staff. This will enhance their efficiency in monitoring park resources, their use, and any violations.

7.5 ACKNOWLEDGEMENTS

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7.6 REFERENCES

Ahmad, S., Hameed, S., Ali, H., Khan, T.U., Mehmood, T., Nawaz, M.A., 2016. Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. Eur. J. Wildl. Res. https://doi.org/10.1007/s10344-016-1029-6

Allen, L.R., Sparkes, E.C., 2001. The effect of dingo control on sheep and beef cattle in Queensland. J. Appl. Ecol. https://doi.org/10.1046/j.1365-2664.2001.00569.x

Bagchi, S., Mishra, C., 2006. Living with large carnivores: Predation on livestock by the snow leopard (Uncia uncia). J. Zool. https://doi.org/10.1111/j.1469-7998.2005.00030.x

Bellemain, E., Nawaz, M.A., Valentini, A., Swenson, J.E., Taberlet, P., 2007. Genetic tracking of the brown bear in northern Pakistan and implications for conservation. Biol. Conserv. https://doi.org/10.1016/j.biocon.2006.09.004

Can, Ö.E., D'Cruze, N., Garshelis, D.L., Beecham, J., Macdonald, D.W., 2014. Resolving Human-Bear Conflict: A Global Survey of Countries, Experts, and Key Factors. Conserv. Lett. https://doi.org/10.1111/conl.12117

Conforti, V.A., De Azevedo, F.C.C., 2003. Local perceptions of jaguars (Panthera onca) and pumas *(Puma concolor*) in the Iguaçu National Park area, south Brazil. Biol. Conserv. https://doi.org/10.1016/S0006-3207(02)00277-X

Dar, N.I., Minhas, R.A., Zaman, Q., Linkie, M., 2009. Predicting the patterns, perceptions and causes of human-carnivore conflict in and around Machiara National Park, Pakistan. Biol. Conserv. https://doi.org/10.1016/j.biocon.2009.04.003

Din, J.U., Nawaz, M.A., Mehmood, T., Ali, H., Ali, A., Hasan Adli, D.S., Norma-Rashid, Y., 2019. A transboundary study of spatiotemporal patterns of livestock predation and prey preferences by snow leopard and wolf in the Pamir. Glob. Ecol. Conserv. https://doi.org/10.1016/j.gecco.2019.e00719

Distefano, E., 2005. Human-wildlife conflict worldwide: A collection of case studies, analysis of management strategies and good practices., FAO. Rome.

Edwards, M., 2014. A Review of Management Problems Arising From Reintroductions of Large Carnivores. J. Young Investig.

Frank, K.T., Petrie, B., Choi, J.S., Leggett, W.C., 2005. Ecology: Trophic cascades in a formerly cod-dominated ecosystem. Science (80-.). https://doi.org/10.1126/science.1113075

Galbreath, G.J., Groves, C.P., Waits, L.P., 2007. Genetic resolution of composition and phylogenetic placement of the Isabelline Bear. Ursus. https://doi.org/10.2192/1537-6176(2007)18[129:GROCAP]2.0.CO;2

Henke, S.E., Knowlton, F.F., 1995. Techniques for Estimating Coyote Abundance. Wildl. Damage Manag. Internet Cent. Symp. Proc. Coyotes Southwest A Compend. our Knowl.

Hussain, S., 2003. The status of the snow leopard in Pakistan and its conflict with local farmers. Oryx 37, 26–33. https://doi.org/10.1017/S0030605303000085

Jamtsho, Y., Katel, O., 2019. Livestock depredation by snow leopard and Tibetan wolf: Implications for herders' livelihoods in Wangchuck Centennial National Park, Bhutan. Pastoralism. https://doi.org/10.1186/s13570-018-0136-2

Kissui, B.M., 2008. Livestock predation by lions, leopards, spotted hyenas, and their vulnerability to retaliatory killing in the Maasai steppe, Tanzania. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2008.00199.x

Kolowski, J.M., Holekamp, K.E., 2006. Spatial, temporal, and physical characteristics of livestock depredations by large carnivores along a Kenyan reserve border. Biol. Conserv. https://doi.org/10.1016/j.biocon.2005.10.021

Lodhi, A., 2007. Conservation of Leopards in Ayubia National Park, Pakistan. Forestry.

Macdonald, D.W., Sillero-Zubiri, C., 2004. Wild canids - an introduction and dramatis personae, in: The Biology and Conservation of Wild Canids.

Macdonald, Loveridge, A.J., Rabinowitz, A., 2010. Felid futures: crossing disciplines, borders, and generations. Biol. Conserv. wild felids 599.

Meyer, W.M., 2011. Trophic Cascades: Predators, Prey, and the Changing Dynamics of Nature edited by John Terborgh and James A. Estes (2010), xx + 464 pp., Island Press, Washington, DC, USA. ISBN 9781597264877 (pbk), GBP 27.00. Oryx. https://doi.org/10.1017/s0030605310001742

Michalski, F., Boulhosa, R.L.P., Faria, A., Peres, C.A., 2006. Human-wildlife conflicts in a fragmented Amazonian forest landscape: Determinants of large felid depredation on livestock. Anim. Conserv. https://doi.org/10.1111/j.1469-1795.2006.00025.x

Mishra, C., 1997. Livestock depredation by large carnivores in the Indian trans-Himalaya: Conflict perceptions and conservation prospects. Environ. Conserv. https://doi.org/10.1017/S0376892997000441

Mishra, C., Madhusudan, M.D., Datta, A., 2006. Mammals of the high altitudes of western Arunachal Pradesh, eastern Himalaya: An assessment of threats and conservation needs. ORYX. https://doi.org/10.1017/S0030605306000032

Musiani, M., Mamo, C., Boitani, L., Callaghan, C., Gates, C.C., Mattei, L., Visalberghi, E., Breck, S., Volpi, G., 2003. Wolf Depredation Trends and the Use of Fladry Barriers to Protect Livestock in Western North America, in: Conservation Biology. https://doi.org/10.1111/j.1523-1739.2003.00063.x

Nawaz, M.A., 2008. Ecology, genetics and conservation of Himalayan brown bears. Ecol. Nat. Resour. Manag.

Nawaz, M.A., 2007. Status of the brown bear in Pakistan. Ursus. https://doi.org/10.2192/1537-6176(2007)18[89:SOTBBI]2.0.CO;2

Nawaz, M.A., Swenson, J.E., Zakaria, V., 2008. Pragmatic management increases a flagship species, the Himalayan brown bears, in Pakistan's Deosai National Park. Biol. Conserv. https://doi.org/10.1016/j.biocon.2008.06.012

Nawaz, M.A., Valentini, A., Khan, N.K., Miquel, C., Taberlet, P., Swenson, J.E., 2019. Diet of the brown bear in Himalaya: Combining classical and molecular genetic techniques. PLoS One. https://doi.org/10.1371/journal.pone.0225698

Noss, R.F., Quigley, H.B., Hornocker, M.G., Merrill, T., Paquet, P.C., 1996. Conservation Biology and Carnivore Conservation in the Rocky Mountains. Conserv. Biol. https://doi.org/10.1046/j.1523-1739.1996.10040949.x

Palazón, S., 2017. The Importance of Reintroducing Large Carnivores: The Brown Bear in the Pyrenees, in: Advances in Global Change Research. https://doi.org/10.1007/978-3-319-55982-7_10

Qashqaei, A.T., Karami, M., Etemad, V., 2014. Wildlife conflicts between humans and Brown Bears, Ursus arctos, in the Central Zagros, Iran. Zool. Middle East. https://doi.org/10.1080/09397140.2014.914711

Rigg, R., Finďo, S., Wechselberger, M., Gorman, M.L., Sillero-Zubiri, C., MacDonald, D.W., 2011. Mitigating carnivore-livestock conflict in Europe: Lessons from Slovakia. ORYX. https://doi.org/10.1017/S0030605310000074

Ripple, W.J., Beschta, R.L., 2012. Trophic cascades in Yellowstone: The first 15years after wolf reintroduction. Biol. Conserv. https://doi.org/10.1016/j.biocon.2011.11.005

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., Schmitz, O.J., Smith, D.W., Wallach, A.D., Wirsing, A.J., 2014. Status and ecological effects of the world's largest carnivores. Science (80-.). https://doi.org/10.1126/science.1241484

Rosenblatt, A.E., Heithaus, M.R., Mather, M.E., Matich, P., Nifong, J.C., Ripple, W.J., Silliman, B.R., 2013. The roles of large top predators in coastal ecosystems new insights from long term ecological research. Oceanography. https://doi.org/10.5670/oceanog.2013.59

Soto-Shoender, J.R., Giuliano, W.M., 2011. Predation on livestock by large carnivores in the tropical lowlands of Guatemala. ORYX.

https://doi.org/10.1017/S0030605310001845

Suryawanshi, R., 2013. Human-Carnivore Conflicts: understanding predation ecology and livestock damage by snow leopards. Manipal University.

Terborgh, J., 1992. Maintenance of Diversity in Tropical Forests. Biotropica. https://doi.org/10.2307/2388523

Terborgh, J., Lopez, L., Nuñez, P. V., Rao, M., Shahabuddin, G., Orihuela, G., Riveros, M., Ascanio, R., Adler, G.H., Lambert, T.D., Balbas, L., 2001. Ecological meltdown in predator-free forest fragments. Science (80-.). https://doi.org/10.1126/science.1064397

Thorn, M., Green, M., Dalerum, F., Bateman, P.W., Scott, D.M., 2012. What drives human-carnivore conflict in the North West Province of South Africa? Biol. Conserv. https://doi.org/10.1016/j.biocon.2012.02.017

Treves, A., Karanth, K.U., 2003. Human-Carnivore Conflict and Perspectives on Carnivore Management Worldwide, in: Conservation Biology. https://doi.org/10.1111/j.1523-1739.2003.00059.x

Vos, J., 2000. Food habits and livestock depredation of two Iberian wolf packs (*Canis lupus signatus*) in the north of Portugal. J. Zool. https://doi.org/10.1017/S0952836900008050

Woods, C.A., 1997. Biodiversity and conservation of the Deosai Plateau, Northern areas, Pakistan. In Biodiversity of Pakistan. Proceedings of International symposium, Pakistan Museum of Natural History and Florida Museum of Natural History (Gainesville). Islamabad.

Worthy, F.. R., Foggin, J.M., 2008. Conflicts between local villagers and Tibetan brown bears threaten conservation of bears in a remote region of the Tibetan Plateau. Human-Wildlife Conflicts 2, 200–205.

Xu, Y., Yang, B., Dou, L., 2015. Local villagers' perception s of wolves in Jiuzhaigou County, western China. PeerJ. https://doi.org/10.7717/peerj.982

APPENDIX 7.1. PARK RESOURCE USE SURVEY

Enumerator Name________________________________Date ______________________________________

Loaction Name: ____ __

GPS Coordinates:

N	□□.□□□□□□	E	□□.□□□□□□

Type of Human Activity:

(Tick the relevent column)

Gujjar Livestock Camp	Local Livestock Camp	Contractor's Camp	Military Post/camp	Hotel	Other

Deatil Description:

No. of Tents: __________________________ Area Covered: _________________________

No. People: ___________________________ Total Stay in DNP (months): ____________

Date of Arrival: ________________________ Date of Departure: ____________________

Livestock:

Goats	Sheep	Cattle	Other

Areas being used for grazing or other purpose:

(Mark area on a map attached to this form)

____

Comments/Additional Details:

Predation Losses

Predation in 5 years:

	Goats	Sheep	Cattle	Other
Brown Bear				
Wolf				
Snow Leopard				
Lynx				

Details of Predation:

Predator	Season, year	Location	Prey type, no.	Prey sex	Prey Age	Circumstances

Seasons: Winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug), autumn (Sep-Nov)

Crop damage by wildlife in past 1 year (estimated economic loss):

Species	Winter	Spring	Summer	Autumn
Brown Bear				
Ibex				

Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

CHAPTER 8

Pattern of Human-Carnivore Conflicts in Northern Pakistan

8 Pattern of Human-Carnivore Conflicts in Northern Pakistan

ABSTRACT

Large terrestrial carnivores, considered as apex predators, have very important ecological role due to their position in trophic systems. Carnivores often alter the structure of and function of whole ecosystem by limiting the abundance of their prey. In Pakistan, multiple large-sized carnivores occur in the northern parts of the country, but these carnivores are facing many threats, particularly conflict with humans. Despite the wide prevalence, limited studies are describing human-carnivore conflicts in Pakistan, especially in northern Pakistan, where various large carnivores like snow leopards, common leopards, brown bears, and Asiatic black bears dwell. The present study was conducted in northern Pakistan covering three major landscapes—the Himalayas, Hindu Kush, and Karakoram-Pamirs—to determine the nature of two large-sized carnivores' (snow leopard and brown bear) conflict with humans. A semi-structured questionnaire was used to collect information and data from different villages of three landscapes during the period 2009–2014. A total of 2,733 respondents were questioned about their livestock, depredation by carnivores, carnivore sightings, and fear about snow leopards, wolves, lynx, and brown bears, and the perceived danger by these carnivores. The 2,733 respondents of the study area reported 32,753 livestock losses (6,551 per year with an average 2.39 per household, per year) to various carnivores and diseases with an economic loss of PKR 38,423,996 (PKR 7,684,799 per year with an average PKR 2,812 per household, per year). Among the total economic losses, diseases contributed to an economic loss of PKR 30,581,024 (PKR 6,116,204.8 per year with an average PKR 2,237.90 per household), while economic loss due to depredation was PKR 7,842,972 (PKR 1,568,595 per year with an average PKR 574 per household, per year). Higher economic loss (53.80%) was in the form of small-sized livestock, while large-sized livestock loss contributed 46.19%. The mixed effect model showed that a one-degree rise in the longitude and latitude positively affected the acceptance of local people toward snow leopards, while snow leopard sightings (by local people) changed acceptance negatively. Depredation of small-sized livestock by snow leopards, and the occupation of local people affected their acceptance negatively toward snow leopards. On other hand, the acceptance of local people turned positive with an increase in latitude and became negative with education. Data related to the perceived danger of snow leopards and brown bears showed that in the case of snow leopards, public acceptance increased negatively with a one-degree rise in longitude. The fear of local people towards snow leopards turned positively with the sightings of snow leopards, the mortality of small-sized livestock due to diseases and increases in education and age. In the case of the brown bear, the mixed effect model showed that the fear of local people increased negatively with the increase in the number of earning members. This study concluded that conflict is a serious threat to the survival of both snow leopards and brown bears in northern Pakistan. Mitigation measures include the vaccination of livestock, compensation for the loss of livestock due to carnivores, construction of predator-proof corrals, and improvements in watch-and-ward practices. An awareness programme should be launched in the area to change the fears of local people from negative to positive.

Keywords: carnivores, humans, snow leopard, brown bear, Pakistan, conflict

8.1 INTRODUCTION

Large terrestrial carnivores, considered as apex predators, have very important ecological role due to their position in trophic systems (Ordiz et al., 2013). Carnivores often alter the structure and function of whole ecosystem by potentially limiting the abundance of their prey (Treves and Karanth, 2003). Additionally, top predators, who have large spatial requirements, play crucial roles in the longer maintenance of diversity (Glen and Dickman, 2014). Worldwide decline in abundance and distribution of apex predators because of human persecution has brought changes to the structure of biodiversity in various systems (Ordiz et al., 2013). Global population of most of the large carnivores is declining and their range is being contracted (Ripple et al., 2014). This is happening due to human-carnivore conflict (Swanepoel et al., 2015), human-caused threats like persecution (Trinkel et al., 2017), decline in prey, and loss of habitat (Wolf and Ripple 2016). About 53% of their historic ranges have been lost by large carnivore species (Ripple et al., 2014). Despite having top position, about 59% of large carnivores have now become threatened with extinction (Ripple et al., 2016), and this will be worsened due to continues modification of environment by humans (Di Minin et al., 2016).

The occupation of the top positions in food webs by large carnivores and their potential impact on human communities makes them especially important in conservation and management measures (Moore et al., 1999). The human population has increased globally, which has resulted in an increased human variation of natural landscapes and resource use, which pushes wildlife to stay in close vicinity of humans (Inskip and Zimmermann, 2009). Such circumstances often lead to human-wildlife conflict (Inskip and Zimmermann, 2009). Human-carnivore conflict is a situation associated with the persecution of carnivores, livestock depredation, and efforts to conserve carnivores (Woodroffe et al., 2005). Due to their large spatial requirements and sizeable food requirements, large carnivores are especially prone to interacting with humans (Linnell et al., 2001; Treves and Karanth, 2003). In addition to threats like prey depletion, habitat loss, poaching and fragmentation, which stand to reduce the populations of large carnivores, (Cardillo et al., 2004; Chapron et al., 2008; Wolf and Ripple, 2016), retaliatory killings for depredation on livestock are perhaps the most direct and widespread threat to their survival (Inskip et al., 2014).

The mitigation of human-predator conflict is challenging. Reliable knowledge of the factors involved in livestock depredation is crucial in devising strategies to mitigate this conflict (Khanal et al., 2020). Recently strategies for livestock management to reduce killing by predators drew the attention of wildlife managers and herders. However, still lesser importance was given to the various environmental factors affecting such predations (Ugarte et al., 2019). Livestock depredation is the sparking factor of human-carnivore conflicts in landscapes used for livelihood (Loveridge et al., 2010). Domestic animals lose their anti-predator abilities because of living in low-risk areas/human-arbitrated environments, which makes them more vulnerable to predators (Madhusudan and Mishra, 2003).

Large carnivores often do not stay confined to spaces like nature reserves. Instead, they move out to search for an easy prey like livestock, and sometimes even humans within shared spaces—their traits, like low population density, solitary or social hunting, and large ranges, facilitate them (Ugarte et al., 2019). Dispersal also makes subadults and young adults leave a protected area to explore their neighborhoods Many species of predators are involved in livestock depredation, including pumas (*Puma concolor*), jaguars (*Panthera onca*), and culpeo foxes (*Lycalopex spp.*) in Central and South America (González et al., 2012; Palmeira et al., 2008; Soto-Shoender and Main, 2013); bears (*Ursus spp.*), lynx (*Lynx spp.*), and wolves (*Canis lupus*) in North America and Europe (Musiani et al., 2003; Smith et al., 2014; Thorn et al., 2013), lions (*Panthera leo*), cheetahs (*Acinonyx jubatus*), black-backed, jackals (*Canis mesomelas*), and caracals (*Caracal caracal*) in Africa (Thorn et al., 2013; Woodroffe and Frank, 2005), and snow leopards (*Panthera uncia*), common leopards (*Panthera pardus*), and tigers (*Panthera tigris*) in Asia (Bagchi and Mishra, 2006; Miller et al., 2015).

Multiple factors affect the magnitude of livestock depredation by large carnivores, including livestock husbandry practices (Kuiper et al., 2015; Woodroffe et al., 2007), wild prey availability (Odden et al., 2008), seasonal patterns (Farhadinia et al., 2017; Johansson et al., 2015), predators' behavioural characteristics (Lucherini et al., 2018)), habitat type and structure (Miller et al., 2015), and predator abundance (Weise et al., 2018). One of the major reasons of prey population decline is livestock grazing, which decreases available forage (Madhusudan and Mishra, 2003) and increases the risk of disease transmission to wild animals (Kaul, 2003), resulting in large carnivores switching their dietary preferences from wild prey to domestic prey. Poor livestock management is another important reason for livestock killings by predators (Woodroffe et al., 2007).

Humans and predators share spaces and resources, and this overlap causes livestock depredation (Kalaivanan et al., 2011; Khorozyan et al., 2015; Madhusudan and Mishra, 2003). Retaliatory killings, a serious issue worldwide, happen due to negative attitude of humans towards predators, emerged due to the attacks of predators on humans and their livestock (Augugliaro et al., 2020; Mishra et al., 2016). Abundance of wild prey and livestock are key factors affecting livestock predation (Khanal et al., 2020).Towhich extent density of wild herbivore can determine the livestock killing by predators is still dubious (Khorozyan et al., 2015; Soofi et al., 2019). It was also revealed that livestock depredation is high in areas of higher densities of livestock (Pimenta et al., 2018).

Acceptance of large carnivore by public varies, affected by different factors like livelihood, education, religion, type of carnivore and culture ((Liu et al., 2011; Mishra, 1997). Social organization, regions, culture, history, and wildlife conservation program can influence these factors (Behr et al., 2017; Kusi et al., 2020; Suryawanshi et al., 2014). If humans are compensated for their livestock loss caused by predators, they generally become more lenient (Woodroffe, 2000). Additionally, any activity, like ecotourism, which provides economic benefits to human has positive effect on human acceptance of large carnivore (Dickman et al., 2011; Tortato and Izzo, 2017). The main reason for negative attitude of humans is the drastic effect of predators on their livestock (Farhadinia et al., 2017; Woodroffe, 2000).

Livestock depredation is enormously destructive in areas where communities depend on livestock for their livelihood (Bhattarai and Fischer, 2014; Talbert et al., 2020). Human-predator conflicts affect both local communities and wild carnivores. Local communities can be imposed to critical economic loss (Augugliaro et al., 2020; Woodroffe and Frank, 2005), and sometimes, direct attacks by large carnivores on humans cause serious wounds and in worst case scenario even death (White and Gehrt, 2009). If there is no practical solution, livestock owners often adopt other means like traps, guns, and poison to kill the predators for their anger management (Aryal et al., 2014; McManus et al., 2015). This retaliatory killing by human is one of the biggest as well as complex issue for conservationists to tackle.

Human-predator conflict is poorly studied in Pakistan, and only a few studies have described it (Ahmad et al., 2016; Bibi et al., 2013; Dar et al., 2009; Din et al., 2017; Kabir et al., 2014) despite the wide prevalence of the issue, particularly in northern Pakistan where various large carnivores—snow leopards, common leopards, brown bears, Asiatic black bears (*Ursus thibetanus*), and grey wolves—often come into contact with humans and contribute to significant economic losses (Ahmad et al., 2016). All these studies were also limited to specific areas, and therefore, do not reflect the overall trends of human-bear conflict. The present study is the first-ever covering the whole of northern Pakistan to assess human-predator conflicts. Main objectives of the study were a) to assess livestock mortality due to predators and diseases at spatial scale and their comparison across northern Pakistan, b) modelling public acceptance and fear of large predators at different scales and factors that shape them.

8.2 MATERIALS AND METHODS

8.2.1 Study area

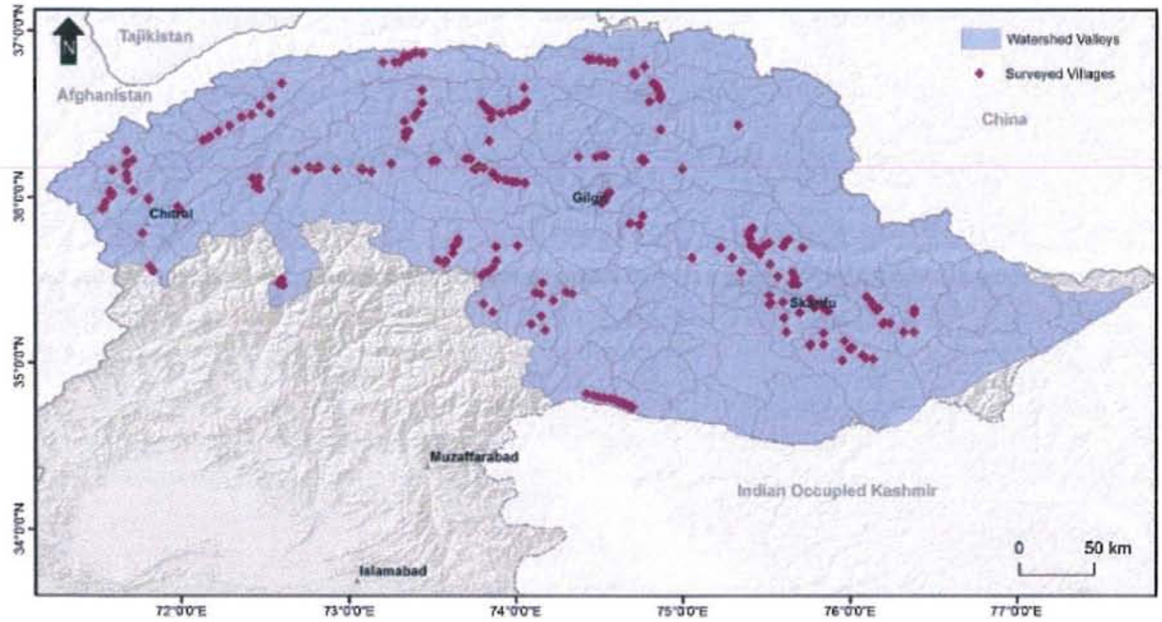


Figure 8.1 Map of study area showing watershed valleys and village locations of human-carnivore interaction surveys.

This study focused on the shared range of snow leopards and brown bears in Pakistan (Fox, 1989; Nawaz, 2007; Roberts and d'Olanda), 1977) which encompasses four high mountain ranges, the Himalayas, Karakorams, Pamirs, and Hindu Kush, spread across three administrative units, Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and Azad Jammu and Kashmir (AJK). The area was divided into watershed valleys based on natural watersheds. Targeting major protected areas and other potentially suitable habitats, we surveyed 47 watershed valleys, including 264 villages (Figure 8.1).

High altitudes and sub-zero temperatures make our study area one of the most heavily glaciated parts of the world outside the polar regions. The Western Himalayas are situated in AJK and GB to the south and east of the Indus River. The Hindu Kush rise southwest of the Pamirs. The Karakoram range covers the borders between three countries in the regions of GB in Pakistan, Ladakh in India, and the Xinjiang region in China. They are considered to extend from the Wakhjir Pass at the junctions of the Pamirs and Karakorams to the Khawak Pass north of Kabul. The mountains of Pakistan are relatively densely populated despite harsh geographic and climatic conditions.

Nevertheless, the special ecological conditions and remoteness of these mountainous areas also support unique biodiversity of plants and animals. Climatic conditions vary widely across the study area, ranging from the monsoon-influenced moist temperate zone in the western Himalayas to the semi-arid cold deserts of the northern Karakorams and Hindu Kush. Four vegetation zones can be differentiated along the altitudinal ascents: alpine dry steppes, subalpine scrub zones, alpine meadows, and permanent snowfields. Various rare and endangered animals occur in the study area, including the snow leopard *(Panthera uncia)*, grey wolf (*Canis lupus*), brown bear (*Ursus arctos*), Asiatic black bear (*Ursus thibetanus*), Himalayan lynx (*Lynx lynx*), Himalayan ibex (*Capra ibex sibirica*), blue sheep (*Pseudois nayaur*), flare-horned markhor (*C. f. cashmirensis*), musk deer (*Moschus chrysogaster*), Marco Polo sheep (*Ovis ammon polii*), Ladakh urial (*Ovis orientalis vignei*) Pallas's cat (*Otocolobus manul*), and woolly flying squirrel (*Eupetaurus cinereus*).

8.2.2 Human-carnivore interaction surveys

A semi-structured questionnaire (Appendix 4.1) was used to gather information from local communities about the status of large carnivore species—snow leopards, brown bears, wolves, and lynx. Each respondent was an adult person and representative of a household. Interviews were conducted during 2009–2014, and data were collected from different villages of watershed valleys for the past five years. A total of 2,733 respondents were questioned about their livestock, depredation by carnivores, sighting of carnivores, and fear about snow leopards, wolves, lynx and brown bears. Extreme care was taken to avoid biases, and in case of a sighting or depredation report, it was further checked by asking general and specific questions about snow leopards or other carnivore species, their appearance, and where the event occurred. Photos of carnivores were also shown to respondents for identification. Questionnaires surveys were used to determine the presence-absence of snow leopards and human-carnivore conflict in the study area.

8.2.3 Data organization and analysis

Data were organized at the valley and village level to observe the various trends in acceptance of local people towards predation, range-wide mortality due to predation and diseases, and factor affecting predation. Mixed effect models were run in the programme R (R Core Team, 2019) with function 'lmer' to examine the effects of various factors on the acceptance of local people towards brown bears and snow leopards. The mixed effect models were also run to determine the factors that contributed the most to local communities' perceived danger from snow leopards and brown bears. In mixed effect model district and landscape are taken as random factors, the considered models;

$$\begin{aligned} Response = lmer(&\ Longitude + Latitude + Snow\ Leopard\ Sighting \\ &+ Livestock\ Holding + Average\ Income \\ &+ Predation\ on\ Small\ Ruminants \\ &+ Predation\ on\ Large\ Ruminants \\ &+ Economic\ Value\ of\ Small\ Ruminants'\ Predation \\ &+ Economic\ Value\ of\ Large\ Ruminants'\ Predation \\ &+ Disease\ Caused\ Mortality\ in\ Small\ Ruminants \\ &+ Disease\ Caused\ Mortality\ in\ Large\ Ruminants \\ &+ Economic\ Loss\ to\ Disease + Education\ Index + Age\ Index \\ &+ Occupation\ Index + Earning\ Members\ of\ Family \\ &+ Agriculture\ Land\ Holdinge + (1|District) + (1|Landscape)) \end{aligned}$$

We have two response factors 'public fear' and 'public acceptance' of snow leopard and brown bear, so we have fitted 04 models. For final model, backward elimination procedure is used where non-significant factors are removed from the model against p-value of 0.10.

8.3 RESULTS

8.3.1 Livestock demography

The livelihoods system in the study area depends mainly on livestock. In the present survey, a total of 2,733 respondents were interviewed from different villages of three major landscapes, the Himalayas, Hindu Kush, and Karakoram-Pamirs. The surveyed households reared a total of 68,009 heads of livestock with an average herd size of 25 per household. Of the reported livestock, 80 % were small ruminants (goats and sheep) and 20 % were large ruminants (cattle, yaks, donkeys, horses, etc.) (Figure 8.2).

Respondents reported a total income of PKR 37,988,989 (7,597,798 per year) as a result of livestock sold in five years with an average income of PKR 13,900 (2,780 per year).

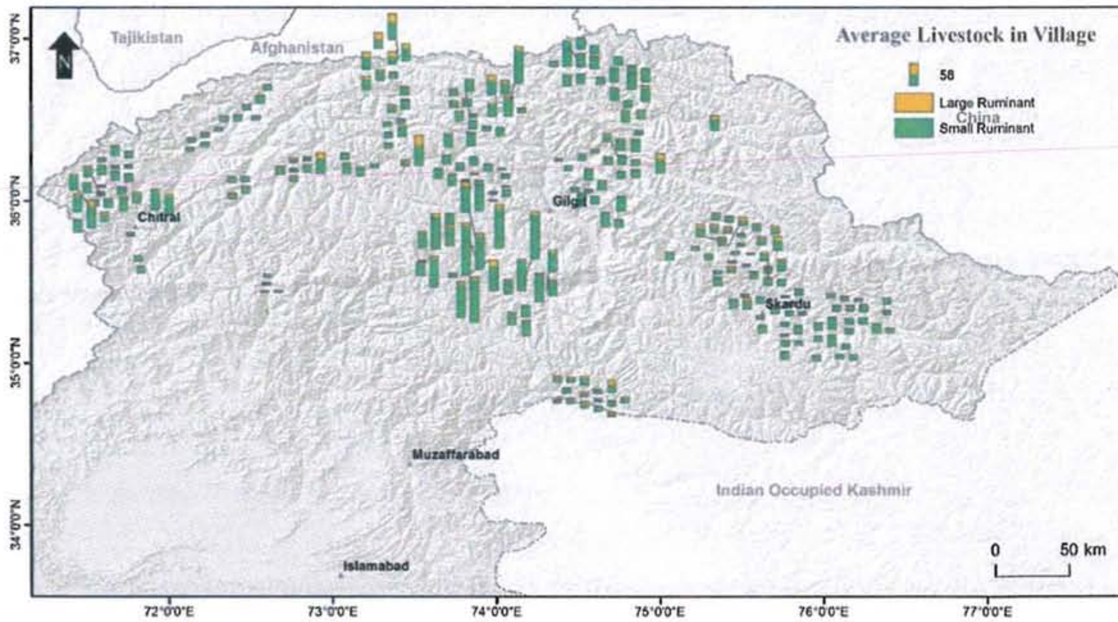


Figure 8.2. Average livestock per village.

8.3.2 Livestock mortality by predators

During the questionnaire survey, our respondents reported 7,648 (1,530 per year) livestock head losses to various large-sized carnivores such as snow leopards and brown bears from different villages in our study area. Among livestock, the most vulnerable

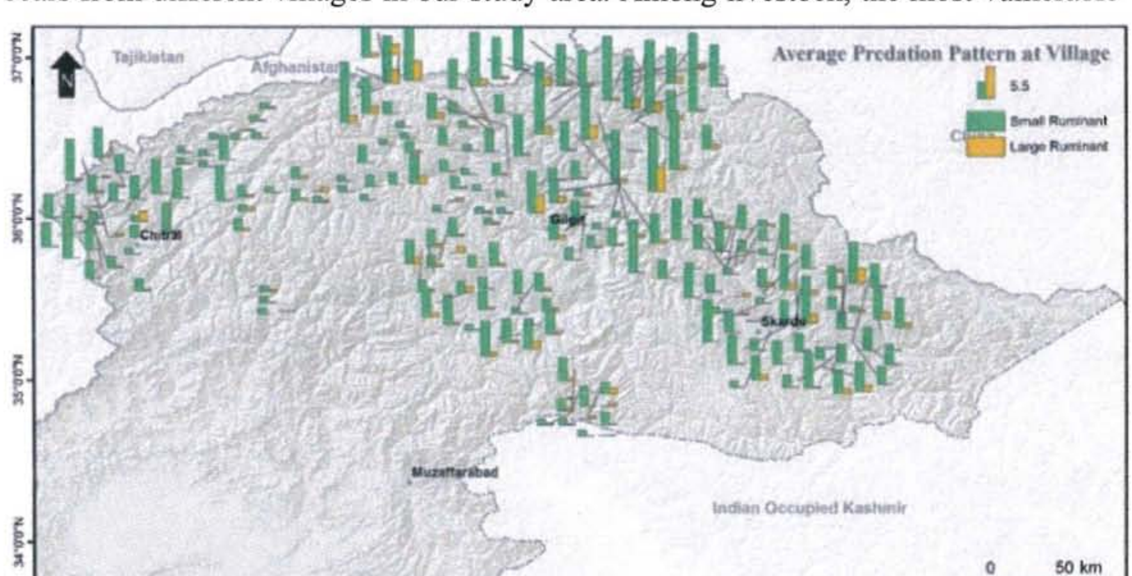


Figure 8.3. Village wise average livestock mortality by predators.

livestock were goats and sheep, which were 89% (n = 6,798) of the total livestock loss, while large-sized livestock were about 11.11% (n = 850). The highest number of livestock loss was reported from Misgar Valley where 398 livestock (80 per year) heads were reported for five years. This was followed by Hooper-Hisper Valley, Hushe Valley, and Shimshal Valley, where a total of 249 (50 per year), 235 (47 per year), and 217 (43 per year) losses respectively were reported (Figure 8.3).

8.3.3 Livestock mortality by disease

Respondents reported a total livestock loss of 25,105 in five years due to different diseases across the three landscapes (Figure 4). The average number of livestock mortality per year reported by local people due to various diseases was 5,021,

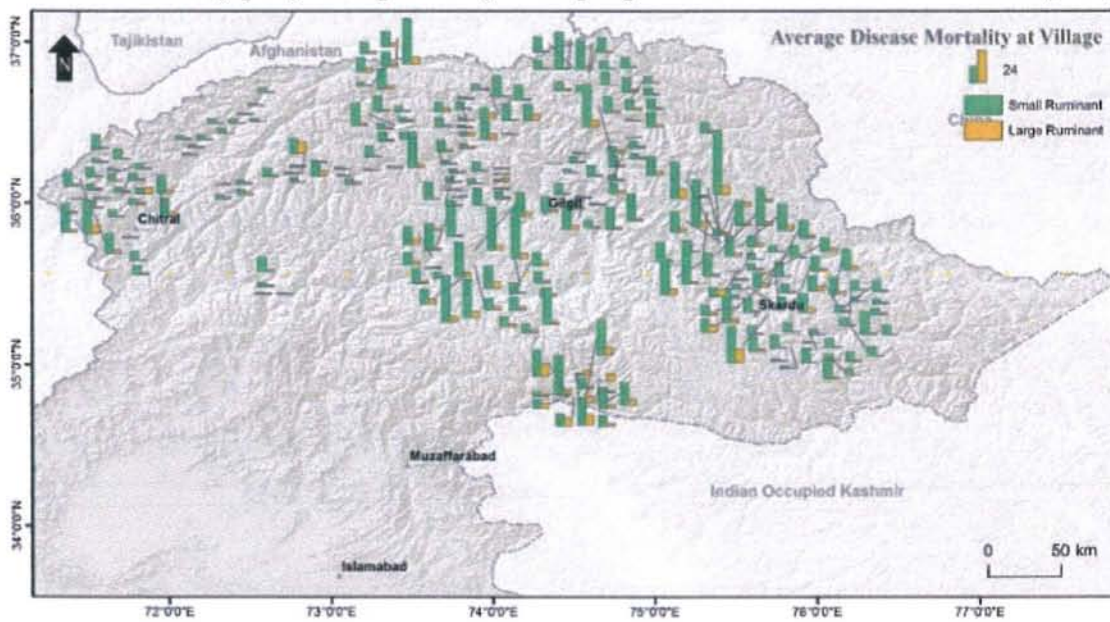


Figure 8.4. Village-wise livestock loss through diseases.

while the average numbers of livestock mortality due to diseases in five years were 9.18 per household (1.83 heads per household, per year). Among livestock losses due to diseases, small-sized livestock (goats and sheep) were the more vulnerable to diseases, and respondents reported 21,264 (85%) small-sized livestock losses to various diseases in five years (5,253 livestock loss per year). Respondents reported 3,841 (15.30%) large-sized livestock losses due to diseases (768 per year).

8.3.4 Economic loss by predators vs. diseases

The 2,733 respondents of the study area reported 32,753 livestock (6,551 per year with an average 2.39 per household, per year) losses to various carnivores and diseases, with an economic loss of PKR 38,423,996 (PKR 7,684,799 per year with an average PKR 2,812 per household, per year) (Figure 8.5). Among the total economic loss, diseases contributed to an economic loss of PKR 30,581,024 (PKR 6,116,205 per year with an average PKR 2,238 per household), while economic loss due to depredation was PKR 7,842,972 (PKR 1,568,595 per year with an average PKR 574 per household, per year).

Most of the economic loss of 54% (PKR 20,674,725 with an average PKR 1,513 per household, per year) was in the form of small-sized livestock, while large-sized livestock losses contributed 46% (PKR 17,749,271 with an average PKR 1,299 per household, per year).

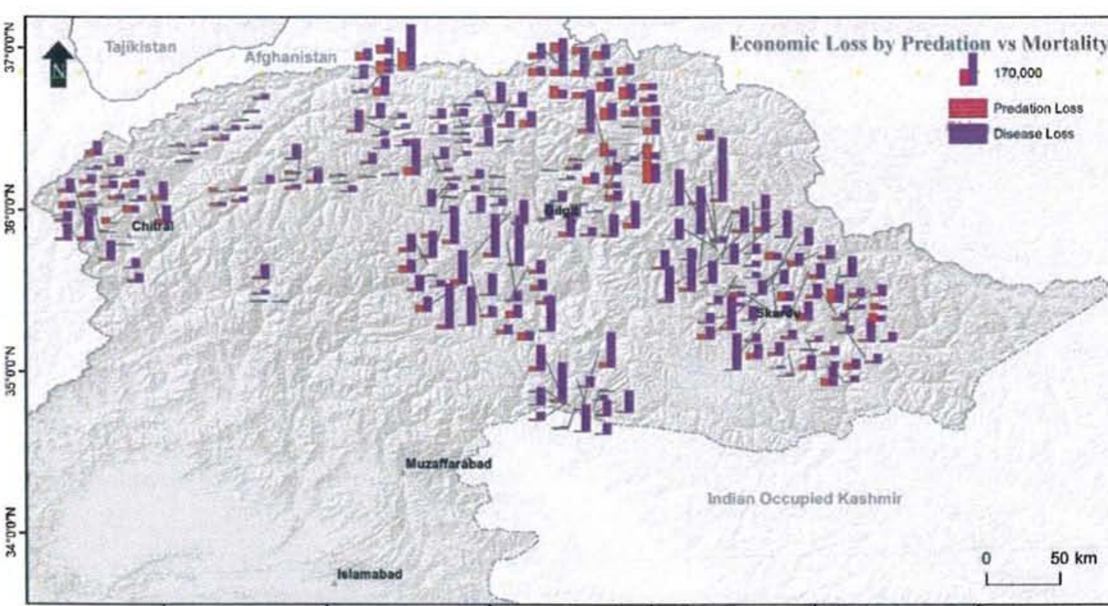


Figure 8.5. Economic loss due to depredation and diseases.

8.3.5 Public acceptance towards snow leopards and brown bears

We have fitted 04 mixed effect models to study the variation in 'public fear' and 'public acceptance' of snow leopard and brown bear. Optimal final fitted are discovered through backward elimination procedure, where non-significant factors are removed from the model against p-value of 0.10.

In the case of snow leopards, all considered factors in mixed effect model results with 19 (17 fixed and 02 random) factors in AIC= 510.17, BIC=572.75. The backword elimination as results the final model with 7 (06 fixed and 01 random) factors with AIC =498.42, BIC= 529.71 as listed in Table 2. The mixed effect model showed that local people's acceptance towards snow leopards were affected by various factors like latitude, longitude, snow leopard sightings, depredation on small- and large-sized livestock, and occupation. The analysis of the mixed effect model showed that a unit rise in longitude (from west to east) in our study area affected the acceptance of local people positively by 0.30 units. Similarly, the acceptance of local communities changed positively (0.75 units) with a one-degree rise in the latitude (south to north). The sighting of snow leopards by local people changed acceptance negatively. Depredation of small-sized livestock pronounced the negative acceptance in public, while depredation of large-sized livestock did not affect the acceptance of local people. The higher proportion of herding families in village reflected lower acceptance for snow leopards. The public acceptance decreases as occupation index increases (Table 8.1). Moreover, the public acceptance changes significantly with change of district which is treated as random factor.

Table 8.1. Effect of various factors on the acceptance of local people towards snow leopards

Coefficients	*Estimate*	*SE*	*df*	*t-value*	*p-value*
Intercept	-46.84	8.41	89	-5.569	<0.001
Longitude	0.31	0.08	25	3.66	0.001
Latitude	0.75	0.16	38	4.677	<0001
Snow Leopard Sighting	-0.09	0.05	228	-1.939	0.053
Predation on Small Ruminants	-0.06	0.02	230	-2.647	0.009
Predation on Large Ruminants	0.19	0.09	229	2.061	0.041
Occupation Index	-0.28	0.17	230	-1.676	0.095

Signif. codes: 0***, 0.001**, 0.01*, 0.05, 0.1, 1, df= degree of freedom

In the case of brown bears, mixed effect model results with 19 (17 fixed and 02 random) factors in AIC= 512.63, BIC=569.01. The backword elimination as results the final model with 03 (02 fixed and 01 random) factors with AIC= 506.17, BIC=562.75 as showed an effect on the acceptance of local communities (Table 8.2). The mixed effect model showed that local people's acceptance toward brown bears was affected only by latitude and education. The analysis of the mixed effect model showed that a one-degree rise in the latitude (from south to north) in our study area affected the acceptance of local people positively 0.28 times, while the acceptance changed negatively with education. Additionally, the public acceptance of brown bear changes significantly with change of district which is treated as random factor.

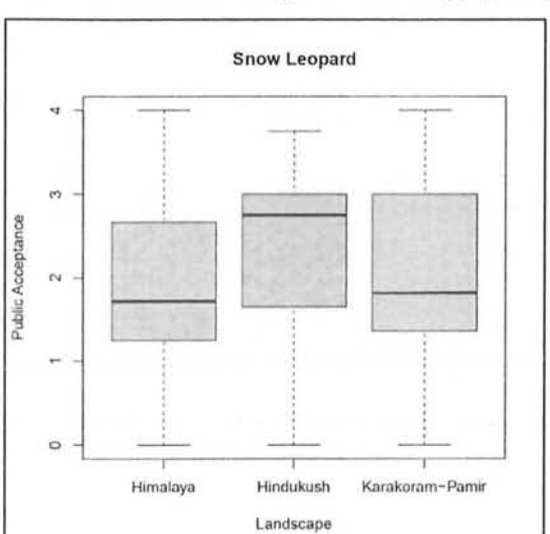
Table 8.2. Effect of various factors on the acceptance of locals towards brown bears.

Coefficients	*Estimate*	*SE*	*df*	*t-value*	*p-value*
Intercept	-7.37	4.17	29	-1.767	0.087
Latitude	0.29	0.12	28	2.456	0.020
Education	-0.25	0.09	225	-2.951	0.003

Significance codes: 0***, 0.001**, 0.01*, 0.05, 0.1, 1, df= degree of freedom

The acceptance level of brown bears and snow leopards by local communities of all three landscapes were categorized into negative (1 = eliminate and 2 = reduce), and positive (3 = maintain and 4 = increase).

In the case of snow leopards, the local people of the Himalayas and Karakoram-Pamir landscapes possessed highly negative acceptance, where the median value fell below 2.0, while the local people of the Hindu Kush landscape were more positive with a median value of about 3.0 (Figure 8.6a). In the case of brown bears, the local people of the Himalayas and Karakoram-Pamir landscapes possessed highly positive acceptance with a median value range of 3.0–3.5 (Figure 8.6b). Communities residing in the Hindu Kush range showed highly negative acceptance toward brown bears.



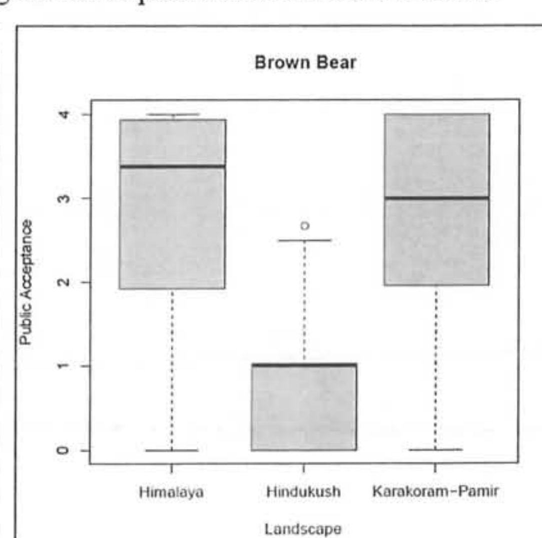


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Figure 8.6. a) Public acceptance of snow leopards by respondents in three major landscapes in northern Pakistan, **b)** Public acceptance of brown bears by respondents in three major landscapes in northern Pakistan

The district-wise analysis showed that the local people of district Diamer, Swat, Nagar, Hunza, Ghanche, and Gilgit possessed highly negative acceptance towards snow leopards—they wanted either the elimination or reduction of the animal. Conversely, the local people of district Ghizer, Skardu, Chitral, and Neelum Valley had highly positive acceptance towards snow leopards (Figure 8.7a).

The district-wise acceptance of local people about brown bears is plotted in Figure 8.7b. The box plot shows that the local people of district Chitral, Diamer, Ghizer, and Swat showed a highly negative acceptance toward brown bears, while the respondents of district Ghanche, Gilgit, Hunza, Neelum Valley, etc. possessed a highly positive acceptance and wanted to either maintain or increase the brown bear population.

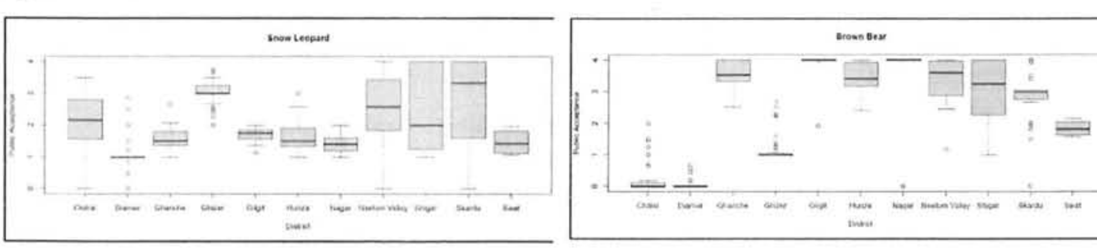

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Figure 8.7. a) District-wise acceptance of local people toward snow leopards, **b)** District-wise acceptance of local people toward brown bears

8.3.6 Public fear towards snow leopards and brown bears

The effects of various factors on the fear of local people about snow leopards and brown bears retained by the mixed effect model are shown in Table 8.3 and 8.4, respectively.

In the case of snow leopard mixed effect model results with 19 (17 fixed and 02 random) factors in AIC= 612.25, BIC=676.48. The backword elimination as results the final model with 07 (05 fixed and 02 random) factors with AIC= 604.63, BIC=636.75 as showed an effect on the fear of local communities. In the case of snow leopards, the fear of local people increased -0.43 negatively with a one-degree rise in the longitude. The fear of local people towards snow leopards increased 0.23 and 0.40 times with increases in education and age, respectively (Table 8.3). The sightings of snow leopards by local people and mortality of small-sized livestock due to diseases also slightly affected the fear of local people positively. Additionally, the public fear of snow leopard changes significantly with change of district and landscape which were treated as random factor.

Table 8.3. Effect of various factors on the fear of local people towards snow leopards, β represents estimates of parameters retained by the mixed effect model.

Coefficients	*Estimate*	*SE*	*df*	*t-value*	*p-value*
Intercept	33.29	8.80	153	3.782	0.000
Longitude	-0.44	0.12	154	-3.731	0.000
Snow Leopard Sighting	0.09	0.05	250	1.735	0.084
Disease Caused Mortality in Small Ruminants	0.01	0.01	247	1.726	0.085
Education Score	0.24	0.10	252	2.32	0.021
Age Score	0.41	0.15	247	2.681	0.007

Significance codes: 0***, 0.001**, 0.01*, 0.05, 0.1, 1, df= degree of freedom

In the case of brown bear mixed effect model results with 19 (17 fixed and 02 random) factors in AIC= 589.42, BIC=653.48. The backword elimination as results the final model with 02 (01 fixed and 01 random) factors with AIC= 571.74, BIC=585.74 as showed an effect on the fear of local communities. In the case of brown bears, the mixed effect model retained only the effect of earning members on the fear of local people. The fear of local people increased -0.13 negatively with an increase in the number of earning members (Table 8.4). Additionally, the public fear of brown bear changes significantly with change of district which were treated as random factor.

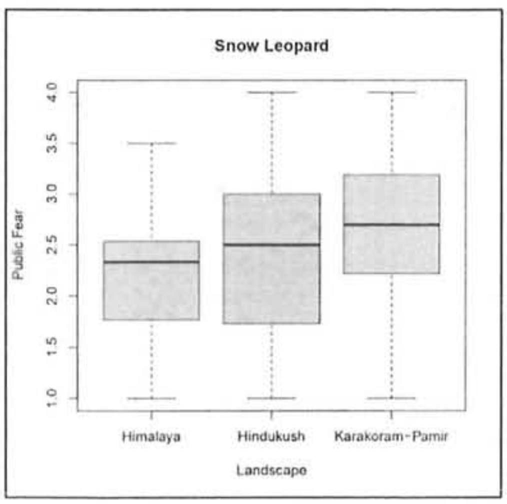
Table 8.4. Effect of various factors on the fear of local people towards snow leopards, β represents estimates of parameters retained by the mixed effect model.

Coefficients	*Estimate*	*SE*	*df*	*t-value*	*p-value*
Intercept	2.66	0.43	12	6.199	0.000
Earning members	-0.14	0.08	251	-1.799	0.073

Significance codes: 0***, 0.001**, 0.01*, 0.05, 0.1, 1, df= degree of freedom

The perceived public fear of carnivores by local people to livestock was ranked 1–4 (1 = least dangerous, while 4 = most dangerous). The perceived danger of snow leopards and brown bears by the local people of three major landscapes—the Himalayas, Karakoram-Pamirs, and Hindu Kush) in our study area were plotted in the programme R.

The box plots show that local people's fear of snow leopards and brown bears was the lowest in the Himalayan landscape, with a median value below 2.5, while the maximum value was about 2.5 in the case of snow leopards, and about 2.8 for brown bears (Figure 8.8a). The box plot shows that the highest fear from snow leopards and brown bears was in the Karakoram-Pamir range with a median value of 2.5–3.0 for both snow leopards and brown bears. The outlier value fell between 3.0 and 3.5 for snow leopards. It was about 3.0 for brown bears (Figure 8.8b).



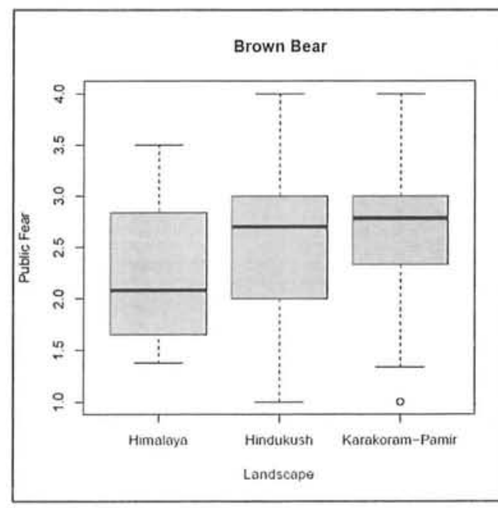


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Figure 8.8. a) Fear of snow leopards perceived by respondents in three major landscapes in northern Pakistan, **b)** Fear of brown bears perceived by respondents in three major landscapes in northern Pakistan.

The perceived danger of snow leopards and brown bears to livestock by local people was also analysed district-wise. They were ranked 1–4 (1 = least dangerous, while 4 = most dangerous). The perceived dangers of each district about carnivores are shown in the form of a plotted box.

The box plots show that fear of snow leopards and brown bears was the lowest in district Neelum where the median value fell below 2.0 (Figure 8a and Figure 8b). On the other hand, the highest fear of snow leopards was in district Gilgit, Nagar, and Diamer (Figure 8a). The highest fear of brown bears was in district Diamer, Ghanche, and Hunza (Figure 8b).

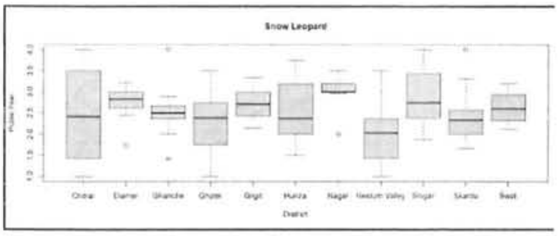

Figure 8a: District-wise acceptance of local people toward snow leopards

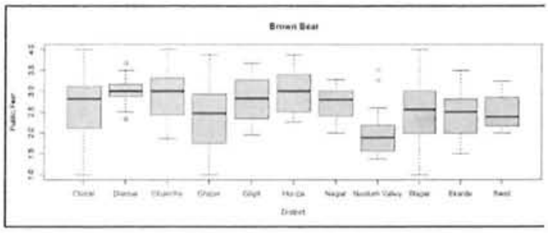

Figure 8b: District-wise acceptance of local people toward brown bears

8.4 DISCUSSION

Human-wildlife conflict is an emerging issue that has intensified over time. Many wildlife species have become threatened due to this conflict, especially large carnivores (Qamar et al., 2010). Worldwide, one of the main causes of human-carnivore conflict is the killing of livestock by large carnivores and is common in and around reserves in the developing world (Distefano, 2005). In the Hindu Kush and Himalayan mountains, an increasing population of livestock has elicited an increased livestock depredation by large carnivores (Hussain, 2003; Mishra, 1997). In the present study, respondents of different villages across three major landscapes in northern Pakistan reported an annual loss of 1,529.61 (0.55 heads per household, per year) heads of livestock due to brown bear and snow leopard predation. Small-sized livestock such as goats and sheep were killed by these apex predators in greater numbers as compared to large-sized livestock such as cattle, yaks, donkeys, and horses. Other studies in the snow leopard and brown bear ranges showed that large carnivores kill small-sized livestock in greater numbers (Ahmad et al., 2016; Kabir et al., 2014; Rehman et al., 2021). Medium-sized livestock (25–45 kg) are the most vulnerable to predation because large carnivores can easily kill and drag them to safety (Ahmad et al., 2016; Dar et al., 2009). Worldwide, the decline in natural prey triggers increasing livestock depredation by large carnivores (Meriggi and Lovari, 1996). In snow leopard and brown bear ranges in Pakistan, Abbas et al. (2013) also documented a decreasing trend in the population of wild ungulates which provide food for large carnivores, particularly snow leopards.

The annual 1,529.61 livestock loss translated into an annual economic loss of PKR 1,568,594.5 (PKR 573.94 per household). The economic loss reported in the present study was much lower than the economic loss caused by different carnivores in northern Pakistan ((Ahmad et al., 2016; Din et al., 2017; Rehman et al., 2021). Although the annual economic loss reported by respondents in the current study was much lower than in other reported studies, it is not acceptable to local communities. Such losses are likely to generate aggressive acceptance towards conservation and may provoke retaliatory action by farmers (Conforti and De Azevedo, 2003).

Facilitating human-carnivore co-existence is a major conservation concern in human-dominated landscapes worldwide (Dorresteijn et al., 2014). Studies have shown that humans and carnivores can co-exist (Schuette et al., 2013). Human-carnivore conflict has consequences for both humans and carnivores. People living close to conflict areas possess negative acceptance towards carnivores which makes biodiversity protection a challenging task (Woodroffe et al., 2005). Both ecological and social factors are important to understand long-term co-existence in multiple-use landscapes (Carter et al., 2012). In the present study, various social and other factors like latitude, longitude, snow leopard sightings, predation on small ruminants, predation on large ruminants, landscape, district, education level, occupation, age, agriculture land owned, etc. were run against local people's fear of snow leopards and brown bears. The analysis showed that the acceptance of local people towards snow leopards turned positively with a one-degree rise in latitude and longitude that is probably due to the awareness and knowledge of the species in those areas. But this acceptance turned negatively with depredation on small-sized livestock which is understandable because most of the economic losses caused by carnivores were in the form of small livestock. In our study, most local people kept much more small-sized livestock than large-sized livestock to fulfil their basic livelihood needs—depredation may be a possible reason for the negative acceptance. Possibly this was the reason, large-sized depredation didn't affect their attitude at large scale. Also, people who do livestock herding as an occupation and those who sighted snow leopard in the area had negative acceptance towards snow leopard probably due to their concerns about its attacks on their animals. ... In the case of brown bears, the acceptance of local people turned positively with an increase in latitude but turned negatively with an increase in education level. Livestock depredation of any kind did not affect acceptance of brown bear by local people probably because of very low killing by it as compared to snow leopard. As livestock killing brown bear was not a big issue therefore livestock herder attitude was also neutral. Although the fear of local people normally changes from negative to positive with increasing education, this study showed the opposite. We were unable to explain this.

Data related to the perceived public fear of snow leopards and brown bears showed that in the case of snow leopards, public fear increased with a one-degree rise in longitude. The fear of local people towards snow leopards turned increase with the sighting of snow leopards that is understandable. Increase in age increased fear probably because older people may become more concerned, again education increased fear that is strange but probably educated people consider these predators as 'potential threats' due to news from other areas or anything like that, the mortality of small-sized livestock due to diseases may caused an overall fear in people mind and they fear anything which could be harmful to their livestock, for example, snow leopard. In the case of brown bears, the mixed effect model showed that people largely remained neutral and did not show significant fear to it due to its less harmful profile as compared to snow leopard. However, that the fear of local people increased with increases in the number of earning members and that is completely understandable as increase of earning member means dependency on livestock decreases and it positively affect attitude of local people.

8.4.1.1 Conclusion

This study concluded that conflict is a serious threat to the survival of both snow leopards and brown bears in northern Pakistan. Mitigation measures include livestock vaccination, compensation for the loss of livestock due to carnivores, the construction of predator-proof corrals, and improving watch-and-ward practices. An awareness programme should be launched in the area to change the fear of local people from negative to positive. More studies should be conducted across the distribution range of both carnivores, and issues related to their conservation should be highlighted.

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8.6 REFERENCES

Abbas, F., Rooney, T.P., Mian, A., 2013. Grey wolf in Gilgit-Baltistan, Pakistan: Distribution, abundance and persecution. Canid Biol. Conserv.

Ahmad, S., Hameed, S., Ali, H., Khan, T. U., Mehmood, T., & Nawaz, M. A. (2016). Carnivores' diversity and conflicts with humans in Musk Deer National Park, Azad Jammu and Kashmir, Pakistan. European journal of wildlife research, 62(5), 565-576.

Aryal, A., Brunton, D., Ji, W., Barraclough, R. K., & Raubenheimer, D. (2014). Human–carnivore conflict: Ecological and economical sustainability of predation on livestock by snow leopard and other carnivores in the Himalaya. Sustainability Science, 9(3), 321-329.

Augugliaro, C., Christe, P., Janchivlamdan, C., Baymanday, H., & Zimmermann, F. (2020). Patterns of human interaction with snow leopard and co-predators in the Mongolian western Altai: Current issues and perspectives. Global Ecology and Conservation, e01378.

Bagchi, S., and C. Mishra. 2006. Living with large carnivores: Predation on livestock by the snow leopard (Uncia uncia). Journal of Zoology 268: 217-224.

Behr, D. M., Ozgul, A., & Cozzi, G. (2017). Combining human acceptance and habitat suitability in a unified socio-ecological suitability model: A case study of the wolf in Switzerland. Journal of Applied Ecology, 54(6), 1919-1929.

Bhattarai BR, Fischer K. Human-tiger Panthera tigris conflict and its perception in Bardia National Park, Nepal. Oryx. 2014;48(4): 522-528.

Bibi SS, Minhas RA, Awan MS, Ali U, Dar NI (2013) Study of ethnocarnivore relationship in Dhirkot, Azad Jammu and Kashmir. P J Anim Plant Sci 23: 854-859.

Cardillo, M., Purvis, A., Sechrest, W., Gittleman, J. L., Bielby, J., & Mace, G. M. (2004). Human population density and extinction risk in the world's carnivores. PLoS Biology, 2, e197.

Carter, N. H., Riley, S. J., & Liu, J. (2012). Utility of a psychological framework for carnivore conservation. Oryx, 46(4), 525-535.

Chapron, G., Miquelle, D. G., Lambert, A., Goodrich, J. M., Legendre, S., & Clobert, J. (2008). The impact on tigers of poaching versus prey depletion. Journal of Applied Ecology, 45(6), 1667-1674.

Conforti, V.A., De Azevedo, F.C.C., 2003. Local perceptions of jaguars (Panthera onca) and pumas (Puma concolor) in the Iguaçu National Park area, south Brazil. Biol. Conserv.

Dar NI, Minhas RA, Zaman Q, Linkie M (2009) Predicting the patterns, perceptions and causes of human-carnivore conflict in and around Machiara National Park, Pakistan. Biol Conserv 10: 2076-2082.

Dickman, A. J., Macdonald, E. A., & Macdonald, D. W. (2011). A review of financial instruments to pay for predator conservation and encourage human–carnivore coexistence. Proceedings of the National Academy of Sciences, 108(34), 13937-13944.

Din, U.J., Ali, H., Ali, A., Younus, M., Mehmood, T., Norma-Rashid, Y., Ali Nawaz, M., 2017. Pastoralist-predator interaction at the roof of the world: Conflict dynamics and implications for conservation. Ecol. Soc.

Distefano E (2005) Human-wildlife conflict worldwide: A collection of case studies, analysis of management strategies and good practices. FAO, Rome, p 34.

Dorresteijn, I., Hanspach, J., Kecskés, A., Latková, H., Mezey, Z., Sugár, S., ... & Fischer, J. (2014). Human-carnivore coexistence in a traditional rural landscape. Landscape Ecology, 29(7), 1145-1155.

Farhadinia, M. S., Johnson, P. J., Hunter, L. T., & Macdonald, D. W. (2017). Wolves can suppress goodwill for leopards: Patterns of human-predator coexistence in northeastern Iran. Biological Conservation, 213, 210-217.

Glen, A. S., & Dickman, C. R. (2014). The importance of predators. Carnivores of Australia: Past, present and future. Australia: CSIRO Publishing, 1-12.

Gonzalez, A., Novaro, A., Funes, M., Pailacura, O., Bolgeri, M. J., and Walker, S. (2012). Mixed-breed guarding dogs reduce conflict between goat herders and native carnivores in Patagonia. Hum. Wildl. Interact. 6, 327-334.

Hussain S (2003) The status of the snow leopard in Pakistan and its conflict with local farmers. Oryx 37: 26-33.

Inskip, C., & Zimmermann, A. (2009). Human-felid conflict: A review of patterns and priorities worldwide. Oryx, 43(1), 18-34.

Inskip, C., Fahad, Z., Tully, R., Roberts, T., & MacMillan, D. (2014). Understanding carnivore killing behaviour: Exploring the motivations for tiger killing in the Sundarbans, Bangladesh. Biological Conservation, 180, 42-50.

Janeiro-Otero, A., Newsome, T. M., Van Eeden, L. M., Ripple, W. J., & Dormann, C. F. (2020). Grey wolf (Canis lupus) predation on livestock in relation to prey availability. Biological Conservation, 243, 108433.

Johansson, Ö., McCarthy, T., Samelius, G., Andrén, H., Tumursukh, L., & Mishra, C. (2015). Snow leopard predation in a livestock dominated landscape in Mongolia. Biological Conservation, 184, 251-258.

Kabir M, Ghoddousi A, Awan MS, Awan MN (2014) Assessment of human-leopard conflict in Machiara National Park, Azad Jammu and Kashmir, Pakistan. Eur J Wildl Res 60: 291-296.

Kalaivanan, N., Venkataramanan, R., Sreekumar, C., Saravanan, A., Srivastava, R.K., 2010. Secondary phorate poisoning of large carnivores in India. Eur. J. Wildl. Res. 57, 191e194

Khanal, G., Mishra, C., & Ramesh Suryawanshi, K. (2020). Relative influence of wild prey and livestock abundance on carnivore-caused livestock predation. Ecology and evolution, 10(20), 11787-11797.

Khorozyan, I., Soofi, M., Ghoddousi, A., Hamidi, A.K., Waltert, M., 2015. The relationship between climate, diseases of domestic animals and humancarnivore conflicts. Basic Appl. Ecol. 16, 703e713.

Kuiper, T. R., Loveridge, A. J., Parker, D. M., Johnson, P. J., Hunt, J. E., Stapelkamp, B., & Macdonald, D. W. (2015). Seasonal herding practices influence predation on domestic stock by African lions along a protected area boundary. Biological Conservation, 191, 546-554.

Kusi, N., Sillero-Zubiri, C., Macdonald, D. W., Johnson, P. J., & Werhahn, G. (2020). Perspectives of traditional Himalayan communities on fostering coexistence with Himalayan wolf and snow leopard. Conservation Science and Practice, 2(3), e165.

Linnell, J. D., Swenson, J. E., & Anderson, R. (2001). Predators and people: Conservation of large carnivores is possible at high human densities if management policy is favourable. Animal Conservation, 4(4), 345-349.

Liu, F., McShea, W. J., Garshelis, D. L., Zhu, X., Wang, D., & Shao, L. (2011). Human-wildlife conflicts influence attitudes but not necessarily behaviors: Factors driving the poaching of bears in China. Biological Conservation, 144(1), 538-547.

Loveridge, A. J. S. W., Wang, S. W., Frank, L., & Seidensticker, J. (2010). People and wild felids: Conservation of cats and management of conflicts. Biology and conservation of wild felids.

Lucherini, M., Guerisoli, M. D. L. M., & Luengos Vidal, E. M. (2018). Surplus killing by pumas *Puma concolor*: Rumours and facts. Mammal Review, 48(4), 277-283.

Madhusudan, M. D., & Mishra, C. (2003). Why big, fierce animals are threatened: Conserving large mammals in densely populated landscapes. In Battles over nature: Science and the politics of wildlife conservation (pp. 31-55).

Madhusudan, M.D., 2003. Living amidst large wildlife: Livestock and crop depredation by large mammals in the interior villages of Bhadra Tiger Reserve, south India. Environ. Manag. 31, 466e475.

Madhusudan, M.D., Mishra, C., 2003. Why big, fierce animals are threatened: Conserving large mammals in densely populated landscapes. In: Saberwal, V., Rangarajan, M. (Eds.), Battles over Nature: Science and Politics of Conservation. Permanent Black, New Delhi, pp. 31e55.

McManus, J. S., Dickman, A. J., Gaynor, D., Smuts, B. H., & Macdonald, D. W. (2015). Dead or alive? Comparing costs and benefits of lethal and non-lethal human–wildlife conflict mitigation on livestock farms. Oryx, 49(4), 687-695.

Meriggi, A., Lovari, S., 1996. A Review of Wolf Predation in Southern Europe: Does the Wolf Prefer Wild Prey to Livestock? J. Appl. Ecol. 33: 1561-1571.

Miller, J. R., Jhala, Y. V., Jena, J., & Schmitz, O. J. (2015). Landscape-scale accessibility of livestock to tigers: Implications of spatial grain for modeling predation risk to mitigate human–carnivore conflict. Ecology and evolution, 5(6), 1354-1367.

Mishra, C. (1997). Livestock depredation by large carnivores in the Indian trans-Himalaya: Conflict perceptions and conservation prospects. Environmental Conservation, 24(4), 338-343.

Mishra, C., Allen, P., McCarthy, T. O. M., Madhusudan, M. D., Bayarjargal, A., & Prins, H. H. (2003). The role of incentive programs in conserving the snow leopard. Conservation Biology, 17(6), 1512-1520.

Mishra, C., Redpath, S.R., Suryawanshi, K.R., 2016. Livestock predation by snow leopards: Conflicts and the search for solutions. In: McCarthy, T.M., Mallon,

D. P. (Eds.), Snow Leopard, Biodiversity of the World: Conservation from Genes to Landscapes. Elsevier, New York, pp. 59e67.

Mizutani, F., 1999. Impact of leopards on a working ranch in Laikipia, Kenya. Afr. J. Ecol. 37, 211e225.

Moore N, Whiterow A, Kelly P, Garthwaite D, Bishop J, Langton S, Cheeseman C (1999) Survey of badger Meles meles damage to agriculture in England and Wales. J Appl Ecol 36: 974-988.

Musiani, M., Mamo, C., Boitani, L., Callaghan, C., Gates, C. C., Mattei, L., ... & Volpi, G. (2003). Wolf depredation trends and the use of fladry barriers to protect livestock in western North America. Conservation Biology, 17(6), 1538-1547.

Odden, J., Herfindal, I., Linnell, J. D. C., & Andersen, R. (2008). Vulnerability of domestic sheep to lynx depredation in relation to Roe deer density. Journal of Wildlife Management, 72, 276-282.

Ordiz, A., Bischof, R., & Swenson, J. E. (2013). Saving large carnivores, but losing the apex predator? Biological Conservation, 168, 128-133.

Palmeira, F. B. L., Crawshaw, P. G., Haddad, C. M., Ferraz, K. M. P. M. B., and Verdade, L. M. (2008). Cattle depredation by puma (Puma concolor) and jaguar (Panthera onca) in central-western Brazil. Biol. Conserv. 141, 118-125.

Perveen F, Abid M (2013) Asian black bear, Ursus thibetanus: Human-bear conflict in the Palas Valley, Kohistan, Pakistan. IJFAS 2: 1172-1178.

Pimenta, V., Barroso, I., Boitani, L., & Beja, P. (2018). Risks a la carte: Modelling the occurrence and intensity of wolf predation on multiple livestock species. Biological Conservation, 228, 331-342.

Qamar QZ, Dar NI, Ali U, Minhas RA, Ayub J, Anwar, M. (2010) Human-leopard conflict: An emerging issue of common leopard conservation in Machiara National Park, Azad Jammu and Kashmir, Pakistan. Pak J Wildl 1: 50-56.

R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rahmani, A.R., 2003. Conservation outside protected areas. In: Saberwal, V., Rangarajan, M. (Eds.), Battles over Nature: Science and Politics of Conservation. Permanent Black, New Delhi, pp. 117e138.

Rehman, E. U., Din, J. U., Ahmad, S., Hameed, S., Shah, K. A., Mehmood, T., & Nawaz, M. A. (2020). Insight into Occupancy Determinants and Conflict Dynamics of Grey Wolf (Canis lupus) in the Dry Temperate Zone of Hindukush Range. Global Ecology and Conservation, e01402.

Ripple, W. J., Chapron, G., López-Bao, J. V., Durant, S. M., Macdonald, D. W., Lindsey, P. A., ... & Corlett, R. T. (2016). Saving the world's terrestrial megafauna. Bioscience, 66(10), 807-812.

Ripple, W. J., Estes, J. A., Beschta, R. L., Wilmers, C. C., Ritchie, E. G., Hebblewhite, M., ... & Schmitz, O. J. (2014). Status and ecological effects of the world's largest carnivores. Science, 343(6167).

Schuette P, Creel S, Christianson D (2013) Coexistence of African lions, livestock, and people in a landscape with variable human land use and seasonal movements. Biol Conserv 157: 148-154.

Smith, J. B., Nielsen, C. K., and Hellgren, E. C. (2014). Illinois resident attitudes toward recolonizing large carnivores. J. Wildl. Manage. 78, 930-943.

Soofi, M., Ghoddousi, A., Zeppenfeld, T., Shokri, S., Soufi, M., Egli, L., ... & Filla, M. (2019). Assessing the relationship between illegal hunting of ungulates, wild prey occurrence and livestock depredation rate by large carnivores. Journal of Applied Ecology, 56(2), 365-374.

Soto-Shoender, J. R., and Main, M. B. (2013). Differences in stakeholder perceptions of the jaguar Panthera onca and puma Puma concolor in the tropical lowlands of Guatemala. Oryx 47, 109-112.

Suryawanshi, K. R., Bhatia, S., Bhatnagar, Y. V., Redpath, S., & Mishra, C. (2014). Multiscale factors affecting human attitudes toward snow leopards and wolves. Conservation Biology, 28(6), 1657-1666.

Suryawanshi, K. R., Redpath, S. M., Bhatnagar, Y. V., Ramakrishnan, U., Chaturvedi, V., Smout, S. C., & Mishra, C. (2017). Impact of wild prey availability on livestock predation by snow leopards. Royal Society open science, 4(6), 170026.

Swanepoel, L. H., Somers, M. J., & Dalerum, F. (2015). Functional responses of retaliatory killing versus recreational sport hunting of leopards in South Africa. PLoS one, 10(4), e0125539.

Talbert, L., Leslie, S. C., & Black, S. A. (2020). Use of predator controls to address human wildlife conflict. Int J Avian & Wildlife Biol, 5(1), 9-13.

Thorn, M., Green, M., Scott, D., and Marnewick, K. (2013). Characteristics and determinants of human-carnivore conflict in South African farmland. Biodivers. Conserv. 22, 1715-1730.

Tortato, F. R., & Izzo, T. J. (2017). Advances and barriers to the development of jaguar-tourism in the Brazilian Pantanal. Perspectives in Ecology and Conservation, 15(1), 61-63.

Treves, A., & Karanth, K. U. (2003). Human-carnivore conflict and perspectives on carnivore management worldwide. Conservation biology, 17(6), 1491-1499.

Trinkel M, Fleischmann PH, Slotow R. 2017. Electrifying the fence or living with consequences? Problem animal control threatens the long-term viability of a free-ranging lion population. J. Zool. 301, 41-50.

Ugarte, C. S., Moreira-Arce, D., Simonetti, J. A., Valenzuela, C. M., Acuña, E., Ortega, A., ... & Morales-Salinas, L. (2019). Ecological attributes of carnivore-livestock conflict. Frontiers in Ecology and Evolution, 7, 433.

Weise, F. J., Hayward, M. W., Aguirre, R. C., Tomeletso, M., Gadimang, P., Somers, M. J., & Stein, A. B. (2018). Size, shape and maintenance matter: A critical appraisal of a global carnivore conflict mitigation strategy–Livestock protection kraals in northern Botswana. Biological Conservation, 225, 88-97.

White, L. A. & Gehrt, S. D. Coyote attacks on humans in the United States and Canada. Hum. Dimensions Wildl. 14, 419-432 (2011).

Wolf C, Ripple WJ. 2016. Prey depletion as a threat to the world's large carnivores. R. Soc. open sci. 3, 160252

Woodroffe R, Thirgood S, Rabinowitz A (2005) People and wildlife, conflict or co-existence? Cambridge University Press, Cambridge

Woodroffe R. 2000. Predators and people: Using human densities to interpret declines of large carnivores. Anim. Conserv. 2000: 165-73.

Woodroffe, R., and Frank, L. G. (2005). Lethal control of African lions (*Panthera leo*): Local and regional population impacts. Anim. Conserv. 8, 91-98.

Woodroffe, R., Frank, L. G., Lindsey, P. A., Ole Ranah, S. M. K., & Romañach, S. (2007). Livestock husbandry as a tool for carnivore conservation in Africa's community rangelands: A case-control study. Biodiversity and Conservation, 16(4), 1245-1260.

Ecology and Conflict Dynamics of Apex Predators in Northern Pakistan

CHAPTER 9

Conclusion and Future Implications

9 Conclusion and Future Implications

This study constructed distributional ranges for snow leopards and brown bears through predictive modelling of empirical data. These ranges were strikingly different from previously known distributions of species. Previous distribution records were based largely on expert judgements, but this study refined them with precise species occurrences.

Based on habitat analysis, three landscapes were identified—the Himalayas, Hindu Kush, and Karakoram-Pamirs—to be considered as regional priority areas to safeguard the future of apex predators in Pakistan and the region. These landscapes also provide connectivity of predator populations with regional populations. For instance, the Himalayan landscape provides connectivity with populations in India on the eastern side and connects with the Karakorams in the northwest. The Karakoram landscape provides wider connectivity with populations in China in the north and connects to the Hindu Kush in the west. The Hindu Kush provides connectivity with Central Asian populations through Afghanistan and Tajikistan. Targeted conservation efforts in these landscapes will ensure the long-term existence of key predators in Pakistan, including the snow leopard, brown bear, grey wolf, and Himalayan lynx.

Contrary to the good regional connectivity of populations, populations of snow leopards and brown bears appear to have weaker connections in certain areas within Pakistan. These areas include; Broghil-Qurumber National Parks and Khunjerab-Central Karakoram National Parks. Protection and habitat management in these areas are vital for maintaining viable populations of large predators in the country.

The current protected area network in northern Pakistan appears to cover most of the suitable habitats identified during this study, except for a few gaps. These gaps need to be filled either through the expansion of existing protected areas or the declaration of new protected areas. Candidate habitats that need legal protection are Misgar and Chapursan in Gilgit-Baltistan and Terichmir in Chitral.

Population estimation for rare and elusive species has always been a daunting task. The current study demonstrates that the latest detection methods—camera traps, molecular genetics—in combination with SCR hold promise for some of the elusive species living in low densities. However, camera trap is more effective for those species which are individually recognizable and follow preferred routes as compared to unmarked species and for those which don't follow trails. The application of such techniques needs to be up-scaled in Pakistan and in the region to achieve range-wide population estimates for Asia's iconic predators.

Though highly effective for snow leopards, camera trapping did not yield desirable data for brown bears. This is because brown bears do not follow trails, and camera detections are generally higher for species that follow trails. We found that visual counts in alpine meadows were the simplest and most effective way of enumerating Himalayan brown bears. Counts through the double-observer method allow for the estimation of reliable populations through the capture-mark-recapture approach.

This study also revealed that human-predator conflict is a serious threat to the survival of large carnivores in Pakistan. Livestock killing, predator sightings, and the livelihood conditions of households were the key determinants shaping human attitudes to predators. The introduction of safety nets against economic loss to predation and conservation education can promote acceptance of carnivores and longer-term co-existence between humans and predators in northern Pakistan.

PLOS ONE

RESEARCH ARTICLE

Identifying priority landscapes for conservation of snow leopards in Pakistan

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Abstract

Pakistan's total estimated snow leopard habitat is about 80,000 km^2 of which about half is considered prime habitat. However, this preliminary demarcation was not always in close agreement with the actual distribution—the discrepancy may be huge at the local and regional level. Recent technological developments like camera trapping and molecular genetics allow for collecting reliable presence records that could be used to construct realistic species distribution based on empirical data and advanced mathematical approaches like MaxEnt. The current study followed this approach to construct an accurate distribution of the species in Pakistan. Moreover, movement corridors, among different landscapes, were also identified through circuit theory. The probability of habitat suitability, generated from 98 presence points and 11 environmental variables, scored the snow leopard's assumed range in Pakistan, from 0 to 0.97. A large portion of the known range represented low-quality habitat, including areas in lower Chitral, Swat, Astore, and Kashmir. Conversely, Khunjerab, Misgar, Chapursan, Qurumber, Broghil, and Central Karakoram represented high-quality habitats. Variables with higher contributions in the MaxEnt model were precipitation during the driest month (34%), annual mean temperature (19.5%), mean diurnal range of temperature (9.8%), annual precipitation (9.4%), and river density (9.2). The model was validated through receiver operating characteristic (ROC) plots and defined thresholds. The average test AUC in Maxent for the replicate runs was 0.933 while the value of AUC by ROC curve calculated at 0.15 threshold was 1.00. These validation tests suggested a good model fit and strong predictive power. The connectivity analysis revealed that the population in the Hindukush landscape appears to be more connected with the population in Afghanistan as compared to other populations in Pakistan. Similarly, the Pamir-Karakoram population is better connected with China and Tajikistan, while the Himalayan population was connected with the population in India. Based on our findings we propose three model landscapes to be considered under the Global Snow Leopard Ecosystem Protection Program (GSLEP) agenda as regional priority areas, to safeguard the future of the snow leopard in Pakistan and the region. These landscapes fall within mountain ranges of the Himalaya,

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Human Perceptions about the Himalayan Brown Bear and other Carnivores in Chitral District in the Hindu Kush Range, Pakistan

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MAN and SH conceived the idea and designed the study. SH and JUD conducted the field work. SA and SH wrote the manuscript. MAN supervised the study and reviewed the draft.

Key words
Himalayan brown bear, *Ursus arctos isabellinus*, Grey wolf, Snow leopard, Himalayan lynx, Chitral, Conflict, Livestock loss, Perception, Carnivores

ABSTRACT

The Himalayan brown bear (*Ursus arctos isabellinus*) historically occupied the vast mountain ranges of South and Central Asia. Their range has shrunken significantly in the past century and they currently live in small and isolated populations. Most of their range has not been surveyed; hence information on their distribution is largely based on anecdotal information and expert judgments. The present study investigated the species' current distribution in the Hindu Kush Range in Pakistan, gathering information on human-brown bear conflict along with other large carnivore species in the study area. Multiple survey techniques questionnaire surveys, sign surveys and camera trapping were used during the period 2008–2010 in five study blocks delineated on natural watersheds in Pakistan's Chitral district. Based on questionnaire surveys, sign surveys and direct sighting, Himalayan brown bear presence was confirmed only in the Yarkhun and Laspur valleys. Ninety-six respondents (59 from Laspur Valley and 37 from Broghil Valley) reported a total of 449 livestock losses (90 heads per year) to carnivore species—grey wolf (*Canis lupus*), snow leopard (*Panthera pardus)*, Himalayan lynx (*Lynx lynx isabellinus*)—during the five-year (2005–2009) period, which translated into an economic loss of USD 34,297 (PKR 2,931,022); USD 357 (PKR 30,531) per household. Himalayan brown bear was not accounted for any livestock loss. Though the public was seen to be strongly against large carnivores, brown bear was considered 'less dangerous'. Despite limited conflict with humans, brown bear has lost a large part of its historical range in the Hindu Kush Range. The species is confined to the eastern valleys where it is maintaining connectivity with brown bear in Gilgit-Baltistan towards the east and with Afghan populations towards the west.

INTRODUCTION

The Himalayan brown bear (*Ursus arctos isabellinus*) is a subspecies that represents an ancient lineage of the brown bear (Galbreath *et al*., 2007). The brown bear historically occupied the western Himalayas, Karakoram, Hindu Kush, Pamirs, western Kunlun Shan, and the Tian Shan ranges in South and Central Asia (Nawaz, 2008). In Pakistan, approximately 150–200 bears may survive in seven populations over approximately 150,000 km^2 (Nawaz, 2007) across three provinces/states Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and Azad Jammu and Kashmir (AJ and K) (Nawaz, 2007). In KP, this species is distributed in Chitral, Kalam (Kohistan), Pallas Valley (Indus Kohistan) and Kaghan Valley (Akbar, 2003; Nawaz, 2007). Chitral district, with an area of 14,850 km^2, provides the largest habitat in KP and marks the western extremity of the brown bear range in Pakistan. It is the high mountainous dry temperate area of the Hindu Kush Range that connects to brown bear habitat in Afghanistan towards the west (Nawaz, 2007), GB in the east, and a narrow strip of the Wakhan Corridor separating Chitral from Tajikistan in the North (AASA, 2015). Brown bear presence has been reported from several localities in Chitral, including Trich Mir Valley (Schaller, 1977), Torkhow Valley and Yarkhun Valley (Fulton, 1903; Schaller, 1977; Nawaz, 2007). However, the species is rare in the Hindu Kush Range (Nawaz, 2007) and extirpated from a large part of Chitral district. For example, it has been wiped out from Chitral Gol National Park and surrounding areas (Mirza, 2003).

Growing human population, expanding infrastructure, loss of habitat, increasing number of domestic animals, declines in food supply, climate change and increasing human dependence on natural resources are the primary reasons contributing to a persistent decline in brown bear population in Pakistan. Unmanaged and growing tourism also contributes to population decline (Nawaz, 2007) by exposing pristine habitats to human movement, hoteling, camping, and littering. Other threats include killing bears

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