Distribution, Site Use and Impact of Climate Change on the Wild Ungulates of Gilgit-Baltistan, Pakistan

By

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A dissertation submitted in partial fulfilment of the requirements for the degree of

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بسم الله الرحمن الرحيم

DEDICATION

This thesis is dedicated to my father for ensuring that his children should acquire quality education, to eldest brother for his guidance from school to graduation level education, and to my wife for taking care of family when I was away from home for this degree.

Author's Declaration

I **Mr. Hussain Ali** hereby state that my Ph.D., thesis titled " Distribution, Site Use and Impact of Climate Change on the Wild Ungulates of Gilgit-Baltistan, Pakistan" is my own work and not been submitted previously by me for taking any degree form Quaid-i-Azam University, Islamabad, Pakistan.

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LIST OF ACRONYM/ABBREVIATIONS

Abbreviation	Full Form
%	Percent
°C	Degree Centigrade
AJ&K	Azad Jammu And Kashmir
alt	Altitude
AUC	Area Under the Curve
CCL	Carnivore Conservation Lab
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
e.g.,	For example
ENMs	Ecological Niche Models
et al	And Others
etc	Et Cetera
FAO	Food and Agriculture Organization
GB	Gilgit-Baltistan
GIS	Geographic Information System
glc2000	Global Landcover 2000
GLM	General Linear Model
GPS	Global Positional System
HEC	Higher Education Commission-Pakistan

IRSIP	International Research Support Initiative Program
IUCN	International Union for Conservation of Nature
kg	Kilogram
km	Kilometer
KNP	Khunjerab National Park
KPK	Khyber Pakhtunkhwa
KVO	Khunjerab Villagers Organization
m	Meter
MaxEnt	Maximum Entropy
NDVI	Normalized Difference Vegetation Index
PKR	Pakistan Rupees
QNP	Qurumber National Park
ROC	Receiver Operating Characteristic
SDMs	Species Distribution Models
SE	Standard Error
SLF	Snow Leopard Foundation
SLT	Snow Leopard Trust
UK	United Kingdom
USA	United States of America
USD	United States Dollar
i.e.,	That is
MERGE	Multi-site Experiment in Rangeland and Grassland Ecosystems
Ph.D.,	Doctor of Philosophy
M.Phil.,	Master of Philosophy
TSS	True Skill Statistics
NCF	Nature Conservation Foundation
GCMs	Global Circulation Models
RCPs	Representative Concentration Pathways

viz.	As follows
p	Detection probability
psi (ψ)	Probability of occupancy
SE	Standard error
AIC	Akaki Information Criteria

GENERAL ABSTRACT

Wild ungulates are crucial in maintaining proper functioning of many ecosystems because they aid in nutrient recycling and provide a food base for many carnivores. Pakistan is home to seven species and five subspecies of wild caprinae (sheep and goats). These 12 members of caprinae are distributed across the country.

The Gilgit-Baltistan (GB) province is situated in the north of the Pakistan with an area of 72,791 km^2 and is divided into ten administrative districts. The land area of GB is dominated by rugged mountains of the Himalayas, Hindu Kush, and Karakoram-Pamirs. These mountain ranges are covered by world's largest mass of glaciers outside the poles, and harbor five species of caprinae viz., Himalayan ibex (*Capra ibex sibirica*), Astor markhor (*Capra falconeri falconeri*), Ladakh urial (*Ovis vignei vignei*), Marco Polo sheep (*Ovis ammon polii*) and Kashmir musk deer (*Moschus cupreus*). Historically, these wild ungulates were rampantly poached, leading to population decline, local extirpation, and significant reduction in their geographical ranges. Conservation programs, law enforcement and trophy hunting programs helped recovery in populations of some of these species in selected parts of the range.

In last two decades, GB has witnessed a remarkable development of infrastructure, particularly monumental expansion in network of roads which though benefited inhabitants but led to increased access to remote habitats, habitat fragmentation, and habitat degradation due to encroachment, deforestation. The tourism traffic and land use changes increase every year. This further aggravates the situation, as mountainous habitats are the most vulnerable ecosystems in the world due to climate change.

All wild ungulates species are threatened in Pakistan, and intensifying threats make their future uncertain. Trophy hunting programs are effective, yet not adequate to secure range wide populations of these iconic species. These species carry global conservation significance and are vital for local economies. For example, revenue from trophy hunting program is estimated at 500,000 US$ per annum in GB. Loss of these invaluable creatures means jeopardizing integrity of delicate mountain ecosystems. Thus, a long-term

conservation strategy is required to safeguard future of wild ungulates, which is based on species ecology, existing and emerging threats, and response of these species to climate change.

The Correct understanding of species distribution and habitat preferences is fundamental prerequisite for an effective conservation planning. Despite high biological and economic significance of wild ungulates in GB, they remained poorly studied. Particularly knowledge on their distribution and habitat requirements is dated and largely anecdotal. This risks spatial conservation efforts for wild ungulates in the province. This study was designed to fill this critical information gap.

Focusing on four key ungulates of GB: Himalayan ibex, blue sheep, Marco Polo sheep, and Kashmir musk deer, this study aimed to validate the current distributions of mountain ungulates in GB with empirical data, predict range shifts under climate change, and provide recommendations for landscape level management of wild ungulates in Pakistan.

Gilgit-Baltistan province was surveyed with multiple methods (Questionnaire, sign surveys, visual counts, and camera trapping) to record occurrence of target species. I developed predictive models for mountain ungulates distribution using presence locations and environmental covariates. Possible shifts in ranges were also investigated under various climate change scenarios predicted by the Intergovernmental Panel on Climate Change (IPCC).

Himalayan ibex was the widely distributed wild ungulate in GB with an estimated suitable habitat of 26,500 km^2 (37.71% of the province) followed by Kashmir musk deer with 9,115.52 km^2 (12.52%), blue sheep with 6,500 km^2 (9.26%), and Marco Polo argali 78.3 km^2. Habitat for Himalayan ibex was spread across all mountain ranges, though contagious patches existed only in Karakoram-Pamir range. Main stronghold for the Kashmir musk deer occurred mostly in the Himalayan range and limited part of the Hindu Kush. Blue sheep was also in Karakoram-Pamir range, Marco Polo sheep existed only in Pamir range. Himalayan ibex, Kashmir musk deer, and blue sheep were still occupying a large part of their historical range, while Marco Polo sheep's range was reduced and was only confined to Karachanai Nullah of Khunjerab National Park. Similarly major portion of current surviving population of Kashmir musk deer existed in Astor and Diamer districts. Habitat selection of mountain ungulates was significantly influenced by climatic and terrain features, and each species exhibited specific niche in terms of habitat covariates. Mountain ungulates also adjusted site use in presence of predator.

Himalayan ibex was most impacted species by climate change as it will lose most of its current range (56% and 58%), the blue sheep which will also lose 33.70% to 64.80% under moderate to severe representative concentration pathways (RCPs). If IPCC's climate change prediction holds, Himalayas and Hindu Kush will become unsuitable for the Himalayan ibex, and its suitable habitat will be concentrated in the Karakoram range. Contrary to ibex, blue sheep will extend its range towards Baltoro glacier in Baltistan. In conclusion, Karakoram-Pamir will serve as climate refugia for ibex and blue sheep, and Himalaya is expected same for the musk deer.

The results of this study are relevant for protected areas planning and management in the province. The Karakoram-Pamir Mountain ranges carry high significance for long-term survival of several ungulates. Luckily a substantial part of these ranges is already protected under national parks regulations. To strengthen their effectiveness, we recommend improvement in management of these parks, improving connectivity among them and with protected areas in neighboring China. Unfortunately, good quality habitats (dense/Birch Forest) of musk deer are out of existing protected area network of the province, that risks survival and recovery of this species. We recommend creation of new national parks in the Himalayan range, particularly in Astor and Diamer districts to safeguard high quality musk deer habitat from further deterioration.

CHAPTER ONE

GENERAL INTRODUCTION

1 GENERAL INTRODUCTION

1.1 WHAT ARE UNGULATES?

'Ungulate' (/ˈəŋgjələt, -ˌleɪt) is a generic term for hooved mammals that originated from the Latin word *ungula,* meaning 'hoof.' Ungulates consist of two orders of the class *Mammalia* of kingdom *Animalia,* i.e., *Artiodactyla* (even-toed ungulates like pigs or cattle) or *Perissodactyla* (odd-toed ungulates like horses and donkeys). Combined, the two orders represent 243 species, including 221–227 species of *Artiodactyla* and 16 species of *Perissodactyla* (Hutchins et al., 2003a). 'Herbivore' is used as a synonym for 'ungulate,' as it describes all animals that are exclusively herbivorous and have hooves (Hutchins et al., 2003b).

1.2 IMPORTANCE OF UNGULATES

Ungulates are the most primitive form of wild animals associated with humans, and gradually became part and parcel of human life as food, in agricultural practices, and as a means of transportation. The members of *Perissodactyla,* i.e., equids, have been providing transportation for centuries, while the horns of rhinoceroses were used in medicine and to make weapons (Gross, 2018). The order *Artiodactyla* provides four of the world's most important domestic animals, i.e., cattle, sheep, goats, and water buffalos. Unlike *Perissodactyls, Artiodactyls* are used for meat and dairy products, while their large horns were also used for weaponry (Bellezza, 2002). In some cultures, *Artiodactyl* parts were used for medicine. The members of *Caprinae,* which are the mandate of this study, have been a source of meat, dairy products, and wool for rugs and cloth. Ibex body parts have had great value in medicinal use even the blood of some animals like serow and goral has been used for medicinal purposes. The members of *Caprinae* were traditionally valued for their large, elegant horns, and still are. This provides an opportunity for local communities to offer their *Ovis* and *Capra* species to outside hunters, who, in return, pay thousands of dollars as a reward to these communities for their conservation efforts. Trophy hunting programs are now a multi-million-dollar industry and help poor communities in social development (Khattak et al., 2019). In other parts of the world, especially Africa, bushmeat is a source of livelihood for rural communities (Alexander et al., 2015) and a source of food during shortages and famines (Mwakatobe et al., 2012).

Ungulates also benefit humans indirectly in many ways. As the major herbivores in many ecosystems, they act as keystone species and have vital effects on vegetation development and on forest, woodland, and grassland productivity. As outputs of ecosystems, they serve as regulators of many important ecosystem processes at multifaced spatial and temporal scales by acting as agents of changes in the environment, creating spatial heterogeneity, accelerating successional processes, and controlling the switching of ecosystems between alternative states (Hobbs, 1996). Ungulates play an important role in nitrogen fixation and cycling, which influence plant size and morphology (Singer et al., 2003). Ungulate grazing affects the structure, biomass, and type of vegetation to burn, and hence regulates the dynamics of fire (Hobbs, 1996). They are also crucial prey for all major carnivores (Suryawanshi et al., 2012), which helps maintain ecosystem functions (Karanth et al., 2004).

1.3 SPECIES OF THE STUDY AREA

Pakistan is home to seven species of wild ungulates with as many as eleven subspecies (Hess et al., 1997). Six of these, the Astore markhor *(Capra falconeri falconeri),* Himalayan ibex *(Capra ibex sibirica),* Ladakh urial *(Ovis vignei vignei),* Marco Polo sheep *(Ovis ammon polli),* Kashmir musk deer *(Moschus cupreus),* and blue sheep *(Pseudois nayyaur)* occur in Gilgit-Baltistan (GB) (Ali and Din, 2013).

1.3.1 Himalayan ibex

1.3.1.1 Taxonomy

Capra ibex sibirica, commonly known as the Himalayan ibex, Asiatic ibex, or Siberian ibex (Dzięciołowski et al., 1980; Fox et al., 1992; Khan et al., 2016), hereinafter referred to simply as 'ibex,' belongs to the family *Bovidae,* subfamily *Caprinae,* tribe *Caprini,* and genus *Capra* (Fedosenko and Blank, 2001). Ibex have four sub-species, the Alpine ibex *(Capra ibex ibex)* (Parrini et al., 2009), Nubian ibex *(Capra ibex Nubian),* Walia ibex *(Capra ibex walia),* and Himalayan, Siberian, or Asiatic ibex *(Capra Ibex sibirica)*

(Hutchins et al., 2003b). Researchers are still unsure whether *Capra sibirica* is distinct from other ibex, some use the name *Capra [ibex] sibirica,* while some regard this as a separate species (Heptner et al., 1988; Schmid et al., 1993). (Fedosenko and Blank, 2001) recognized four subspecies of *Capra ibex sibirica,* i.e., *C. sibirica hagenbecki* in Mongolia's Gobi Desert, *C. sibirica* in the Altai Mountains, *C. sibirica alaiana* in the Tien Shan range, and *C. sibirca sakeen* in the Pamirs, Hindu Kush, and Karakorum. Another species was recognized in the Kunlun Mountains near its junction with the Karakorum and Pamirs by (Sung, 1998; Xie, 2008). *Capra ibex sibirica* was listed as 'near threatened' in the IUCN Red List by (Reading et al., 2020).

1.3.1.2 Physical features

The ibex is considered the largest and heaviest species in the genus *Capra* (Fedosenko and Blank, 2001) because of its long horns and body weight (Hutchins et al., 2003b). Both sexes have beards on their short and broad faces, but male beards are longer. Horn size and shape and pelage color make ibex dimorphic; their pelage color varies around the year. Males (Plate 1.1) become striking dark brown with a white saddle—in some males, whitish areas are also present on the shoulders, abdomen, legs, and thighs in winter. The pelage of females becomes more grey-brown with less conspicuous whites on their bodies (Roberts, 1997; Schaller, 1977). Male ibex horns are scimitar-shaped. In the Himalayas, the mean horn size may be 128 cm, with a maximum size of 140 cm. The interior surfaces of horns are relatively flat. Prominent transverse ridges bar the horn from serving as single smooth/flat surface externally (Schaller, 1977). Usually, two ridges or knobs grow on male horns each year between two and nine years. A prominent ridge or knob is usually linked with superior nourishment (Heptner et al., 1988; Schaller, 1977). The horns in female ibex are thin and may be straight or slightly diverging. They are nearly round in cross-section and lack distinct markings or ridges, despite being shorter than male horns. The female ibex's horns are reported to be the longest amongst *Capra* females (Plate 1.2), with reports of up to 24 cm in the Himalayas, 29 cm in Tien Shan (Schaller, 1977), and 31 cm in Pin Valley (Bhatnagar, 1997). An adult ibex male weighs roughly 130 kg (Hutchins et al., 2003b), while an adult female weighs roughly 50–60 kg, which is 1.5–2 times less than an adult male. The shoulder height of an adult male is about 100 cm, and that of a female is

70 cm (Heptner et al., 1988; Schaller, 1977). The head-to-tail length of male ibex is 171 cm (Hutchins et al., 2003b). The head and horns of a male constitute 6–8% of total weight (Schaller, 1977).

Yearling males roughly equal adult females in body size and horn length. However, they tend to have thicker horns and darker bodies. Yearling females are over half the size of adult females and have thin, short horns measuring *ca.* 10–15 cm (Schaller, 1977). Like all other *Capra,* ibex have a potent body odor, callus on their knees, and lack pre-orbital, inguinal, and pedal glands (Nadler et al., 1974; Schaller, 1977).

Plate 1.1. A herd of male ibex sighted during the study in Khunjerab National Park in 2017.

Plate 1.2. A female ibex with her kids sighted in Khunjerab National Park in 2017.

1.3.1.3 Global distribution

Ibex occur in the mountains of central and middle Asia, southern Siberia, and the northwestern Himalayas (Figure 1.1) of Mongolia, Russia, China, Kazakhstan, Kyrgyzstan, Afghanistan, Pakistan, and India (Schaller, 1977). In Mongolia, ibex are present along the entire Altai and Gobi Altai ranges; on the main ridges of the Hangai ranges of central Mongolia; on the Turgen Uul ranges of northwest Mongolia; on Lake Khovsgol; and many isolated mountains in the Transaltai (Bannikov, 1954; Mallon et al., 1997). In Russia, ibex inhabit the mountain ranges of southern Siberia, Altai and Sayan, Tuva, Southeastern Altai, Katunskiy, and Argut; and the Chuiskiy ranges (Fedosenko and Blank, 2001). In China, ibex are confined to the northwest in the mountains surrounding Xinjiang, northern Gansu, Inner Mongolia, and extreme northwestern Tibet (Sung et al., 1997). In Tajikistan, ibex are distributed in the mountain ranges of Hissar and Pamir (Meklenburtsev, 1949). In Kyrgyzstan, they inhabit central and western Tien Shan and the northern Pamir (Alai range) Terskei Alatau range. In Uzbekistan, ibex occur in west Tien Shan (Weinberg et al., 1997). In Kazakhstan, ibex are numerous in southeastern and eastern

Kazakhstan, mostly on the Tien Shan range, but make occasional visits to the Tarbagatai-Saur mountains of eastern Kazakhstan from China (Fedosenko and Blank, 2001). In Afghanistan, ibex are found throughout the Hindu Kush mountains of the Badakshan, Hazarajat, Spinghar, and Kohe Baba ranges near Kabut, Feroz Koh in the northeast; in northern Nuristan and the mountains of Badakhshan, including Darwaz; throughout the Pamirs in glaciated ranges south of the Wakhan River, and mountains to the borders with Iran and Turkmenistan. (Fedosenko et al., 1992). In India, *Capra sibirica* is distributed in the mountain ranges of the Karakoram, Himalayas, and Trans-Himalayas of Jammu, Kashmir, Himachal Pradesh, and Ladakh; and in the east along the Sutlej River (Bhatnagar, 1997; Schaller, 1977).

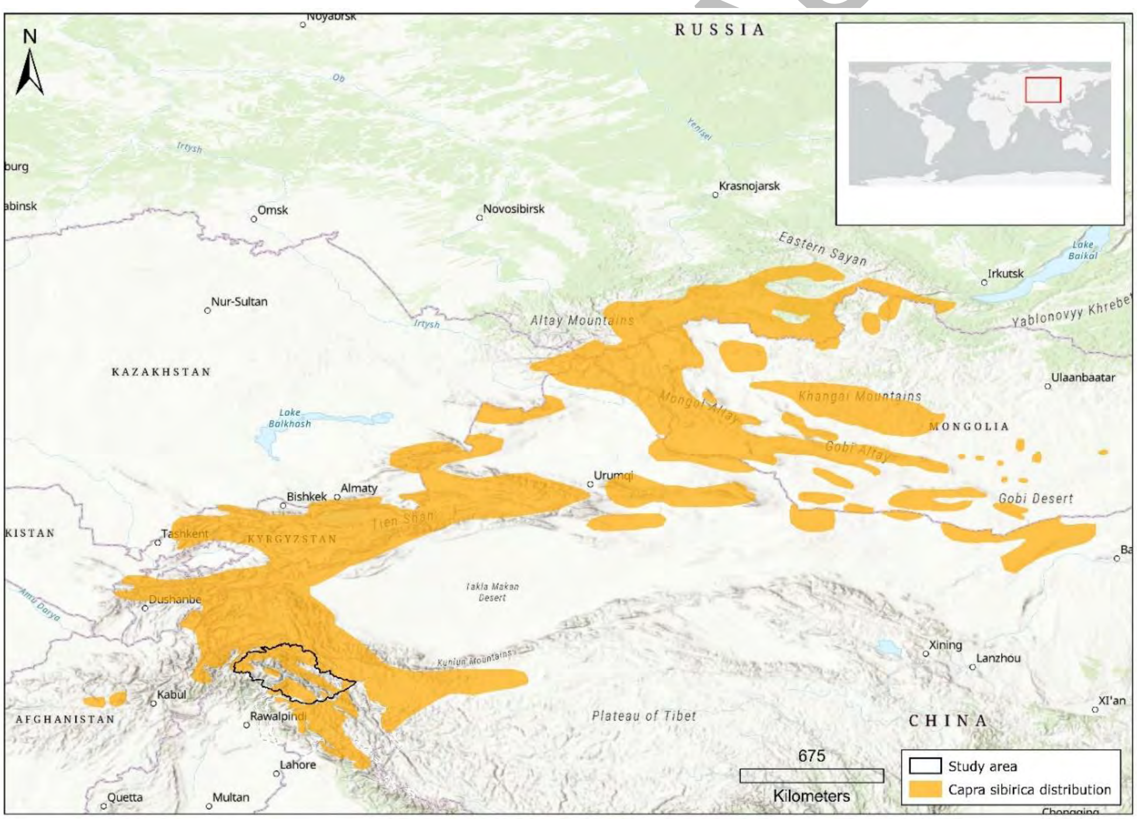

Figure 1.1. *Capra ibex sibirica*: IUCN's global distribution in the study area.

1.3.1.4 Distribution in Pakistan

Ibex are the most numerous and widely distributed wild ungulates in Pakistan (Hess et al., 1997). They are reported to occur in all the major mountain ranges of northern Pakistan (Schaller, 1977) (Figure 1.1). Roberts (1997) consolidated the ibex distribution range reported by many authors and noticed that ibex were widespread throughout the higher mountain ranges of Gilgit, Diamer, Ghizer, and Baltistan districts; the northern part of Chitral, Dir, Swat, Kohistan, and Mansehra districts; and the northern part of Azad Jammu and Kashmir. Khan et al. (2014) confirmed the presence of ibex in ten districts of GB. Hameed (2010) counted 174 ibex in Chitral district in the watersheds of Bashqar Gol, Rezhun Gol, Phargram Gol, Shachu Gol/Shahdas Gol, and in Shandur. (Ali et al., 2007) counted 122 ibex in the Upper Neelum valley, especially in the Shouter valley. However, there are no new reports on ibex presence in Dir, Swat, Mansehra, and Kohistan districts.

1.3.2 Blue sheep

1.3.2.1 Taxonomy

The blue sheep (*Pseudois nayaur*), also known as *bharal,* is considered an intermediary between the goat and sheep, in habits and physical structure. Its behavior and habitat requirements are like that of goats (Schaller, 1973). Blue sheep belong to the genus *Pseudois* of the family *Bovidae.* Two subspecies have been identified despite the unresolved nomenclature of the dwarf blue sheep, which is mentioned as *Pseudois schaeferi* by (Sung, 1998) and *Pseudois nayaur schaeferi* by (Shackleton, 1997) . (Harris, 2014) considered *P. nayaur* and *P. schaeferi* as separate species based on a genetic analysis by (Zeng et al., 2008) and (Tan et al., 2012). Blue sheep are listed as 'least concern' species in the IUCN Red List by (Harris, 2014).

1.3.2.2 Physical features

Blue sheep are relatively small bovids—their body size, horn size and structure, and pelage make them a dimorphic species. Males (Plate 1.3) weigh 60 - 75 kg and females weigh 35 - 45 kg (Schaller, 1977). Male horns are smooth and curved up, out, and then backward, while females (Plate 1.4) have small, short, and rather stout horns that are almost nonfunctional. Pelage color is gray to state gray in winter but has a sandy tinge in summer. Males have a black line along the flanks and a black chest and throat. Both sexes have a black front surface to the legs with white knees (Hutchins et al., 2003b).

Blue sheep are considered aberrant goats with sheep-like affinities as they lack beards and calluses on their knees. They have no strong body odor. They have flat, broad tails with a bare ventral surface, conspicuous markings on their forelegs, and large dew claws which liken them to goats (Schaller, 1977).

Plate 1.3. A herd of male blue sheep sighted in Shimshal valley in 2019.

Plate 1.4. A female blue sheep with her lamb sighted in Shimshal valley in 2019.

1.3.2.3 Global distribution

Blue sheep are found in China, Bhutan, India, Nepal, and Pakistan (Figure 1.2) at altitudes of 3,500–5,500 m (Schaller, 1977) in the Tibetan Plateau and its bordering ranges. Their distribution range extends from the Karakoram mountains of northeastern Pakistan along the northern side of the Himalayas from where it penetrates to the southern side of its range in a few places, and then northeastwards into Inner Mongolia (Hutchins et al., 2003b).

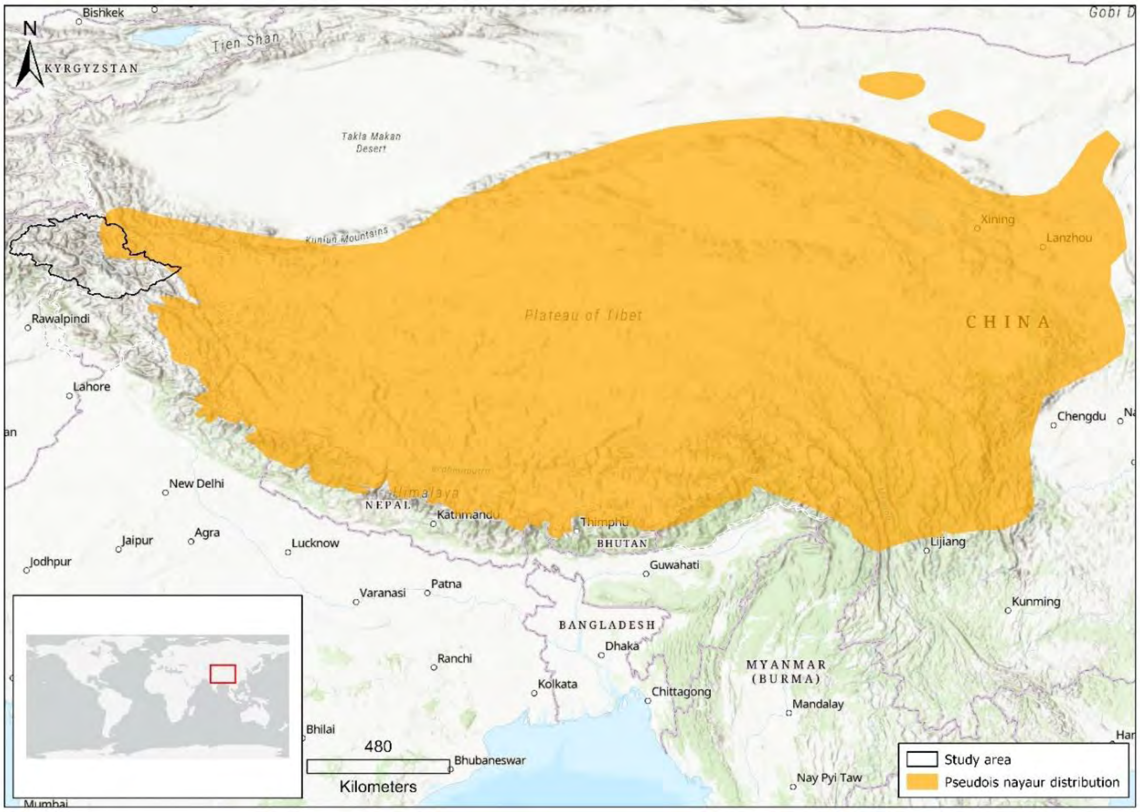

Figure 1.2. *Pseudois nayaur*: IUCN’s global distribution in the study area.

1.3.2.4 Distribution in Pakistan

In Pakistan, blue sheep are endemic to GB and found only in the Shimshal Valley and Sockterabad *Nullah* of Khunjerab (Khattak et al., 2019). Roberts (1997) mentioned the sighting records of Schaller on the Baltoro glacier in Shigar district. However, there is no current evidence of this.

1.3.3 Marco Polo sheep

1.3.3.1 Taxonomy

The Marco Polo sheep (*Ovis ammon polii*) is a subspecies of argali (Ali et al., 2019) and named after the famous Italian traveler, Marco Polo, who first mentioned this magnificent sheep to Europeans in 1273 (Schaller, 1977). Despite uncertainty in the number of *Ovis ammon* subspecies, the Caprinae Specialist Group endorses (Fedosenko and Blank, 2005a;

Wilson and Reeder, 2005) who described nine species of *Ovis ammon,* namely *Ovis ammon ammon* (Altai argali), *Ovis ammon collium* (Kazakhstan argali), *Ovis ammon darwini* (Gobi argali), *Ovis ammon hodgsoni* (Tibetan argali), *Ovis ammon jubata* (North China argali), *Ovis ammon karelini* (Tien Shan argali), *Ovis ammon nigrimontana* (Karatau argali), *Ovis ammon polii* (Marco Polo sheep or Pamir argali), and *Ovis ammon severtzovi* (Severtzov's argali) (IUCN, 2015). The *Ovis ammon polii* belongs to the family *Bovidae* of genus *ammon.* The status of subspecies *Ovis ammon polii* is not assessed separately (Ali et al., 2019), but *Ovis ammon* is reported as a 'near threatened' species in the IUCN Red List of threatened species (IUCN, 2015).

1.3.3.2 Physical features

Ovis ammon is the largest species in the genus *Ovis.* It is stout-bodied but lacks heavily built muscle, and has a short body, thick neck, light bones, and robust legs (Fedosenko and Blank, 2005b). *Ovis ammon* males (Plate 1.5) have the longest horns amongst sheep species, the long spiraling horns of Marco Polo sheep have been measured up to 140 cm (55 inches) or, as has been said, as long as six palms in length (Roberts, 1997; Schaller and Kang, 2008). Ewes have laterally compressed, smaller and thinner saber-like horns, the tops of which are directed backwards and out (Fedosenko and Blank, 2005b). Hence, horns are the most distinctive dimorphic features of *Ovis ammon.* Male *Ovis ammon* weigh up to 200 kg, while females (Plate 1.6) weigh around 75 kg. *Ovis ammon polii* has a pale grayish-brown body sometimes sprinkled with whitish hairs. The elbow to flank runs a slightly darker, broad stripe, dividing the body color from the lighter underparts (Schaller, 1977).

Plate 1.5. A herd of male Marco Polo sheep sighted at Khunjerab National Park in 2012.

Plate 1.6. A female Marco Polo sheep sighted at Khunjerab National Park in 2012.

1.3.3.3 Global distribution

Marco Polo sheep live in open and broad valleys and alpine pastures with rolling hills and mountains with gradual sides in Central Asia, including Afghanistan, Tajikistan, China, Kyrgyzstan, and Pakistan (Schaller, 1977; Schaller and Kang, 2008) (Figure 1.3). This sheep's habitat is climatically harsh due to elevations of 3,500–5,200 m in snow-capped mountains with short growing seasons (Haider et al., 2018). These locations were, however, strategically important for separating the former British India and Union of Soviet Socialist Republics (USSR) (Habib, 2006). In Afghanistan, they live in the Wahkhan Corridor, especially in the Pamir valleys of Ali Su and Wagjir (Habib, 2006; Schaller, 2004). In China, they occur in the Taxkorgan Valley. In Tajikistan, they are present in most of the eastern parts of the country that border Xinjiang of China, west Langar of Afghanistan, and Altyn Mazar of Kyrgyzstan. In Kyrgyzstan, Marco Polo sheep are present in the southeastern and eastern parts toward the Chinese border from

Kazakhstan in the north, to Tajikistan in the south, and in the western parts of Tien Shan along the Uzbek border (Fedosenko and Blank, 2005b).

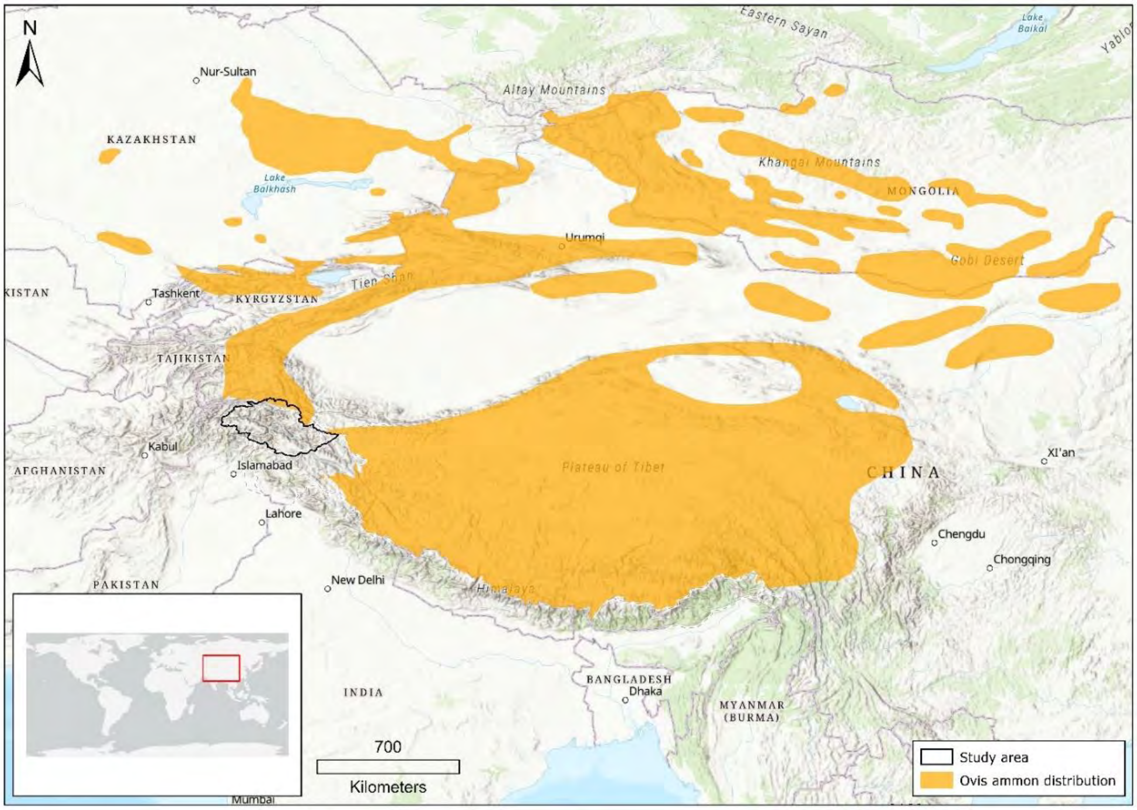

Figure 1.3. *Ovis ammon polii:* IUCN's global distribution in the study area.

1.3.3.4 Distribution in Pakistan

In Pakistan, Marco Polo sheep were historically reported from the Khunjerab top area and the Kilik and Mintika passes in Misgar Valley (Rasool, 1990; Schaller, 1977) in the extreme north of district Hunza (Figure 1.3). They have not been sighted in the Kilik and Mintika *Nullahs* by (Ali et al., 2019; Schaller, 1976). Currently, they make sporadic visits for lambing to the Karachanai watershed of Khunjerab National Park (Ali et al., 2019; Haider et al., 2018; Schaller and Kang, 2008).

1.3.4 Musk deer

1.3.4.1 Taxonomy

The musk deer *(Moschus spp),* also known as 'roze' in the study area, is a deer-like member of the family *Moschidae* (Green, 1986). It has a confounding taxonomy and was first classified into a single species, i.e., *Moschus moschiferus* and placed in two groups, namely *sibirica* with four subspecies and *Himalaica* with three subspecies. Musk deer are believed to originate from the Tibetan plateau. An mtDNA analysis suggested six species for *Moschus* (Pan et al., 2015), although an earlier assessment by (Groves and Grubb, 2011) suggested seven species, namely the alpine musk deer *(Moschus chrysogaster),* black musk deer *(Moschus fuscus),* forest musk deer *(Moschus berezovskii),* Himalayan musk deer *(Moschus leucogaster),* Anhui musk deer *(Moschus anhuiensis),* Kashmir musk deer *(Moschus cupreus),* and Siberian musk deer *(Moschus moschiferus).*

The Kashmir musk deer was first described as a subspecies of the Alpine musk deer *(Moschus chrysogaster)*. Researchers who produced seminal works on the ungulates of the subcontinent used the common name 'Himalayan musk deer' and scientific name *Moschus chrysogaster* for the Kashmir musk deer, e.g., (Roberts, 1997; Schaller, 1977). However, (Groves et al., 1995) treated the Kashmir musk deer as a separate species, which was then also adopted by the IUCN's Red List data book and listed Kashmir musk deer as 'endangered' (Timmins and Duckworth, 2015). The study area is inhabited by Kashmir musk deer, so 'musk deer' will be used for 'Kashmir musk deer.'

1.3.4.2 Physical features

The stockily built musk deer was considered the smallest ungulate of the Himalayas by (Schaller, 1977). Unlike other ungulates, musk deer lack horns and antlers. Males (Plate 1.7) possess tusk-like teeth formed by the elongation of the upper canines. They protrude below the lip of the lower jaw. These teeth are not well developed in females (Plate 1.8). Musk deer have a height of 50 cm at the shoulders (Sathyakumar et al., 2015) and a weight of 13–14 kg; both sexes weigh roughly the same (Schaller, 1977). They have large ears like those of hares, and their hind legs are larger than the forelegs (Schaller, 1977), enabling jumping movements like kangaroos. One significant difference is that males' preputial glands secrete musk or have musk pods, but females lack pods (Green, 1986; Sathyakumar et al., 2015).

Musk deer have a grey-brown color which is vaguely spotted with a conspicuous, coppery-reddish, un-speckled dorsal saddle. The ramp is dark grey with light grey underparts. They have white throats, and the lower segments of their limbs are whitish. The white base and dark brown color of their ears gives them a frosted look. Compared to other musk deer species, they have short hairs with long white bases (Sathyakumar et al., 2015).

Plate 1.7. A Kashmir musk deer, camera trapped in Kalapani Valley, district Astor in 2013.

Plate 1.8. A female Kashmir musk deer, camera trapped in Rupal Valley, district Astor in 2019.

1.3.4.3 Global distribution

The seven species of musk deer are distributed in eleven countries of South Asia i.e., Afghanistan, Bhutan, Nepal, China, India, Myanmar, Pakistan, Vietnam, Mongolia, Russia, and Korea, where they occupy the alpine forested and scrub habitats of the mountains of Asia (Green, 1986; Sathyakumar et al., 2015). The alpine musk deer is present in Bhutan, China, India, and Nepal. The black musk deer is distributed in China, Bhutan, Myanmar, Nepal, and India. The forest musk deer occurs in China and Vietnam. The Himalayan musk deer is present in India, Nepal, and Bhutan. The Anhui musk deer occurs in China only. The Kashmir musk deer is distributed in Afghanistan, Pakistan, and India. The Siberian musk deer is present in China, Mongolia, Russia, and Korea (Green, 1986; Groves and Grubb, 2011; Sathyakumar et al., 2015; Timmins and Duckworth, 2015) (Figure 1.4).

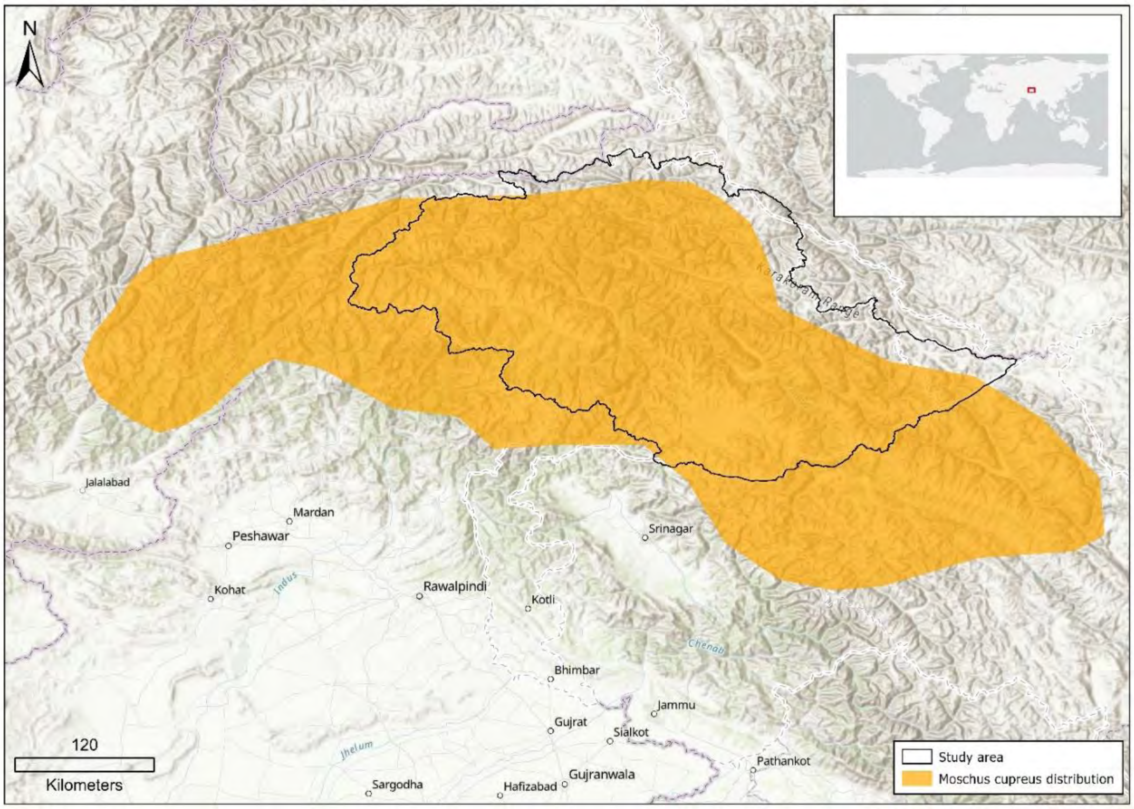

Figure 1.4. *Moschus cupreus: IUCN's global distribution in the study area.*

1.3.4.4 Distribution in Pakistan

Musk deer in Pakistan are reported from subalpine scrub at elevations of 3,000 - 4,000 m close to the tree line in patches of birch *(Betula utilis),* although they have also been reported in patches of Persian juniper *(Juniperus polycarpos)* in Gilgit (Roberts, 1997). Musk deer were reported as a common species in Gilgit, Astor, and Chilas (Green, 1986). Large numbers were observed in GB, especially in Hushey Valley. Roberts (1997) reported them in the Drosh Valley of Chitral, in the Indus Kohistan, and a sparsely distributed population in Kaghan Valley.(Ahmad, 1981) found signs of musk deer in the Panjkora Valley of Dir Kohistan, while (Roberts, 1997) reported them in Salkhalla Sanctuary (Green, 1986). In Azad Jammu and Kashmir, musk deer were reported in good numbers in

Machiara National Park (Green, 1986; Qamar et al., 2008; Roberts, 1997). They also occur in the Neelum Valley and Musk Deer National Park (Khan et al., 2006; Qureshi et al., 2013) (Figure 1.4).

1.4 EMERGING THREATS TO MOUNTAIN UNGULATES

The mountain ranges of the Himalayas, Hindu Kush, Karakoram, and Pamirs rose from the sea during the Tertiary Era (Windley, 1988) and supported two distinct groups of ungulates, i.e., one group on flat and rolling uplands (wild yaks, Tibetan argali, kiangs, and chirus) and another in rugged terrain (ibex, markhor, and musk deer) (Schaller, 1977). The species in both groups co-evolved over centuries by adjusting their resource use and anti-predatory behavior to ensure survival and evolutionary fitness (Favre et al., 2015; Ray, 1960; Wen, 2014). This resulted in adaptability in body size as well, although contemporary increases in human population did not allow these species to extend their ranges. In the last two centuries, rapid human development resulted in encroachment into wild habitats, multiplying harm and disturbance in the form of habitat degradation, deforestation, and reduction in food availability. Studies showed that manmade disturbances have population level consequences on wild animals (Polfus and Krausman, 2012), with higher chance of range contraction and lower chance of persistence in the altered habitat (Laliberte and Ripple, 2004), by pushing animals out of the suitable habitats to colder and dryer habitats (Pineda-Munoz et al., 2021). Animals are resilient to a selective pressure e.g., population of many ungulates' species recovered when poaching was controlled from few (Virk, 1999) to hundreds (Ahmad et al., 2020; Haider et al., 2021; Khattak et al., 2019), but if impacts of rapid population growth has not checked, then it could have devastating impacts on native fauna (Taylor-Brown et al., 2019) and may revert the conservation efforts made thus far.

Earlier practices of basic resource extraction were significantly less harmful as they did not affect biodiversity as a whole (Jacobson et al., 2019). In the late 20th century, humans focused on industrial development that resulted in the production of synthetic products as extracts of natural yields. Human quest for industrial supremacy resulted in the excessive use of fossil fuels (Barroso, 2020), which resulted in excessive releases of carbon dioxide and other gases into the atmosphere. These gases trap escaping infrared radiation which then re-radiates in all directions in the atmosphere, including the earth's surface. This subsequently warms the earth at lower atmospheric surface—the greenhouse effect, a precursor of climate change (Cassia et al., 2018; Hughes, 2000; Mitchell, 1989; Rosenthal et al., 2007).

Climate change has become a reality as it is impacting biodiversity in an alarming manner (Walther et al., 2002). The loss of biodiversity is predicted to continue in the 21st century (Solomon et al., 2007) through climate variability, including temperature, precipitation, and their interaction. It is estimated that 47% of threatened terrestrial mammals and 24% of threatened birds have been negatively impacted by climate change in at least some part of their distribution ranges (Pacifici et al., 2017). Climate change is impacting both individual species and entire ecosystems by changing phenology and population dynamics (Scheffers et al., 2016). In some parts of South and Central Asia, these ecosystems provide an estimated economic value of USD 3,622 per household/year through provisioning services (Murali et al., 2017).

Humans are bearing the climate change brunt of their own activities (Scheffers et al., 2016). Each year, the resulting variability in climatic processes manifests in the form of torrential rains and disastrous floods that incur billions of dollars of loss (Looney, 2012; Rehman et al., 2015).

Species are being affected by shifts in both the mean and variability of climate elements, including temperature, precipitation, and their interaction. Species that are effectively able to respond to climate change do so by distributional or phenological shifts, acclimating, or adapting. Evidence of these responses to recent climate change is rapidly accumulating across taxa and regions, inspiring research into predicting future ecological and evolutionary responses. Majority of mountain ungulates in Central and South Asia are severely affected by the climate change (Aryal et al., 2016; Holt et al., 2018; Hu and Jiang, 2011; Luo et al., 2015), and adapt by moving towards the poles (Hickling et al., 2005). Such areas are considered to future refugia (Li et al., 2016), and identifying such areas is of the utmost importance for long-term conservation of mountain ungulates.

Various prediction techniques use statistical or mechanistic approaches to estimating species niches and examining shifts in these niches through climate change. Species distribution modelling (SDM) and global circulation models (GCMs) have made it possible for wildlife managers/conservationists and scientists to foresee the dire situations that these species could face in future and predict the space or habitat they could then use.

1.5 AIMS AND OBJECTIVES OF THE STUDY

GB has been referred to as a living museum of wildlife in Pakistan because it is home to viable populations of many species of carnivores, e.g., snow leopards, brown bears, black bears, Himalayan lynx, leopard cats, Pallas's cats, grey wolves, and red foxes, and ungulates like Astor markhors, Himalayan ibex, blue sheep, Kashmir musk deer, Ladakh urials, and Marco Polo sheep. Carnivores inflict heavy losses in the form of livestock depredation on local communities, while ungulates are coveted trophies that attract foreign hunters who pay substantial fees to hunt these animals legally. Eighty percent of these fees go directly to local communities for socio-development (Haider et al., 2021). The lost-and-gain concept in GB has eventually protected wildlife from direct anthropogenic threats in the form of severe poaching faced in the past, either as retaliatory killing, for food, or for selling horns and pelts (Haider et al., 2021).

However, the impacts of indirect anthropogenic threats like habitat fragmentation, grazing pressure, and climate change are in full force. The impacts of climate change are more pronounced in the Hindu Kush and Himalayas where glacier masses are shrinking (Mayewski et al., 2020). By contrast, anomalies have been reported from the Karakoram range where glacier masses are relatively stable (Farinotti et al., 2020; Hewitt, 2005). Most of the protected areas in northern Pakistan are part of these mountain ranges and will be the sole habitat for wildlife in the future. Therefore, using the latest techniques like MaxEnt and occupancy models, my study first predicts the current distribution of four wild ungulates of different genera in different habitats. Next, I study the site use of the most numerous and economically important species of the study area. Finally, I assess the impact of climate change on species of different origins and habitat requirements.

Focusing on four key ungulates of GB; Himalayan ibex, blue sheep, Marco Polo sheep, and Kashmir musk deer, this study aimed to achieve following specific objectives:

1) Validate the current distributions of mountain ungulates in Gilgit-Baltistan with empirical data.
2) Establishing how changing climate will impact the distribution of wild ungulates in northern Pakistan.
3) Provide recommendations for informed management of wild ungulates in northern Pakistan

1.6 STRUCTURE OF THE THESIS

This Ph.D., thesis comprises five chapters. Chapter one is a general introduction that introduces the ungulate species of the study, including their distribution and physical features. Chapters two to five are the study's objectives written in the form of independent research articles. The data collection and statistical methods used are described in each chapter along with findings and recommendations.

CHAPTER ONE introduces ungulates and describes the taxonomy, physical features, and global and Pakistani distribution of four species. This is followed by a discussion of the threats these ungulates face, i.e., climate change. The chapter concludes with the rationale for the study, its objectives, and an introduction to the study area.

In **CHAPTER TWO,** I predict current suitable habitats for two ungulates, the blue sheep and ibex, using a MaxEnt model and GCMs. I predict the impact of climate change on these species in two time slices (2050 and 2070) using representative concentration pathways (RCPs) viz., RCP 4.5 and RCP 8.5. Then, using SDMtoolbox, I predict the habitat loss and gain by two species in 2050 and 2070. Finally, the chapter assesses the niche overlap between both species in the future.

In **CHAPTER THREE,** I present distribution of Kashmir musk deer in northern Pakistan, which was constructed through predictive modelling on presence points acquired through multiple methods (questionnaire, sign surveys, and camera trapping).

In **CHAPTER FOUR,** I report the distribution of Marco Polo sheep using three techniques, i.e., camera trapping, the double-observer method, and sign surveys.

In **CHAPTER FIVE,** I investigate how ungulates live in prey-abundant habitats using a multi-species occupancy model in the “unmarked” package of R (statistical software) to investigate prey and predator response. I use an Akaike Information Criteria (AIC) value to select the best-fit model.

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Ali, H., Din, J.U., Bosso, L., Hameed, S., Kabir, M., Younas, M., Nawaz, M.A., 2022. Expanding or shrinking? Range shifts in wild ungulates under climate change in Pamir-Karakoram mountains, Pakistan. PLoS One 16, e0260031. https://doi.org/10.1371/journal.pone.0260031.

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1.8 STUDY AREA

This study investigated four ungulate species with different behaviors and habitat requirements, namely the Himalayan ibex, blue sheep, Marco Polo sheep, and Kashmir musk deer, which occur in the mountain ranges of northern Pakistan, i.e., the Pamir-Karakoram, Hindu Kush, and Himalayas (Figure 1.5) within the administrative boundaries of GB.

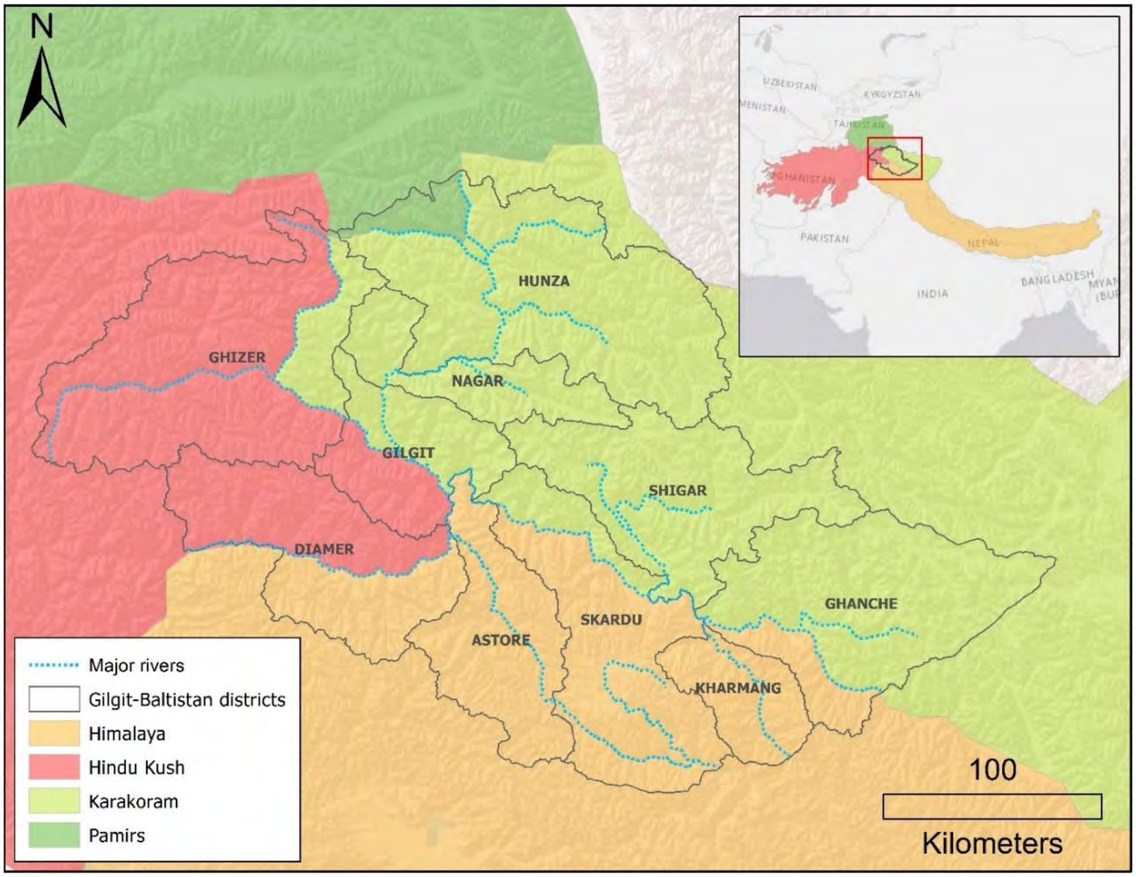

Figure 1.5. Mountain ranges in the study area.

Research was conducted in GB, (Figure 1.6), formerly known as the 'northern areas,' which encompasses an area of 72,791 km^2 (Kazim et al., 2015) and is dominated by large swaths of barren land, rugged mountains, lush green pastures, sporadically distributed forest patches that cover 1,582 km^2 (Qamer et al., 2016), agricultural lands, and the largest glacial system outside the polar regions (Joshi et al., 2013). Administratively, GB is divided into the divisions of Diamer, Baltistan, and Gilgit. These divisions have been further divided into ten districts, i.e., Astor, Diamer, Ghizer, Gilgit, Ghanche, Hunza, Nagar, Shigar, Karmang, and Skardu (Figure 1.6). GB shares borders with districts Kohistan, Swat, and Chitral of Khyber Pakhtunkhwa, and district Neelum of Azad Jammu and Kashmir nationally and internationally. It is bordered by Afghanistan in the north and west, China in the north and east, and India in the south (Joshi et al., 2013) (Figure 1.6).

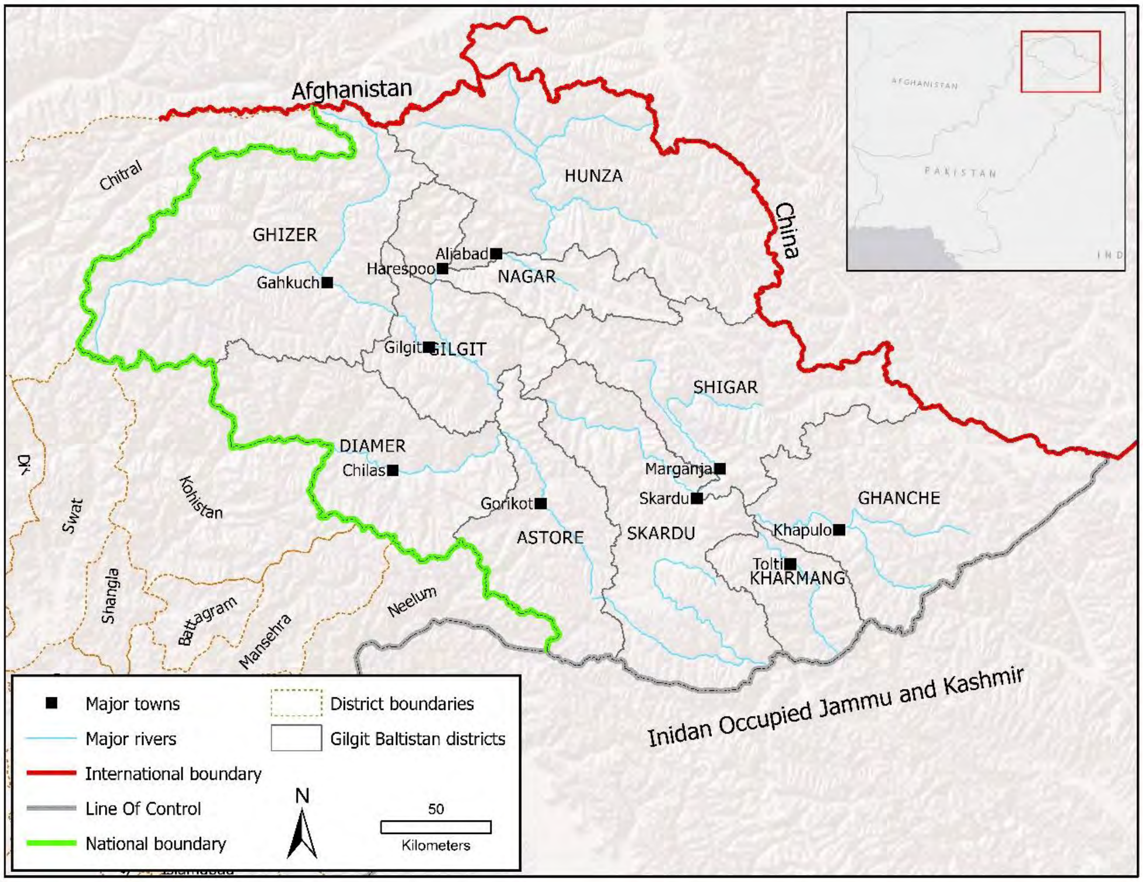

Figure 1.6. Administrative map of the study area.

Most households own small pieces of inherited agricultural land that is used to grow mainly wheat, potatoes, and barley. Grazing lands or pastures are communal (Gioli et al., 2014).

Besides housing 1.8 million humans, GB is home to diverse flora and fauna. The varied climatic conditions and altitudinal range have shaped five ecological zones dominated and characterized by their vegetation (Roberts, 1997). The zones include montane dry sub-tropical, montane dry temperate, montane dry northern scrub, subalpine, and alpine (Roa and Marwat, 2003). The important flora and fauna of these ecological zones are as follows:

1.8.1 Flora

The major woody plants of the study area are deodar *(dedrus deodara)*, blue pine *(Pinus wallichiana),* fir *(Abies spectabilis),* spruce *(Picea simithina),* chilgoza *(Pinus gerardiana),* juniper *(Juniersu* spp*),* oak *(Quercus ilex),* poplar (*Populus* spp)*,* willow (*Salix* spp)*,* and birch *(Betula utilis)*. Major shrubs include wormwood (*Artemisia* spp), joint pine (*Ephedra* spp), guelder rose (*Vibernum* spp), beard grass (*Andorpogon* spp), common barbery (*Berbris* spp), Japanese honeysuckle (*Lonicera* spp), and Lucia gooseberry (*Ribes* spp) (Roa and Marwat, 2003).

1.8.2 Fauna

GB is truly a living museum of wild fauna. It is home to sizeable populations of all extant local species, including the snow leopard *(Panthera uncia),* Himalayan brown bear *(Ursus arctos isabellinus),* Asiatic black bear *(Ursus thibetanus),* grey wolf *(Canis lupus),* red fox *(Vulpes vulpes),* Himalayan lynx *(Lynx lynx),* Pallas's cat *(Otocolobus manul),* leopard cat *(Prionailurus bengalensis),* stone martin *(Martes foina),* weasel (*Mustela altaica*), Himalayan ibex *(Capra ibex sibirica),* blue sheep *(Pseudois nayyaur),* Astor markhor *(Capra falconeri falconeri),* Ladakh urial *(Ovis vignei vignei),* Marco Polo sheep *(Ovis ammon polii),* and Kashmir musk deer (*Moschus cupreus*) (Virk et al., 2003). GB's diverse habitats provide either primary or migratory habitats for more than 230 species of birds (Roberts, 1991). However, the arid habitat is poor for amphibians, of which there are just six species. Reptile species, on the other hand, are well represented by 23 species (Masroor, 2011; Virk et al., 2003). Aquatic fauna include 20 species of fish, including 17 native species, of which four are endemic to GB and three are exotic species that have well-established themselves in the study area (Hassan et al., 2007; Rafique, 2001).

1.8.3 Climate

GB's climate is dry continental Mediterranean. It is divided into three distinct climate regions viz., mild, cool, and cold. Based on precipitation, it is classified into arid, semi-arid, and undifferentiated highlands. Chilas is the hottest place in GB, while Skardu and Astor are the coldest. July is the hottest month of the year where the maximum temperature would soar to 40°C. The mean temperature remains around 27.2°C. January is the coldest month where the maximum temperature remains around 11.1°C and the minimum temperature is -7.6°C. Mean annual precipitation is 20.8 cm, April receives the most precipitation (3.5 cm) and November receives the least (0.5 cm) (Khan et al., 2020).

1.8.4 Socioeconomic conditions

GB's human settlements are sparsely distributed. The rugged terrain makes it difficult for the government to provide equal standards of civic facilities. This topographic constraint has left many areas deprived of modern technologies and infrastructure like roads, schools, medical facilities, and electricity.

About 80% of GB's population is agro-pastoralist (B. Khan et al., 2014). Agriculture uses two percent of the total land area. Rangelands occupy almost 23% while protected land for rearing 1,918,839 animals occupies 9%. This includes 434,851 heads of cattle, 16,314 yaks, 2,263 buffalos, 506,155 sheep, 931,821 goats, 5,097 horses, 186 camels, 21,138 donkeys, and 1,014 mules (GOP, 2006). Arable land is used to cultivate crops like wheat, maize, barley, and potatoes, and fruits like apricots, apples, cherries, and walnuts. Potatoes are the main cash crop, while apricots and cherries yield good returns that farmers use to purchase basic commodities or meet children's educational expenses many local people see education as a means of improving living standards.

GB's harsh climate, rough topography, and lack of suitable roads, reliable communication lines, and electrical power do not allow particularly good opportunities for industry, so local people rely on small businesses like shops. However, GB's diverse topography, including glaciers, lakes, rivers, and alpine pastures, and pleasant weather have turned it into a top destination for local and international tourists. Many local people earn good incomes from hotels and guest houses, as guides and porters, and from transportation (Baig and Hussain, 2020; Nigar, 2018).

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CHAPTER TWO

RANGE SHIFTS IN WILD UNGULATES UNDER CLIMATE CHANGE IN PAMIR-KARAKORAM MOUNTAINS, PAKISTAN

2 RANGE SHIFTS IN WILD UNGULATES UNDER CLIMATE CHANGE IN, PAMIR-KARAKORAM MOUNTAINS, PAKISTAN

ABSTRACT

Climate change is expected to impact a large number of organisms in many ecosystems, including several threatened mammals. A better understanding of climate impacts on species can make conservation efforts more effective. The Himalayan ibex (*Capra ibex sibirica*) and blue sheep (*Pseudois nayaur*) are economically important wild ungulates in northern Pakistan because they are sought-after hunting trophies. However, both species are threatened due to several human-induced factors, and these factors are expected to aggravate under changing climate in the High Himalayas. In this study, we investigated populations of ibex and blue sheep in the Pamir-Karakoram mountains to (i) update and validate their geographical distributions through empirical data; (ii) understand range shifts under climate change scenarios; and (iii) predict future habitats to aid long-term conservation planning.

Presence records of target species were collected through camera trapping and sightings in the field. We constructed Maximum Entropy (MaxEnt) model on presence record and six key climatic variables to predict the current and future distributions of ibex and blue sheep. Two representative concentration pathways (4.5 and 8.5) and two-time projections (2050 and 2070) were used for future range predictions. Our results indicated that ca. 37% and 9% of the total study area (Gilgit-Baltistan) was suitable under current climatic conditions for Himalayan ibex and blue sheep, respectively. Annual precipitation was a key determinant of suitable habitat for both ungulate species.

Under changing climate scenarios, both species will lose a significant part of their habitats, particularly in the Himalayan and Hindu Kush ranges. The Pamir-Karakoram ranges will serve as climate refugia for both species. This area shall remain focus of future conservation efforts to protect Pakistan's mountain ungulates.

Keywords: Himalayan ibex, global circulation model, MaxEnt, niche overlap, blue sheep, species distribution model.

2.1 INTRODUCTION

Climate change has impacted ecosystems in unprecedented ways globally (Parmesan and Yohe, 2003; Walther et al., 2002), and appears to be unrelenting. These impacts are further complicated by rapid economic growth (Hu and Jiang, 2011) and increasing human populations, especially in developing countries (Ahlburg et al., 2013; Schneider et al., 2011).

Pakistan is a developing country and ranks as the seventh most vulnerable country to climate change (Eckstein et al., 2017). Extreme temperatures, heavy rainfall, and floods are devastating several ecosystems in the country (Looney, 2012; Rehman et al., 2015). Climate change impacts are most frequent in Pakistan's northern mountain ranges, including the Pamir-Karakoram, Himalayas, and Hindu Kush (Ishaq et al., 2015) where increasing temperatures, changes in cropping season, receding glaciers or outbursts, and heavy flooding (Ahmad et al., 2012; Akhtar et al., 2008; Ashraf et al., 2012; Joshi et al., 2013; Tahir et al., 2015, 2011) are leading to the extinction of several plant and animal species (Kulkarni et al., 2013; Xu et al., 2009). These mighty mountains are a source of fresh water for half of South Asia (Bolch et al., 2012; Kumar et al., 2015) and home to many floral and faunal species (Schild, 2008). Furthermore, the Himalayas and Hindu Kush act as a barrier to monsoon rains (Li et al., 2016) which helps the Karakoram range maintain its aridity. Highest and steepest among other ranges, the Karakoram is expected to be the one which is least affected by climate change (Forsythe et al., 2017).

Several species of wild ungulate, including the markhor (*Capra facolneri facolneri*), Ladakh urial (*Ovis vignei vignei*), Marco Polo sheep (*Ovis ammon polii*), Kashmir musk deer (*Moschus cupreus*), Himalayan ibex (*Capra ibex sibirica*), and blue sheep (*Pseudois nayaur*) live in these mountains. They play an important role in sustaining mountain ecosystems by influencing vegetation structure, plant composition, and nutrient recycling, in addition to being prey for carnivores (Bagchi and Ritchie, 2010). However, climatic variations in recent years have impacted many ungulate species (Hu and Jiang, 2011), and such impacts could have devasting effects on the ecosystem, including the carnivore community (Laws, 2017). Climate studies in the Himalayas (Aryal et al., 2016), western

Tian Shan and Kyrgyz Alatau mountain ranges in Kazakhstan (Holt et al., 2018), Ghats in India (Sony et al., 2018), and Tibetan plateau in China (Luo et al., 2015) report climate change to be a serious threat to wild ungulates, leading to many species' extinction (Aryal et al., 2016; Hu and Jiang, 2011; Sony et al., 2018).

The Himalayan ibex is the most common of six wild ungulates in Pakistan. Its range historically extended from Swat to Khunjerab, although it has shrunk to the extreme northern parts of the country (Hess et al., 1997). It is found in relatively arid precipitous mountain ranges living well above the tree line at elevations of 3,500–5,000 m (Roberts, 1997). The species does not enter forest zones, preferring steep escape terrain (Fedosenko and Blank, 2001). On the other hand, the blue sheep or *bharal* (Khattak et al., 2019), an intermediate species between the goat and sheep (Schaller, 1977) is found in less precipitous areas compared with ibex, at altitudes of 3,500–5,500 m in slopes covered with grasses and sedges, preferably with a southern-east exposition (Schaller, 1973; Wilson, 1981).

The persistence of mountain ungulates like the Himalayan ibex and blue sheep in northern Pakistan is important because they are coveted trophies for hunters whose license fees help impoverished communities, who, in turn, help conserve biodiversity in far-flung areas (Khattak et al., 2019). Conservation planning that targets the long-term survival of these species is not only important from a nature perspective but is also vital for local human populations. Such planning must be informed by both current occurrence and future distribution of these iconic species in response to climate change. Currently, wild ungulate distributions in Gilgit-Baltistan (GB), is only partially known, and knowledge of climate change-induced impacts on species and habitats is insufficient (Ishaq et al., 2015). We considered the ibex and blue sheep as model species to understand range shifts and other associated impacts of climate change on wild ungulates. The selected species represent two different groups—goats and sheep—and distinctive habitats. Inferences drawn from this study will, therefore, build knowledge for the informed management of wild ungulates in northern Pakistan. To achieve this objective, we used species distribution models (SDMs) which are widely adopted in investigations of species distribution and range shifts (Bosso et al., 2017; Mohammadi et al., 2019).

2.2 MATERIALS AND METHODS

2.2.1 Study Area

This study was conducted in Gilgit-Baltistan, Pakistan that lies between latitudes 36° N to 37° N and longitudes 74° E to 76° E, with an area ca. 72,791 km^2, dominated by glaciers and the snow-capped mountains of the Karakoram, Himalaya, Hindu Kush, and Pamir (Dani, 2001; Zain, 2010). The area is characterized by a variety of climatic conditions 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 (Zain, 2010). There are numerous (forest) plant species, including the deodar *(Cedrus deodara),* blue pine *(Pinus wallichiana),* fir *(Abies spectabilis),* spruce *(Picea smithina),* chilgoza *(Pinus gerardiana),* juniper *(Juniperus spp.),* and birch *(Betula utilis)* (Roa and Marwat, 2003), and 54 mammalian species (Virk et al., 2003), including rare ones (Roberts, 1997) like the snow leopard *(Panthera uncia),* Astor markhor *(Capra falconeri falconeri),* Ladakh urial *(Ovis vignei vignei),* Marco Polo sheep *(Ovis ammon polii),* grey wolf *(Canis lupus),* Himalayan lynx *(Lynx lynx),* brown bear *(Ursus arctos),* and musk deer *(Moschus spp.),* in addition to the previously mentioned Himalayan ibex and blue sheep.

2.2.2 Collection of Presence Records

Himalayan ibex and blue sheep presence points were collected using two methods: camera trapping and double observer surveys.

1) Camera trapping: I installed 225 (Reconyx HC 500 and HC 900; Reconyx, Holmen, USA) cameras during 2010–2016 for *C. ibex sibirica* and *P. nayaur*, in different months of the year i.e., Khunjerab National Park (KNP) (November to January, 2010 and September to November, 2011), in Qurumber National Park (QNP) (May to June 2012) in Misgar Valley (May to July, 2013), in Hopper and Hisper Valleys (March to May, 2016) Cameras were left operational for 10 days in the first camera trapping in KNP. But in the latter surveys they were left operational for 40 days to increase capture rate (Bischof et al., 2014; Kabir et al., 2017).

2) Double observer Surveys: I carried out this survey in 2012–2016 in different parts (KNP, Gojal Valley, Shigar Valley, in Skardu district, and in Gilgit district) of the study area by dividing it into smaller blocks based on watersheds. These watersheds were not larger than daily ungulate/human movement ability. Two observers were sent for survey separated by time (15 minutes) if only one trail was available, or by space, if two trails were available. Each watershed was surveyed by walking along pre-determined routes (Ali et al., 2019). The locations where Himalayan ibex and blue sheep were sighted, have been used as presence points to build the MaxEnt model.

This study collected 143 and 60 presence points for Himalayan ibex and blue sheep, respectively (Figure 2.1 A and B). Then that presence points were screened in ArcGIS 10.7 (ESRI, Redland, CA, USA) using *Nearest Neighbor Analysis* Tool to check spatial autocorrelation (Abellanas and Pérez-Moreno, 2018; Bosso et al., 2017; Kabir et al., 2017). This analysis revealed a high clustering among presence points. Aggregation was, therefore, spatially filtered using SDMTools (Boria et al., 2014) to ensure independence (Bosso et al., 2017; Kabir et al., 2017; Smeraldo et al., 2017) . This operation led to 36 and 29 presence points for Himalayan ibex and blue sheep, respectively, which I used in MaxEnt models (Figure 2.2).

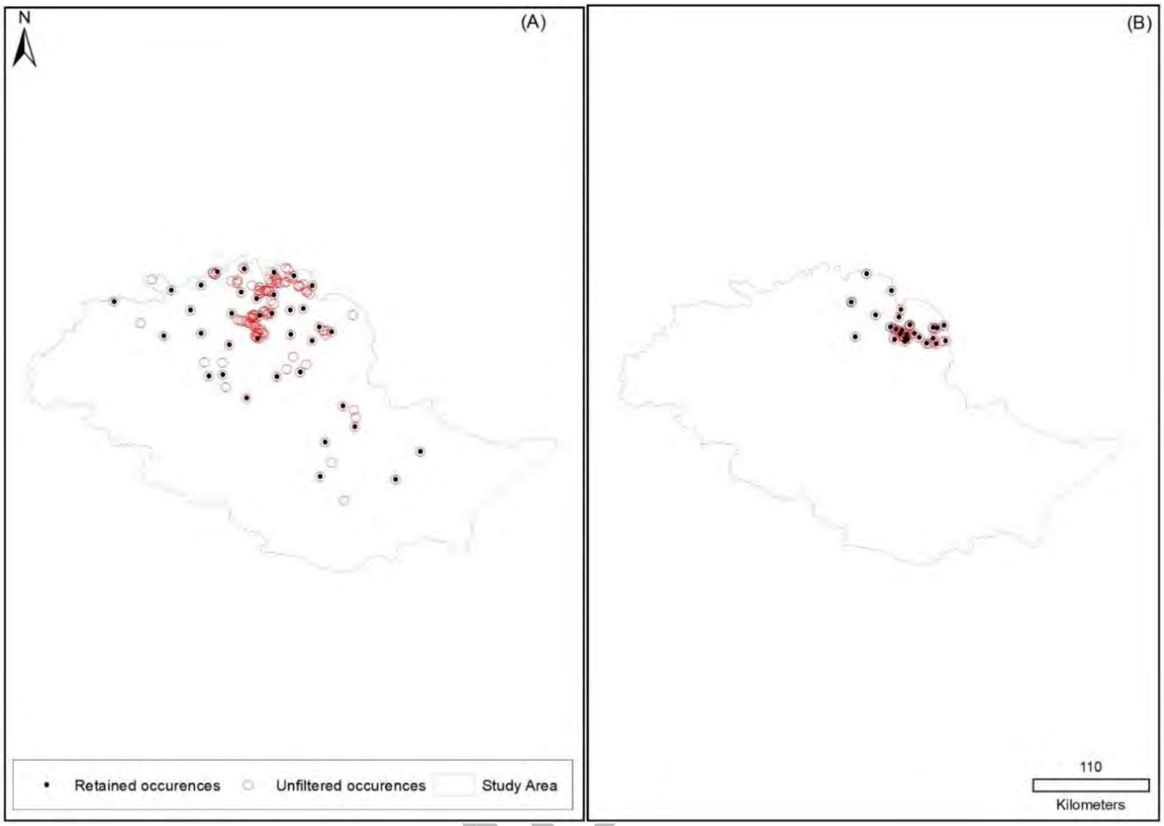

Figure 2.1. Unfiltered and retained occurrences used for the current study A) Himalayan ibex (total 143 points, retained points 36) B) Blue sheep (total 60 points, retained points 29) using SDMtoolbox V1.1(Brown, 2014).

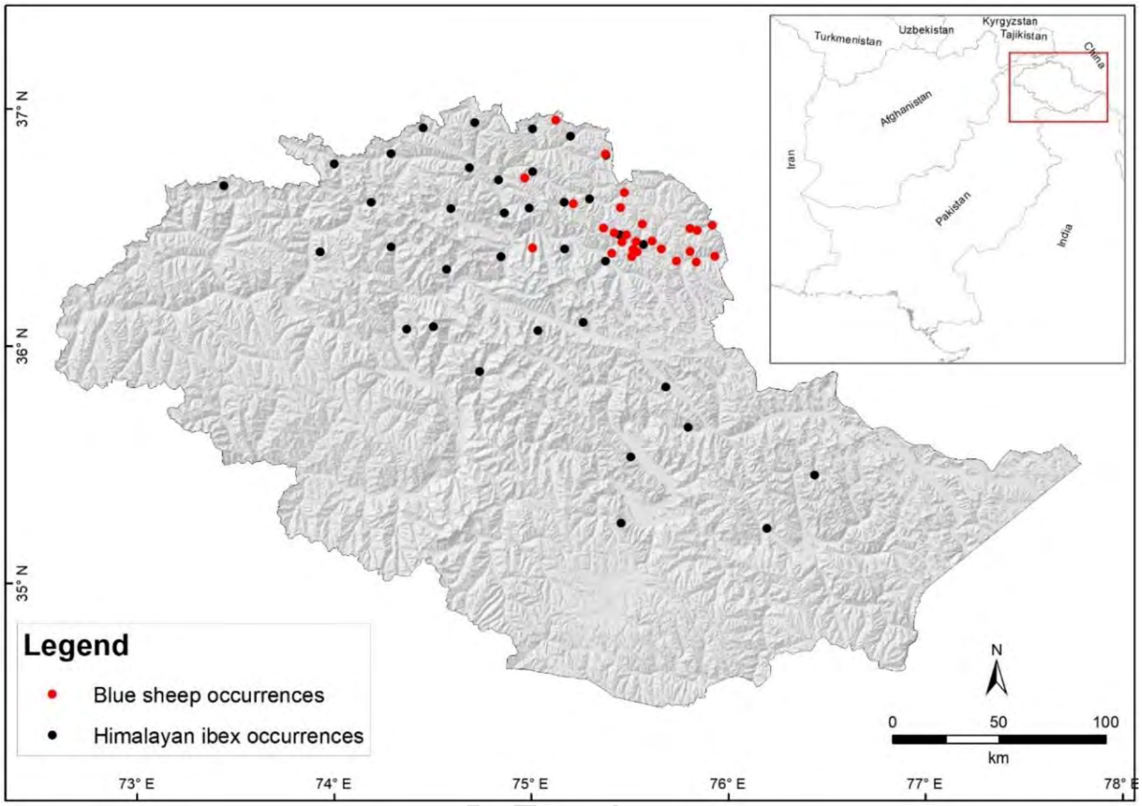

Figure 2.2. Sampling locations of Himalayan ibex and blue sheep in GB, Pakistan used to build model.

2.2.3 Climatic Variables

I downloaded 19 climatic variables (Table 2.1) from WorldClim 1.4 (https://www.worldclim.org/current) (Hijmans et al., 2005) to predict currently suitable areas for Himalayan ibex and blue sheep. All the variables were in raster files (grid) with 30-arc second resolution (0.93 × 0.93 km = 0.86 km^2 at the equator). We checked all variables for multicollinearity and excluded highly correlated variables i.e., r $\geq$ 0.70 (Pearson's correlation coefficient) (Kabir et al., 2017). This process led to use in the modeling analysis of six environmental variables: annual mean temperature (C°), mean diurnal range (°C), temperature seasonality [(standard deviation * 100) (°C)], mean temperature of wettest quarter (°C), annual precipitation (mm), and precipitation seasonality (%).

Table 2.1. List of environmental variables used in MaxEnt model (Asterisks indicates the variables used in the model).

S.N.	Covariates	Data format	Source
01	bio_01*	Annual Mean Temperature	WorldClim version 1.4
02	bio_02*	Mean Diurnal Temperature	WorldClim version 1.4
03	bio_03	Isothermally	WorldClim version 1.4
04	bio_04*	Temperature Seasonality	WorldClim version 1.4
05	bio_05	Max Temperature of Warmest Month	WorldClim version 1.4
06	bio_06	Min Temperature of Coldest Month	WorldClim version 1.4
07	bio_07	Temperature Annual Range	WorldClim version 1.4
08	bio_08*	Mean Temperature of Wettest Quarter	WorldClim version 1.4
09	bio_09	Mean Temperature of Driest Quarter	WorldClim version 1.4
10	bio_10	Mean Temperature of Warmest Quarter	WorldClim version 1.4
11	bio_11	Mean Temperature of Coldest Quarter	WorldClim version 1.4
12	bio_12*	Annual precipitation	WorldClim version 1.4
13	bio_13	Precipitation of Wettest Month	WorldClim version 1.4
14	bio_14	Precipitation of Driest Month	WorldClim version 1.4
15	bio_15*	Precipitation Seasonality	WorldClim version 1.4
16	bio_16	Precipitation of Wettest Quarter	WorldClim version 1.4
17	bio_17	Precipitation of Driest Quarter	WorldClim version 1.4
18	bio_18	Precipitation of Warmest Quarter	WorldClim version 1.4
19	bio_19	Precipitation of Coldest Quarter	WorldClim version 1.4

I used global circulation models (GCMs) MIROC5, BCC-CSM1-1, CCSM4, and HadGEM2ES to predict the future distribution of Himalayan ibex and blue sheep under climate change conditions. Various organizations developed these models under the Coupled Model Intercomparison Project, phase 5 (CMIP5) and are considered highly reliable (Bosso et al., 2017; Khan et al., 2018). The future projections of these GCMs are based on representative concentration pathways (RCPs) which are greenhouse gas (GHG) concentration trajectories on a range of radiative forces suggested in the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report (IPCC, 2014). I used RCP 4.5 and RCP 8.5 the former is a moderate GHG mitigation scenario (Archis et al., 2018) where emissions will peak around 2040 and then decline, while the latter is a scenario where GHG emissions will be the highest of all four RCPs (2.6, 4.5. 6.0 and 8.5) throughout the 21st century (Sony et al., 2018).

2.2.4 Modeling Procedure

I used MaxEnt ver. 3.4.1 (Phillips et al., 2017) to predict the current and future distribution of *C. ibex sibirica* and *P. nayaur* in Pakistan (Aryal et al., 2016). MaxEnt is a machine learning software used to develop SDMs (Balakrishnan et al., 2018; Byeon et al., 2018; Gomes et al., 2018) . It is capable of predicting species distribution using presence-only data (Elith et al., 2011) and predicting the distribution of poorly known species (Bosso et al., 2017; Raxworthy et al., 2003). I built the model using a logistic output format to yield environmental suitability ranging from 0 (unsuitable) to 1 (highly suitable) (Phillips and Dudík, 2008) . I fixed the regularization multiplier to 1, selected 5,000 iterations (Sony et al., 2018), and ran 20 replicates with cross-validations tests (Kabir et al., 2017).

Different GCM projections can have inherited uncertainties. To avoid this, I used area under the curve (AUC) scores as weighting coefficients that resulted from 20 cross-validations for each of four GCMs and produced a single forecast for each time scale by averaging all individual GCMs for that time slice. (Araújo et al., 2005; Araújo and New, 2007; Luo et al., 2015; Marmion et al., 2009). I used ten percentile training presence values as the threshold to develop binary presence/absence maps (Kabir et al., 2017).

The model was projected to entire GB. To project the models calibrated for survey area over entire GB, the variables in the projection area must meet a condition of environmental similarity with the environmental data used for calibrating the model. Therefore, I preliminarily ascertained that this condition was verified for both current and future projections by inspecting Multivariate Environmental Similarity Surfaces (MESS), the MESS calculates the similarity of each point in the region of projection to a set of reference points (e.g., background data) and maps the results (Elith et al., 2011) MESS maps produced by MaxEnt can help users identify extrapolated areas and provide a quantitative measure of projection uncertainty.

2.2.5 Model Validation

I tested the predictive performance of the models with different methods: receiver operated characteristics (ROC) curve, analyzing the AUC (Fielding and Bell, 1997), and the true skill statistic (TSS) (Allouche et al., 2006). AUC assesses models' discrimination ability with values ranging from 0 (equaling random distribution) to 1 (perfect prediction). TSS compares the number of correct forecasts minus those attributable to random guessing, to that of a hypothetical set of perfect forecasts. It considers both omission and commission errors and success because of random guessing. Its values range from -1 (a performance no better than random) to +1 (perfect agreement).

2.2.6 Niche Overlap

I calculated the niche overlap between *C. ibex sibirica* and *P. nayaur* for predicted habitats using ENMTools (Warren et al., 2008) in the current time and future climate change scenarios. ENMTools uses MaxEnt map values of habitat suitability for each grid and measures niche overlap using D and I values (Warren et al., 2008). It uses Schoener's D value to calculate niche overlap and gives probability distributions with values ranging from 0 (no overlap) to 1 (complete overlap). Similarly, Hellinger's I-statistic in ENMTools measures models' ability to estimate true suitability (Warren et al., 2008).

2.3 RESULTS

2.3.1 Model Performance

The AUC values for two current models were 0.969 ± 0.025 (Figure 2.3 A and B) and 0.821 ± 0.138 (Figure 2.4 A and B) for blue sheep and Himalayan ibex, respectively. TSS values were 0.841 ± 0.007 and 0.454 ± 0.281 for blue sheep and Himalayan ibex, respectively. Both tests suggest strong performances of our models.

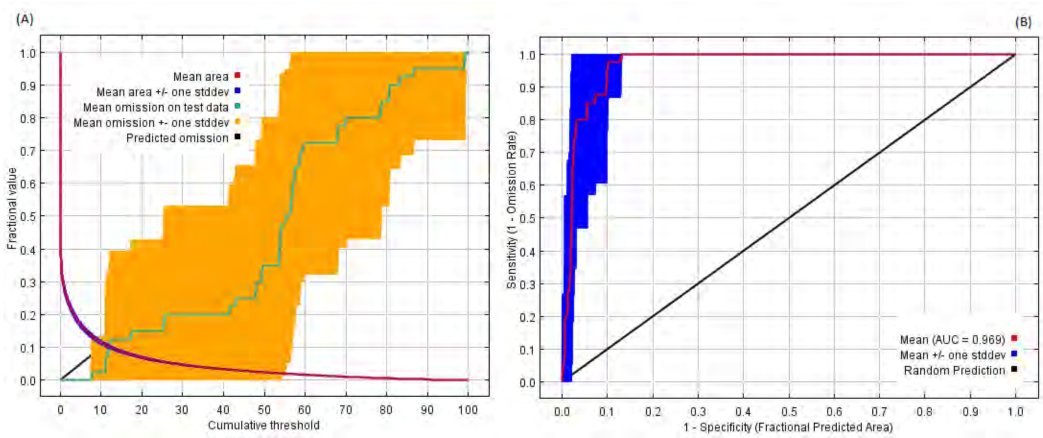

Figure 2.3. MaxEnt model evaluations (A) averaged omission rate and predicted area as a function of cumulative threshold (B) The (ROC) curve by defining specificity using predicted area, rather than true commissions, the averaged AUC value 0.969 for blue sheep.

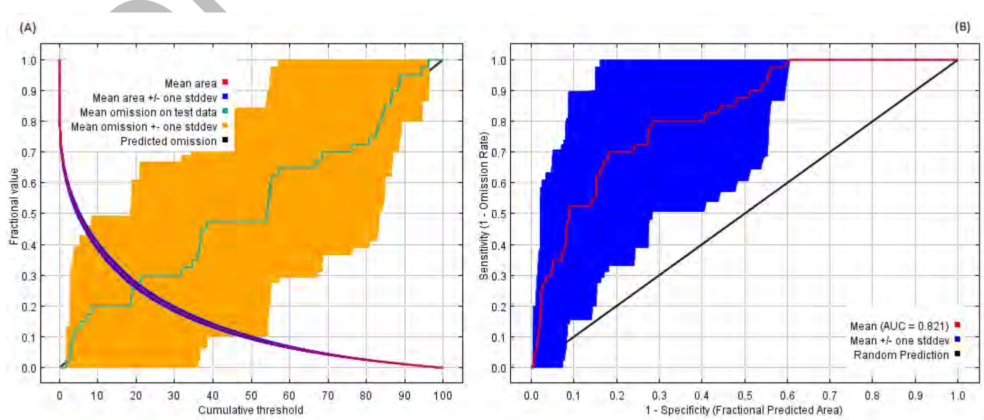

Figure 2.4. MaxEnt model evaluations (A) averaged omission rate and predicted area as a function of cumulative threshold (B) The (ROC) curve by defining specificity using

predicted area, rather than true commissions, the averaged AUC value 0.821 for Himalayan ibex.

2.3.2 Current Distribution of Himalayan Ibex and Blue Sheep

Our binary maps showed ca. 26 500 km^2 (37.71% of total study area) and ca. 6 500 km^2 (9.26% of total study area) suitable for Himalayan ibex and blue sheep, respectively (Figure 2.5).

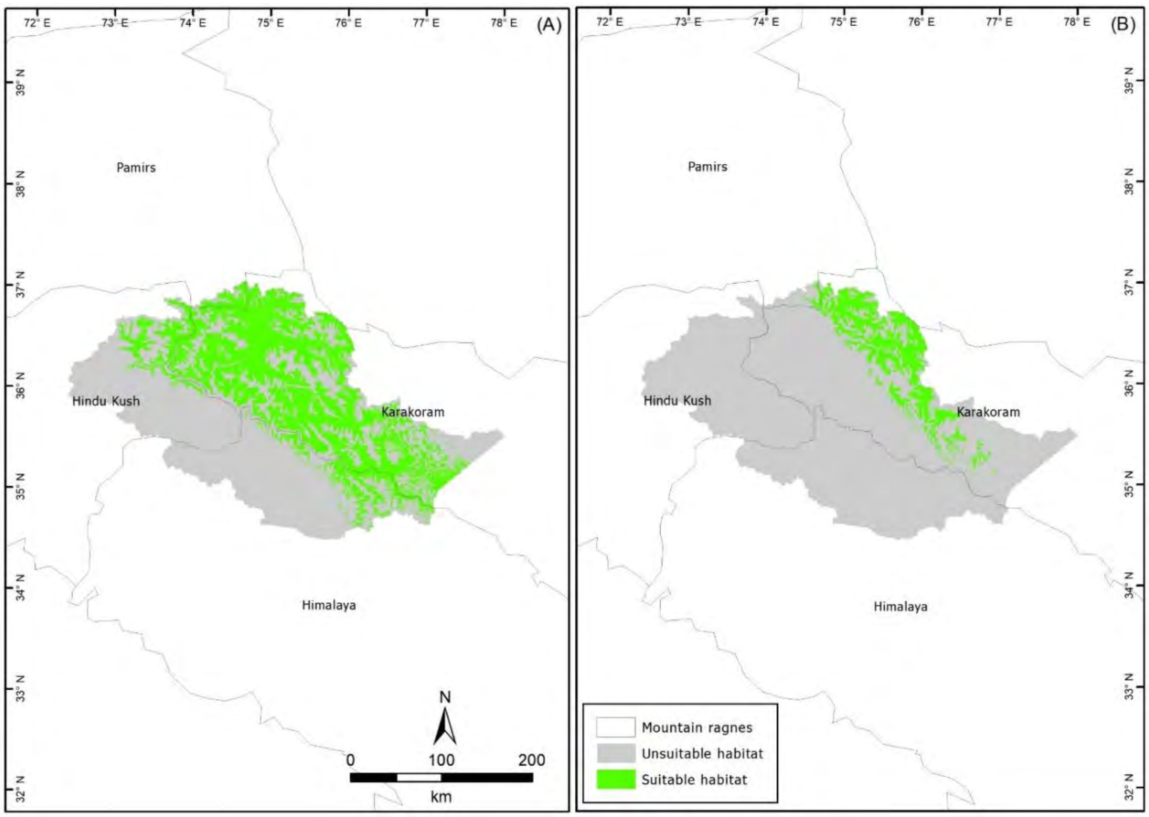

Figure 2.5. Binary maps of habitat suitability for Himalayan ibex (A) and blue sheep (B) under current climatic conditions.

I found that the current habitat predicted for Himalayan ibex included the latitudes from 34° to 37° and the longitudes from 73° to 77°. The most suitable habitats fell in the Karakoram range, followed by the Hindu Kush, and then to a minor extent in the Himalayas (Figure 2.5 A). The habitat suitability of Himalayan ibex was predicted in all ten districts of GB with strongholds in Hunza, Nagar, Shigar, and Ghanche districts. I found that habitats suitable to blue sheep were between the latitudes 35° to 37° and the longitudes 74° to 77° along the Pakistan-China border in the Pamir-Karakorum range that administratively falls in Hunza district, followed by some parts of the Shigar and Ghanche districts along the Pakistan-China border (Figure 2.5 B). I found that annual precipitation, mean temperature of the wettest quarter, and temperature seasonality were the most important variables (with 91.6% contribution) in predicting suitable habitats for blue sheep (Table 2.2 and Figure 2.6), the model predicted high probability of having suitable habitat for blue sheep in areas where annual rainfall was 0 mm to 80 mm (Figure 2.7 A) and in areas where the mean temperature during the wettest season ranged from -25°C to 10°C (Figure 2.7 B). For ibex, annual precipitation, and annual mean temperature were key habitat predictors with an 89% contribution (Table 2.3 and Figure 2.8). The probability of having suitable habitat for ibex was high in areas where annual rainfall was around 90 mm (Figure 2.9 A) and in areas where annual mean temperature ranged from -15°C to 15°C and was maximum where it was between 0°C to 10°C (Figure 2.9 B).

Table 2.2. Estimates of relative contributions of the environmental variables used to build MaxEnt model for blue sheep.

Variable	Percent Contribution	Permutation Importance
bio_12	65	77.3
bio_08	22.8	4.1
bio_04	3.8	0.9
bio_15	3.3	0.5
bio_01	2.8	6.1
bio_02	2.3	11.1

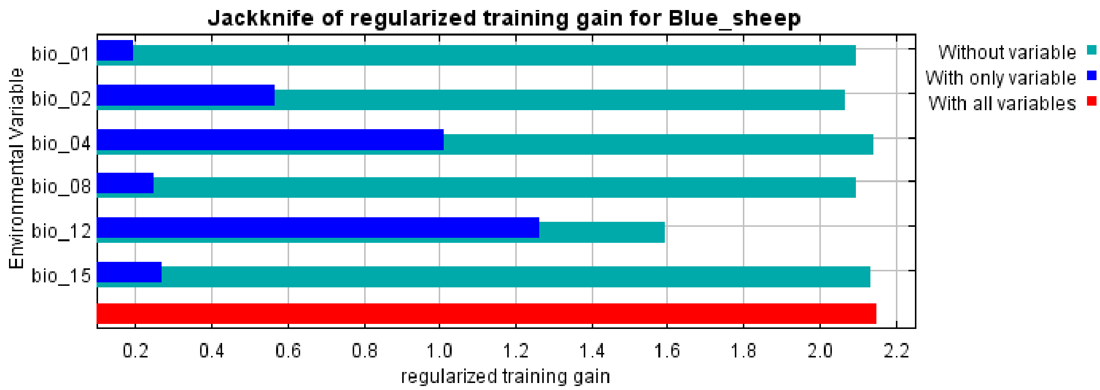

Figure 2.6. Jackknife analysis of variables importance, showing importance of each variable in predicting blue sheep presence 1) how the model's training gain effected when each variable was omitted (aqua blue), 2) when each variable was used separately how it affected the training gain (cobalt blue), 3) total model gain (Red). It further showed that bio_12 was the most useful variable, when used in isolation the model gain increased, and when it was omitted the model gain decreased as bio_12 had most important information that other variables were lacking.

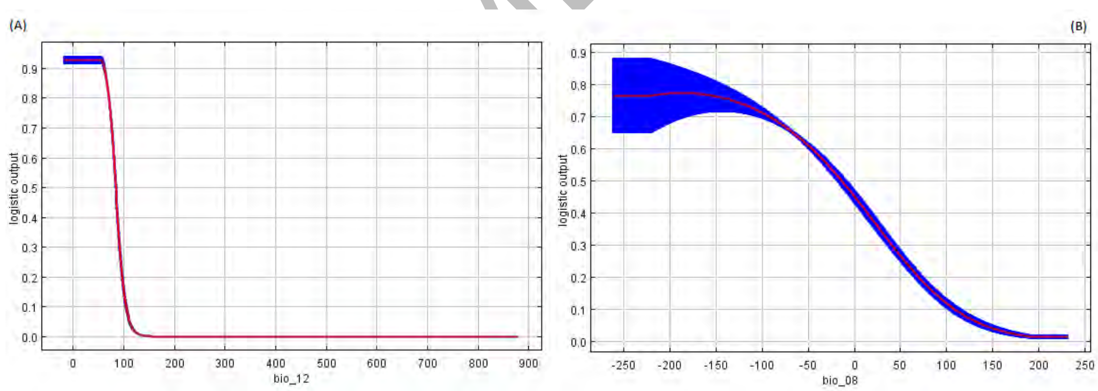

Figure 2.7. Response curves (A) Annual Precipitation (bio_12), (B) Mean Temperature of Wettest Quarter (bio_08) in predicting probability of blue sheep presence. The red line is mean value, while cobalt blue shades show standard deviations from mean value of variable.

Table 2.3. Estimates of relative contributions of the environmental variables used to build MaxEnt model for Himalayan ibex.

Variable	Percent Contribution	Permutation Importance
bio_12	42.7	56.6
bio_01	23.2	24.4
bio_15	23.2	7.5
bio_04	5.8	4.8
bio_08	3.3	2.7
bio_02	1.8	4.1

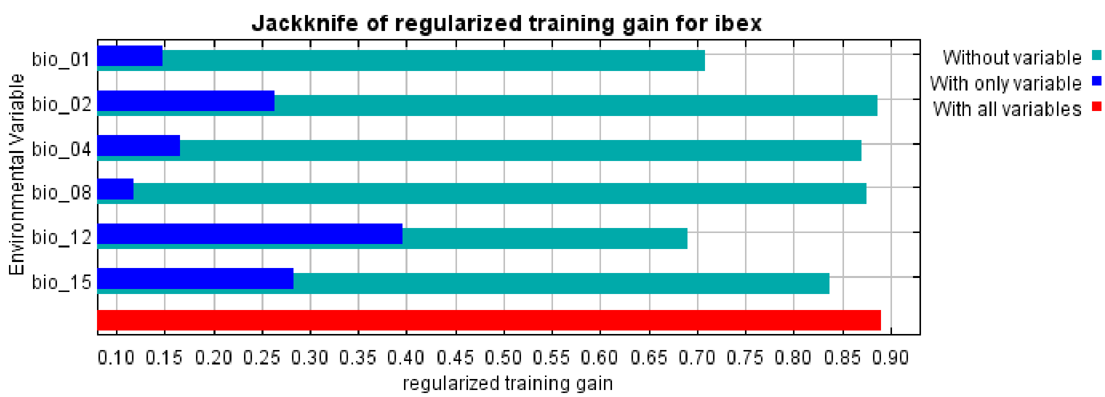

Figure 2.8. Jackknife analysis of variables importance, showing importance of each variable in predicting blue sheep presence 1) how the model's training gain effected when each variable was omitted (aqua blue), 2) when each variable was used separately how it affected the training gain (cobalt blue), 3) total model gain (Red). It further showed that bio_12 was the most useful variable, when used in isolation the model gain increased, and when it was omitted the model gain decreased as bio_12 had most important information that other variables were lacking.

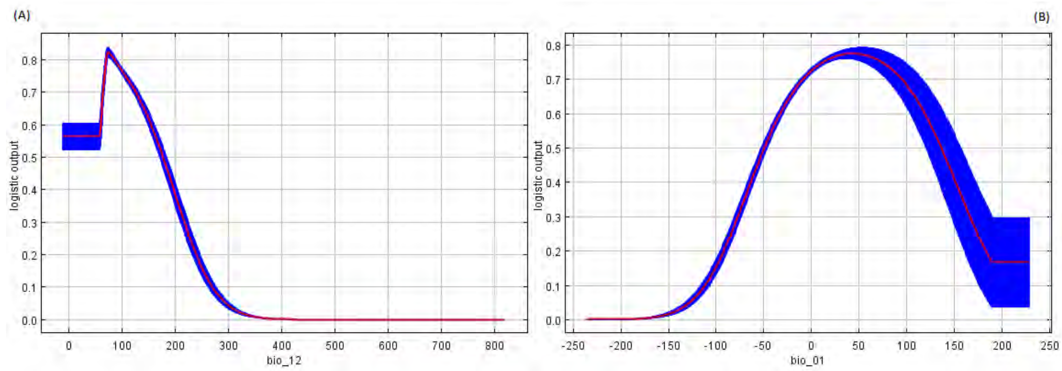

Figure 2.9. Response curves (A) Annual Precipitation (bio_12), (B) Annual Mean Temperature in predicting probability of Himalayan ibex presence. The red line is mean value, while cobalt blue shades show standard deviations from mean value of variable.

2.3.3 Future Distribution of Himalayan Ibex and Blue Sheep

Our models showed habitat shrinkage for both Himalayan ibex and blue sheep for RCP 4.5 and RCP 8.5, in 2050 and 2070 scenarios (Figure 2.10 and 2.11, Table 2.4 and 2.5).

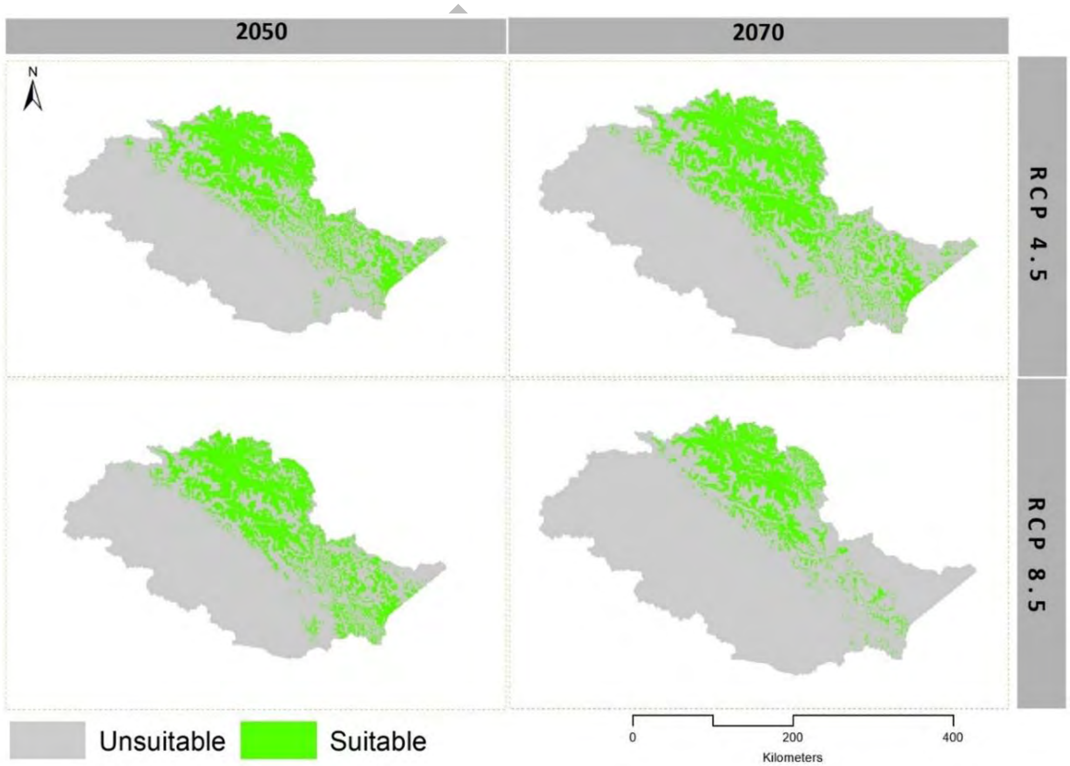

Figure 2.10. Binary maps of Himalayan ibex under RCP 4.5 and RCP 8.5 scenarios in 2050 and 2070.

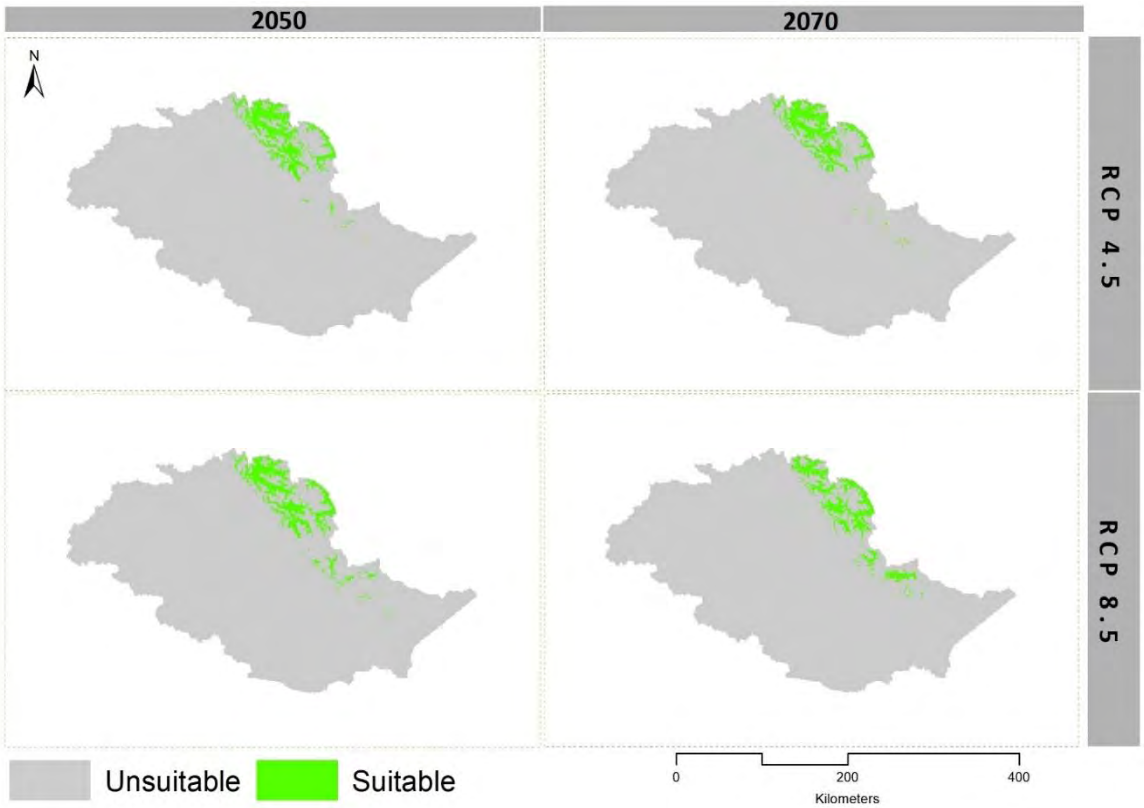

Figure 2.11. Binary maps of blue sheep under RCP 4.5 and RCP 8.5 scenarios in 2050 and 2070.

Table 2.4. Area predicted to be suitable in the current and different future climate change scenarios within GB for blue sheep.

	Scenario	**No. of pixels predicted to be suitable**	**Percentage reduction in future scenarios**
1	Current	9,035	-
2	2050 RCP 4.5	3,922	56.59
3	2050 RCP 8.5	4,039	55.29
4	2070 RCP 4.5	3,738	58.62
5	2070 RCP 8.5	3,491	61.93

Table 2.5. Area predicted to be suitable in the current and different future climate change scenarios within GB for *C. ibex sibirica.*

	Scenario	No. of pixels predicted to be suitable	Percentage reduction in future scenarios
1	Current	36,790	-
2	2050 RCP 4.5	23,797	35.31
3	2050 RCP 8.5	23,804	35.29
4	2070 RCP 4.5	24,391	33.70
5	2070 RCP 8.5	12,950	64.80

In the extreme climate change scenario (RCP 8.5 of 2070), blue sheep lost (58%) from the suitable areas that it has currently occupied and gained new suitable areas by extending its current range towards the east. Himalayan ibex gained the least and lost (64.80%) in RCP 8.5 of 2070 (Table 2.6 and Figure 2.12 and 2.13). The model predicted habitat shrinkage to an area of 2,515 km^2 for blue sheep and 9,248 km^2 for ibex under the extreme climate change scenario.

Table 2.6. Change resulting from climate change in suitable habitats of blue sheep and Himalayan ibex.

Species	Future	Scenario	Expansion	No occupancy	Stable areas	Habitat loss	Total
Blue sheep	2050	RCP 4.5	3.60	63,779	2,822	3,687	70,291
	2050	RCP 8.5	47.55	63,735	2,906	3,604	70,292
	2070	RCP 4.5	23.05	63,759	2,670	3,839	70,291
	2070	RCP 8.5	125.38	63,657	2,390	4,120	70,292
Ibex	2050	RCP 4.5	3,024	40,738	14,126	12,460	70,348
	2050	RCP 8.5	2,957	40,805	14,175	12,411	70,348
	2070	RCP 4.5	3,363	40,009	14,102	12,330	69,804
	2070	RCP 8.5	1,035	42,228	8,213	18,255	69,731

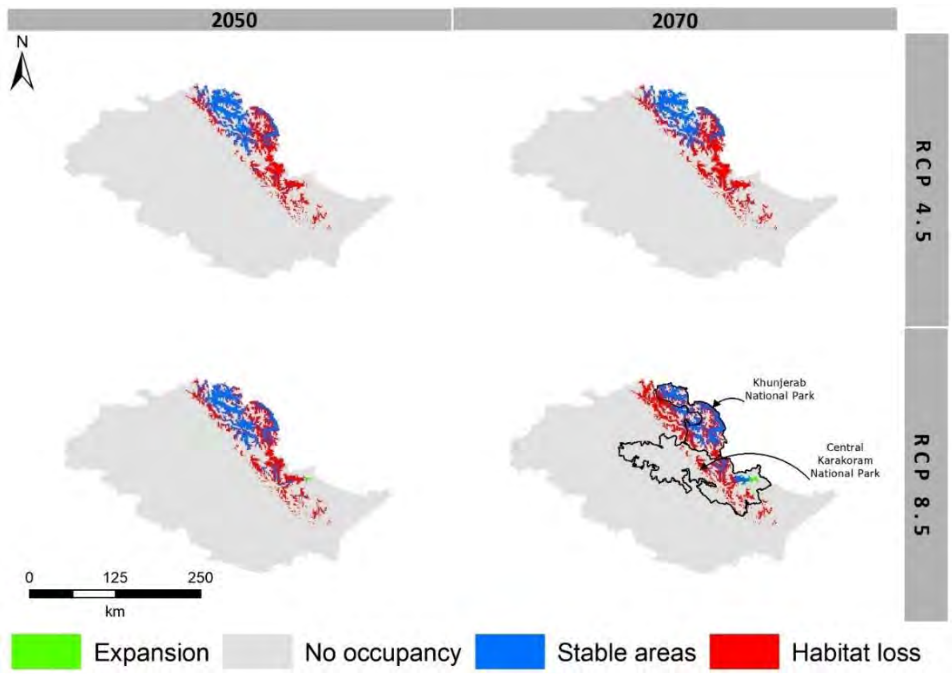

Figure 2.12. The predicted change in the suitable habitats of blue sheep in 2050 and 2070 under RCP 4.5 and RCP 8.5 scenarios.

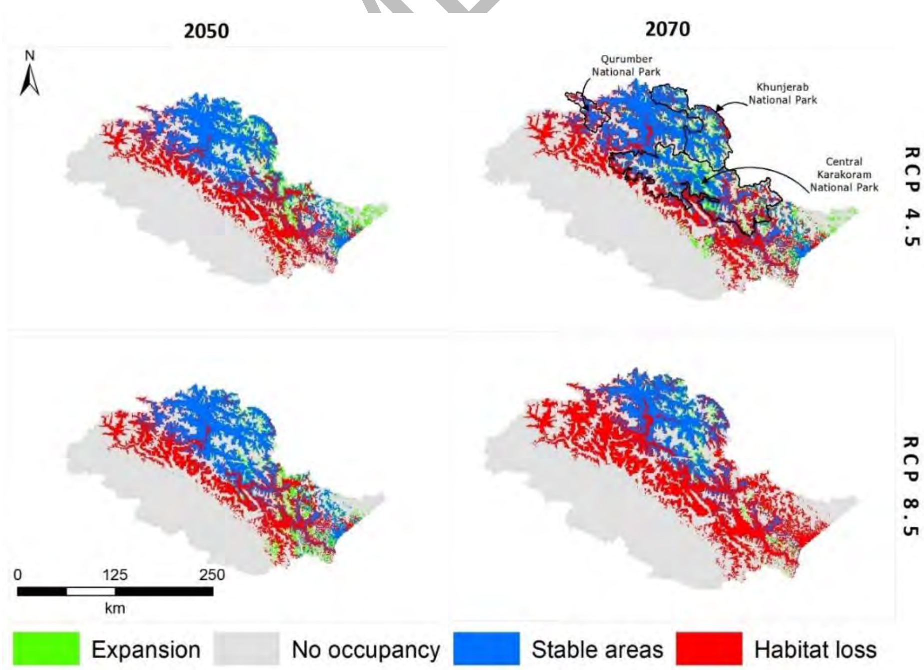

Figure 2.13. The predicted change in the suitable habitats of Himalayan ibex in 2050 and 2070 under RCP 4.5 and RCP 8.5 scenarios.

The center of suitable Himalayan ibex habitat gradually shifted from the north to the east in RCP 4.5 and RCP 8.5 of 2050, and RCP 4.5 of 2070, while in RCP 8.5 of 2070, it again shifted from the east to the north. The center of the suitable habitat of blue sheep first shifted gradually from the west towards the north in RCP 4.5 and RCP 8.5 of 2050, and RCP 4.5 of 2070. In RCP 8.5 of 2070, it shifted towards the east from the north. The MESS analysis predicted some areas with novel climate conditions across the range for both *P. nayaur* and *C. ibex sibirica* in the future projections. However, these areas were found outside the training range of our model.

2.3.4 Niche Overlap

Our analysis of niche overlap between blue sheep and Himalayan ibex indicated a moderate level of niche overlap in the current time. ANOVA test showed that the mean of Schoener's D value for two climate change scenarios (4.5 and 8.5) did not vary significantly ($F (3,12) = 0.15$, $p= 0.68$) on the temporal scale (2050 vs. 2070). Similarly, the probability-based I-statistic values for niche overlap were also not significantly different ($F (3, 12) = 0.37$, $p=77$) for different RCPs of different years (Table 2.7 and Figure 2.14).

Table 2.7. Estimation of niche overlap between Himalayan ibex and blue sheep under different climate change scenarios.

Schoener's niche overlap metric	Current	2050		2070	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
D	0.42	0.44	0.46	0.44	0.47
I	0.69	0.72	0.73	0.72	0.74

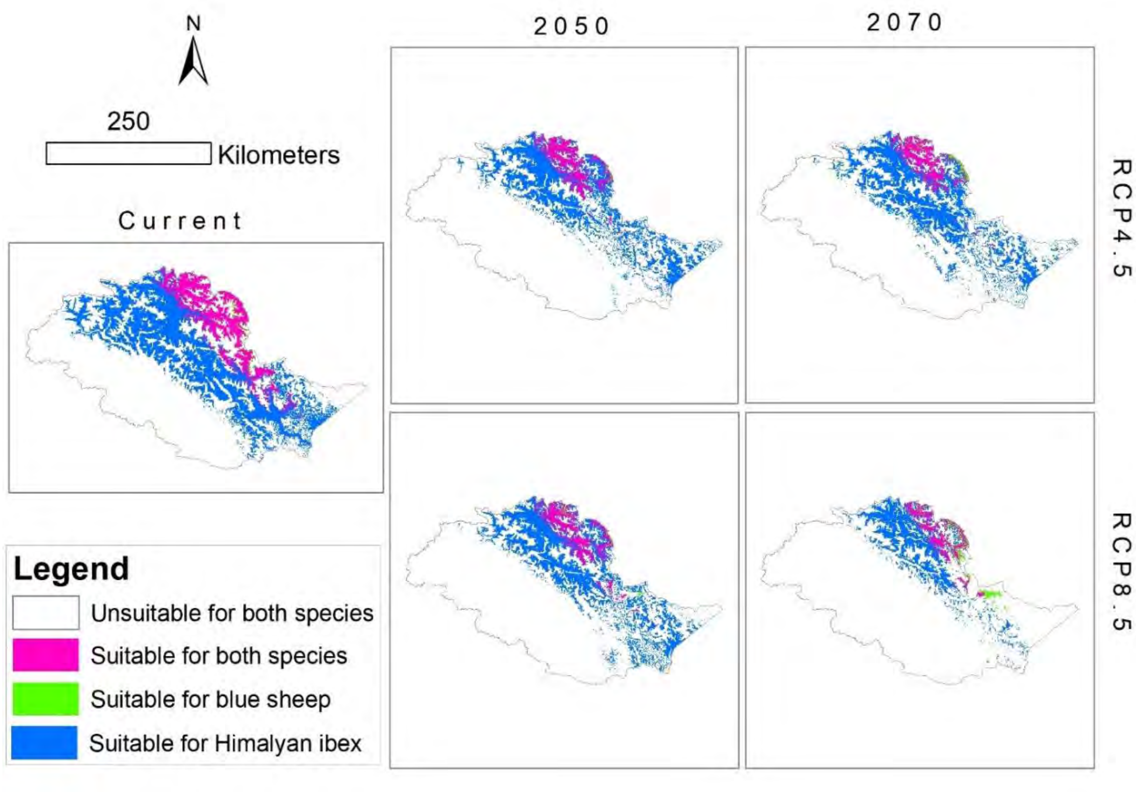

Figure 2.14. The spatial pattern of niche overlap between blue sheep and Himalayan ibex in current and different climate change scenarios.

2.4 DISCUSSION

The use of SDMs for the predictive distribution of biodiversity (Araújo et al., 2019) has increased as the approach is considered efficient in predicting species distribution and climate change impact (El-Gabbas and Dormann, 2018) which aids in species conservation planning (Gomes et al., 2018). MaxEnt is widely used for its proven ability to construct models using presence-only data (Renner and Warton, 2013). This model worked well on our presence data as indicated by the AUC scores (>0.8), which places it among the best-published models (Aryal et al., 2016; Holt et al., 2018; Khan et al., 2016; Luo et al., 2015). The higher TSS values further supported the credibility of results (Bosso et al., 2017; Smeraldo et al., 2017).

The melting of Himalayan glaciers has increased in the 21st century (Maurer et al., 2019) while the glaciers of the Hindu Kush and Karakoram will melt at a slower rate (Wiltshire, 2014). In fact, some glaciers in the higher watersheds of the Karakoram are expanding (Hewitt, 2005) although at the same time they are thinning. However, regardless of the three described scenarios, the snow on these glaciers regulates ecological processes and patterns (Niittynen and Luoto, 2018) and any change in glacier mass, negative or positive, will affect associated biodiversity. Our results for habitat loss and gain were strikingly aligned with the existing knowledge on glaciology. We found that global climate change will have significant effects on the habitats of mountain ungulates in northern Pakistan, though these effects are more pronounced in Hindu Kush, and Himalaya ranges.

Our model for current time predicted 6,510 km^2 and 26,510 km^2 of suitable area for blue sheep and Himalayan ibex, respectively. Both model species are present in most of the predicted habitats, or they occupied those areas historically (Roberts, 1997; Schaller, 1977). Ironically, Khan et al., (2014) reported sighting records of ibex in Tangir Valley of Diamer district, which is beyond the suitable habitat predicted in the current study, as well as outside of the former IUCN range (Reading, 2015). This probably indicates southwards expansion of ibex in recent years. Our model predicted suitable habitat for blue sheep on the Braldu glacier where sheep do not currently exist (Khan et al., 2014). Interestingly, older records indicate the presence of blue sheep in this area, e.g., (Hess et al., 1997) quote a sighting by T. J. Roberts in this area in 1975.

Both blue sheep and Himalayan ibex habitats are usually between the timber and snow lines at elevations of 3,500–5,500 m and differ as blue sheep prefers habitats with steep rolling hills and Himalayan ibex prefer precipitous habitats (Schaller, 1977). These habitats are usually devoid of thick vegetation. Hence, precipitation is a vital factor to sustain life in this zone. We found annual precipitation to be the most contributing variable in predicting suitable habitat for both blue sheep and Himalayan ibex. Annual mean temperature was the second most important variable for Himalayan ibex, and temperature of wettest quarter the second most important for blue sheep. The dry habitats of both ibex and blue sheep have short growing seasons, and any weather fluctuation might leave species starving (Ciach and Pęksa, 2018). *Artemisia* and *Ephedra* shrubs are described as the ibex's main food sources (Schaller, 1977). A year of good winter precipitation and normal mean summer temperature enables shrubs to maximize their growth and green cover (Lu et al., 2016) . Blue sheep's preferred diet comprises of grasses, forbs, and shrubs *Berberis, Polygonum,* and *Ephedra,* respectively (Schaller, 1977). Even in the summers, precipitation at elevations above 4,000 m can bring temperatures below zero and constraint vegetative growth (Lu et al., 2016). Hence, temperatures of wettest quarters (June, July, and August) play a decisive role in selecting suitable habitat for blue sheep. Khan et al. (2016) found annual precipitation and minimum temperature to be important variables for developing suitability models for *C. ibex sibirica* and *P. nayaur,* respectively. Aryal et al. (2016) and Luo et al. (2015) reported annual mean temperature as the most influencing variable in predicting suitable habitat for *P. nayaur.*

We observed a sharp decline (56% in RCP 4.5 and 58% in RCP 8.5) in the currently available suitable habitat for blue sheep and (33.70% in RCP 4.5 and 64.80% in RCP 8.5) for Himalayan ibex in extreme climate change scenarios for 2070. This is consistent with (Aryal et al., 2016)who observed a decrease in blue sheep suitable habitat in the future due to climate change in Nepal. Similarly, Luo et al. (2015) reported a 30–50% range reduction for ungulates on the Tibetan plateau under different climate change scenarios.

Climate drives evolutionary processes, forcing animals to migrate to higher elevations or extend their distributional ranges towards the Northern Hemisphere (Hughes, 2000) or eastward direction (Luo et al., 2015). This process is believed to have occurred in the Miocene Epoch when members of the *Caprinae* in Eurasia and Africa began inhabiting the newly formed mountain ranges of the Himalayas, Karakoram, Hindu Kush, and Pamirs, which emerged from the sea during the Tertiary Period (Schaller, 1977). We expect a similar migration in northern Pakistan because the centers of predicted suitable habitat for Himalayan ibex will shift from north to east in RCP 4.5 and RCP 8.5 of 2050 and 2070 and again from east to the north in RCP 8.5 of 2070. For Himalayan ibex, it will shift from west to north in RCP 4.5 and RCP 8.5 of 2050 and 2070 and from north to east in RCP 8.5 of 2070.

Species co-evolved over millions of years, enabling them to co-exist by selecting different niches (Finke and Snyder, 2008). Our model predicted a moderate niche overlap between blue sheep and Himalayan ibex, and this overlap was predicted to increase if the extreme climatic conditions assumed in future scenarios prevail. Increasing temperatures and precipitation have already impacted Himalayan flora (Salick et al., 2014). Alpine habitats have short growing seasons (Dolezal et al., 2016; Uhlig, 2006) and offer relatively few species of grasses, sedges, forbs, shrubs, ferns, lichens, and mosses to Himalayan ibex and blue sheep (Bagchi et al., 2004; Bhattacharya et al., 2012; Mishra et al., 2004). Hence, these climatic changes in alpine ranges will increase the chances of habitat mismatch for many floral species (Dolezal et al., 2016; Luo et al., 2015). Climate change, together with anthropogenic effects transforming land for agriculture or afforestation, road construction, and mining could further shrink habitats suitable for ungulates (Khan et al., 2016; Luo et al., 2015), potentially affecting their perpetuity and the proper functioning of ecosystems (Hobbs, 2007; Murray et al., 2013).

Conservationists emphasize on locating habitats likely to be least affected by climate change and continue serving as suitable habitats (future refugia) and protecting them from anthropogenic activities (Li et al., 2016; Morelli et al., 2017, 2016) . Our model predicted such climate refugia for exists in the buffer zone of KNP, along with a few patches on the Braldu glacier of CKNP (Figure 2.12), and for Himalayan ibex it exists mostly in three national parks: Khunjerab National Park (KNP), Central Karakoram National Park (CKNP), and Qurumbar National Park (QNP) (Figure 2.13). It is noteworthy, however, that Himalayan ibex will lose most of its current suitable habitat in CKNP in Baltistan division and areas around QNP in the future, but the areas of CKNP in Nagar district will remain stable. All three mountain ranges in our study area provide vital habitats to several mountain ungulates. Unfortunately, most of suitable habitats in Hindu Kush and Himalayas are expected to be altered under future scenarios. On contrary, the Pamir-Karakoram is likely to remain stable and continue accommodating both Himalayan ibex and blue sheep. The relatively lower effect of climate change in this range is likely due to the barrier effect of the Hindu Kush and Himalayas which blunt the monsoon, helping maintain the aridity of the Karakorum's' alpine steppes (Hewitt, 2005; Li et al., 2016).

2.5 CONCLUSIONS

This study demonstrate that the current suitable habitat of Himalayan ibex and blue sheep are vulnerable to climate change. Under the rapid climate change Himalayan ibex will lose most of its current suitable habitat in Himalayans and Hindu Kush while blue sheep that currently exists only in Pamir-Karakoram range will be slightly affected. The current network of protected areas (KNP and CKNP) will serve climate refugia for mountain ungulates.

There is urgent need to revisit protected areas management strategies in Pakistan, to enhance their effectiveness for conservation of mountain ungulates. The finding of this study can be used to revisit or align boundaries of existing protected areas with the future predicted habitats. Management and protection efforts shall remain disproportionally higher in parks that encompass climate refugia for mountain ungulates of the region.

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CHAPTER THREE

COMBINING INDIGENOUS KNOWLEDGE AND GROUND EVIDENCE TO CONSTRUCT DISTRIBUTION OF KASMIR MUSK DEER IN PAKISTAN

3 COMBINING INDIGENOUS KNOWLEDGE AND GROUND EVIDENCE TO CONSTRUCT DISTRIBUTION MODEL OF KASMIR MUSK DEER IN PAKISTAN

ABSTRACT

The Kashmir musk deer is an endangered species that occurs in Afghanistan, India, and Pakistan. The secretive and territorial nature, patchy distribution, habitat attributes, rugged terrain, and logistics make difficult to study musk deer. Resultantly, the regional distribution of the species, especially in Pakistan is poorly known. In this study, we used multiple methods ranging from questionnaire and sign surveys to camera trapping to reliably document the current distribution of musk deer in the Gilgit-Baltistan (GB) region of Pakistan. We also used these records to predict the suitable habitat and key movement corridors of musk deer in the region to facilitate long-term conservation planning.

Based on 37 presence records (33 spoors and 4 camera captures) across the region, MaxEnt model predicted 9,116 km² area as suitable habitats for musk deer. The key habitat determinants were annual precipitation, precipitation seasonality, and annual mean temperature.

Large patches of suitable habitat of musk deer were concentrated in the districts of Astor and Diamer. Except for the low reaches of the Gilgit and Ghizer districts, most of GB represented a poor-quality habitat because of being devoid of dense forest or Birch Forest which has only 277 km^2 cover. The GB has an impressive network of protected areas, but the bulk of the musk deer habitat falls out of it. Lack of protection to its habitat is a major conservation challenge for species in the country. We recommend establishing new national parks and other stringent protected areas in the districts of Astor and Diamer to encompass musk deer habitat. However, demarcations of new protected areas should be rationalized and based on the habitat suitability maps developed in this study to ensure long-term survival of this threatened species in the region.

Keywords: Kashmir musk deer, mammal, distribution, Gilgit-Baltistan, Himalaya, national park.

3.1 INTRODUCTION

The Kashmir musk deer *(Moschus cupreus),* hereafter musk deer, is a shy, solitary, and secretive animal of the family *Moschidae,* and is endemic to 13 countries of Asia (Zhou et al., 2004). Due to its deer-like features, it was initially placed in the family *Cervidae* but was later designated a separate family because it lacked antlers, which are distinguishing features of a true deer. It also possesses several other features that are absent deer, such as facial glands, a gallbladder, caudal gland, musk gland, one pair of teats, and developed and protruding upper canines below the lip of the lower jaw in males (Green, 1986; Sathyakumar et al., 2012).

Musk deer taxonomy has gone through many refinements based on physical features and genetics. Sathyakumar et al., (2012) and Groves & Grubb, (2011) classified musk deer into seven species. Musk deer in Pakistan was considered as alpine musk deer (Green, 1986; Roberts, 1997; Schaller, 1977, Khan et al., 2006; Qamar et al., 2008; Qureshi et al., 2013, 2004), or Himalayan musk deer (Abbas et al., 2015) However, recent literature have confirmed that species found in Pakistan is Kashmir musk deer (Groves & Grubb, 2011; Sathyakumar et al., 2012; Timmins and Duckworth, 2015a).

Historically, the musk deer was reported in good numbers in the Pakistan's Himalaya and Hindukush ranges (Roberts, 1997; Scully, 1881). In Khyber Pakhtunkhwa province, it has been reported from the districts of Chitral, Dir, Kolai-Palas, and Mansehra (Khalid et al., 1995; Roberts, 1997; Green, 1986). In state of Azad Kashmir, it is reported from the Machiara National Park (MNP), and throughout the Neelum valley (Green, 1986; Roberts, 1997; Qureshi et al., 2004; Qamar et al., 2008). The species is also known to historically occur in several districts of Gilgit-Baltistan, including districts of Astore, Diamer, Darel, Tangir, Skardu, Ganche, Kharmang, and part of Gilgit (Scully, 1881; Abbas et al., (2015). However, the species has witnessed drastic decline in numbers and geographic extent in recent decades across its historical range in Pakistan (Roberts, 1997; Qureshi et al., 2004)

Musk deer occurs at elevations of 3,000–4,000 m in subalpine scrub, especially in forests with birch patches *(Betula utilis)*, and in forests with Persian juniper *(Juniperus polycarpos)*. In northwestern Himalayas, it lives on lower elevations where vegetation cover is higher due to the higher rainfall (Roberts, 1997). During the daytime, musk deer rest in dense undergrowth, hence their activity is either nocturnal or crepuscular. They come out to feed in open alpine grasslands mostly during the night, rarely moving far from dense scrub or undergrowth, which they use as escape cover (Green, 1985; Sathyakumar, 1991).

In the Himalayas, musk deer feed on the leaves of woody plants, grasses, ferns, forbs, and lichen. Their diet seldom includes more than ten percent graminoids and they prefer forbs and woody plant leaves throughout the year. In winter, due to snow cover, vegetation is scarce, thus lichen *(Usnea* spp*.)* and moss, constitute 25% and 18% of their diet, respectively. They also feed on oak *(Quercus semecarpifolia),* rhododendron *(Rhododendron capanulatum),* montane bamboo *(Arundinaria* spp*.), Gaultheria nummularioides,* and *Rubus* spp. in winter (Green, 1985; Green, 1987). Natural predators, such as the snow leopard *(Panthera uncia),* common leopard *(Panthera pardus),* Himalayan yellow-throated marten *(Martes flavicula),* and red fox *(Vulpes vulpes),* also hunt and consume musk deer (Sathyakumar et al., 2012; Heptner et al., 1988).

All species of musk deer are listed endangered on the IUCN RedList (Harris, 2016; Timmins and Duckworth, 2015a, 2015b; Wang and Harris, 2015a, 2015b, 2015c), except Siberian musk deer which is (Nyambayar et al., 2015). Musk deer have also been listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The most eminent threat to Kashmir musk deer across its range is poaching for "musk pod" (Khan et al., 2006; Qamar et al., 2008; Qureshi et al., 2013, 2004; Singh et al., 2020; Timmins and Duckworth, 2015b)Musk pods can fetch an estimated USD 65,000 per kilogram in the international market. Due to the high demand for musk pods, several thousand musk deer are slaughtered each year to produce over 300 kg of musk pod (Sathyakumar et al., 2012; Green, 1986). Others threats to the species are habitat degradation (Khan et al., 2006; Qureshi et al., 2013; Singh et al., 2020), climate change (Jiang et al., 2020; Khadka et al., 2017; Singh et al., 2020), and livestock grazing (Khan et al., 2006; Qureshi et al., 2013; Singh et al., 2020).

Musk deer are timid, solitary, and difficult to study (Ostrowski et al., 2016) therefore their distribution ranges are poorly known. This hampers the ability to assess the threats to the species level and management planning (Timmins and Duckworth, 2015b). The management planning for species that are at the verge of extinction includes establishing protected areas (Zhang et al., 2022). These protected areas should not be declared opportunistically on lands not used by humans, rather they are representatives of habitat requirements of species in question (Venter et al., 2014). This requirement is hard to meet in in data poor regions and for habitat specialist species like musk deer.

Musk deer's nocturnal (Green, 1985) and secretive nature (Zhou et al., 2004) and its preference for dense forest (Green, 1986, 1985; Sathyakumar et al., 2012) make them difficult to count using direct count methods (Ostrowski et al., 2016). Their occurrence and distribution range in Pakistan is dated and largely based on indirect methods, e.g., signs and questionnaire surveys(Abbas et al., 2015; Khalid et al., 1995; Khan et al., 2006; Qamar et al., 2008; Qureshi et al., 2013, 2004). Verification of public reports through sign surveys and camera trapping (Ali et al., 2019; Lee et al., 2006; Zaumyslova and Bondarchuk, 2015) adds reliability to detections. These detections can be used to build statistical models, e.g., MaxEnt (Phillips et al., 2006), and predictions can be made for species management.

This study was designed to reliably document the presence of musk deer, based on multiple methods (Questionnaire, sign surveys, camera trapping), throughout its distribution range in the GB province of Pakistan. Based on this, we validated species distribution, identified suitable habitats and key movement corridors in GB through predictive modeling. Lastly, we identified gaps in conservation planning of musk deer in GB, and provided recommendations based on our findings.

3.2 MATERIALS AND METHODS

3.2.1 Study area

The study was conducted in GB (Figure 3.1). The study area is described in chapter one under the section 1.8 (Figure 1.6).

3.2.2 Occurrence point collection techniques

3.2.2.1 Synthesis of knowledge on historical species distribution

I first reviewed historical literature (Green, 1986, 1985; Qamar et al., 2008; Qureshi et al., 2004; Roberts, 1997; Sathyakumar et al., 2012; Schaller, 1980; Scully, 1881) to ascertain the distribution range of musk deer in GB. As the musk deer is associated with birch forests, the floral literature of GB (Rao and Marwat, 2003) was also reviewed, and discussions with regional forest officers (RFOs) were conducted to identify the presence of birch patches in the study area that were not smaller than musk deer minimum home range, i.e., 0.13 km^2 (Kattel, 1992).

3.2.2.2 Questionnaire surveys

The second phase of the study was to develop a questionnaire format that contained questions about the presence or absence of musk deer, time of the sighting, threats to their conservation, and to develop maps using GIS for each watershed that would help interviewers identify the locations of sightings (Appendix 3.1). During the survey respondents were interviewed in 57 valleys across the study area, including ex-poachers, shepherds, wildlife game wardens, and others (any persons residing in the valley permanently and often visiting pastures) from 2013 to 2018. The boundaries of watersheds in which musk deer were sighted in the last ten years were digitized using the 'geo-referencing' tool in ArcGIS 10.8.1 (Figure 3.1).

3.2.2.3 Sign surveys

Potential sites for sign surveys of musk deer were identified through questionnaire survey maps, we surveyed 57 sites (Figure 3.1). for musk deer signs i.e., latrines, pugmarks, and confirmed poaching incidences were collected as evidence of musk deer presence during the surveys from May 2013 to July 2020. For sign surveys we focused in areas close to any water source and at the bases of rocky outcrops.

3.2.2.4 Camera trappings

Next, I selected the most promising sites identified as the outcome of the sign surveys for camera trapping studies. Two Camera trapping studies were conducted in Kala Pani valley (June-July 2013 and in the entire Astore District (November 2018 to May 2019). In addition to these two exclusive camera trapping surveys in musk deer potential habitats, we installed 514 cameras during the 10 camera trapping surveys in the study area from November 2010 to May 2019.

A total of 63 trap stations were set using the infrared/motion-triggered cameras (Reconyx HC 500 and HC 900; Reconyx, Holmen, USA) in the two trapping sessions resulting in 137 trap days. Each camera was separated by one kilometer (km) and mounted on 40–60-cm-long iron stands(Bischof et al., 2013). The presence of indirect animal signs, e.g., latrine sites, and water sources, were considered important locations for camera installation (Pal et al., 2021). Using the camera trapping survey format, information like the GPS coordinates of the camera location, were recorded.

3.2.3 Data preparation

3.2.3.1 Occurrence points

I used 38 presence-only locations that were collected during the field surveys, i.e., sign and camera trap surveys (Figure 3.1). To avoid spatial autocorrelation, I run ‘average nearest neighbor analysis’ in ArcGIS 10.8.1 (ESRI, Redland, USA) on the presence points (Hameed et al., 2020; Kabir et al., 2017). This analysis did not suggest clustering of presence points. Therefore, no further analysis was considered to address spatial autocorrelation.

3.2.3.2 Climatic variables

I used two types of variables to construct the model, climatic (19 bio layers) and topographic (land use layer, slope, and aspect) (Table 1). The 19 bioclimatic variables were downloaded from WorldClim version 2.1 (http://www.worldclim.org), which are developed using monthly minimum and maximum temperature and rainfall values (1970–2000) to provide biologically meaningful variables for species distribution modelling (SDMs) (Fick and Hijmans, 2017). The land-use layer with 14 different land use types (dense broad leaved, dense conifer, dense mix, sparse broad leaved, sparse conifer, sparse mix, linear/block plantation, agriculture land, alpine/summer pastures, winter pastures, rivers/lakes, settlements, rocks/barren land, and snow/glacier) was developed by the GB's Forest, Wildlife, and Environment Department (Ali et al., 2017). Slope and aspect were derived from a digital elevation model (DEM) created by Shuttle Radar Topography Mission (STRM) data (Taubmann et al., 2016), using ArcGIS 10.7.1. Using a geoprocessing script written by (Sappington et al., 2007), I created the vector ruggedness measure of the study area. All the variables' formats and projections were converted to ASCII files to 30-arc seconds resolution (0.93×0.93 km = 0.86 km^2 at the equator) (Bosso et al., 2017). Collinearity among two or more variables can cause problems in statistical models, and regression models are very sensitive to collinearity—it can cause instability in parameter estimation and biases in inferential statistics (Dormann et al., 2013). Therefore, multicollinearity among the layers was addressed by not using two layers that crossed the correlation threshold of $r \geq 0.70$ (Pearson's correlation coefficient) (Kabir et al., 2017). This step left eight variables that were later used in the model (Table 1).

Table 3.1. List of environmental variables used in the MaxEnt model (asterisks indicate variables used in the model).

No.	Covariates	Data format	Source
1	bio_01*	Annual mean temperature	WorldClim, v. 2.1

2	bio_02*	Mean diurnal temperature	WorldClim, v. 2.1
3	bio_03	Isothermality	WorldClim, v. 2.1
4	bio_04*	Temperature seasonality	WorldClim, v. 2.1
5	bio_05	Max. temperature of warmest month	WorldClim, v. 2.1
6	bio_06	Min. temperature of coldest month	WorldClim, v. 2.1
7	bio_07	Annual temperature annual range	WorldClim, v. 2.1
8	bio_08	Mean temperature of wettest quarter	WorldClim, v. 2.1
9	bio_09	Mean temperature of driest quarter	WorldClim, v. 2.1
10	bio_10	Mean temperature of warmest quarter	WorldClim, v. 2.1
11	bio_11	Mean temperature of coldest quarter	WorldClim, v. 2.1
12	bio_12*	Annual precipitation	WorldClim, v. 2.1
13	bio_13	Precipitation of wettest month	WorldClim, v. 2.1
14	bio_14	Precipitation of driest month	WorldClim, v. 2.1
15	bio_15*	Precipitation seasonality	WorldClim, v. 2.1
16	bio_16	Precipitation of wettest quarter	WorldClim, v. 2.1
17	bio_17	Precipitation of driest quarter	WorldClim, v. 2.1
18	bio_18	Precipitation of warmest quarter	WorldClim, v. 2.1
19	bio_19	Precipitation of coldest quarter	WorldClim, v. 2.1
20	strm	Shuttle radar topographic data	www.usgs.gov
21	ruggedness	The vector ruggedness measure of the study area	(Sappington et al., 2007)
22	land_cover*	The land cover of the study area	(Ali et al., 2017)
23	aspect*	The aspect of the study area	Derived from DEM using the 'aspect' tool in the 'spatial analyst' tool of ArcGIS 10.7.1.
24	slope*	The slope of the study area	Derived from DEM using the 'slope' tool in the

			'spatial analyst' tool of ArcGIS 10.7.1.

3.2.4 Modeling process

I used MaxEnt version 3.4.4. MaxEnt is a machine learning algorithm developed by (Phillips et al., 2006) for SDMs. It is the most frequently used and most popular modeling method to generate SDMs owing to its better performance (Banag et al., 2015; Elith et al., 2006; Phillips et al., 2006), reliability, statistical robustness(Elith et al., 2006; Phillips et al., 2006; Wisz et al., 2008) high predictive accuracy, ease of use, and functionality (Jha and Jha, 2021; Mohammadi et al., 2019; Morales et al., 2017).

It is often impractical for researchers to collect confirmed absence points, especially for mobile species (Elith et al., 2006; Mackenzie and Royle, 2005). The major advantage of MaxEnt over other SDMs is that it requires only presence data to generate distribution models(Elith et al., 2006; Jha and Jha, 2021) and can also work well with small sample sizes (van Proosdij et al., 2016).

I selected linear, quadratic, and hinge features to avoid overfitting and Jackknife sensitivity analysis to measure the importance and contribution of each variable (Aryal et al., 2016). The final average map's output was set to logistic with suitability values from 0 (unsuitable) to 1 (suitable) (Phillips et al., 2017, 2006). I changed the following settings in the MaxEnt settings panel: auto features; random seed; write plot data; write background predictions; replicates 20; and 5,000 maximum iterations. In the replicated run type, we used cross-validation due to the small number of occurrence locations as cross-validation makes it possible to replicate "n" sample sets, removing each time-one locality (Pearson et al., 2007). The remaining settings were left as default (Luo et al., 2015).

3.2.5 Model evaluation

Models are often required to evaluate that they have identified the attributes of the species distribution and not simply the artifacts of a noisy sampling process (Cory et al., 2013). MaxEnt has two matrices to serve this purpose e.g., the receiver operating characteristics

(ROC) curve and the area under the curve (AUC), in literature AUC is most reported matrix to evaluate MaxEnt models. On average, a model with a discrimination value above 0.50 is considered better than a random one, while a model with a discrimination value of 1 is considered a perfect model (Phillips and Dudík, 2008). In general, models with an AUC value > 0.75 are considered to have high discrimination performance (Elith, 2000; Elith et al., 2006). We also used another metric, the true skill statistic (TSS) (Allouche et al., 2006), which is defined as sensitivity + specificity -1, and it ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicates a performance no better than random. (Allouche et al., 2006; Russo et al., 2014; Ruete & Leynaud, 2015).

3.2.6 Movement corridors

I used the concept of circuit theory implemented in Circuitscape version 4.0 (McRae et al., 2014), downloaded from (www.circuitscape.org) to predict movement corridors. Corridors are linear, continuous strips of any habitat that connects two habitat patches (Taylor et al., 2006).

I used the averaged output of MaxEnt maps as the conductance layer and musk deer-reported patches as focal habitats (focal nodes) (Zhang et al., 2021). To avoid lengthy and complex analysis, small contiguous polygons with an area less than 0.13 km^2 were dissolved into single polygons using the 'dissolve' tool in ArcGIS 10.8.1. Polygons were converted to raster format using the 'polygon to raster' tool in ArcGIS 10.8.1 to use these polygons in Circuitscape. This raster was then converted to ASCII format using the 'raster to ASCII' tool in ArcGIS 10.8.1. As the landscape was represented as a conductive surface, we used the 'conductance' option instead of 'resistance' that assigned low resistance values to areas with highly suitable values (Hameed et al., 2020; Kabir et al., 2017; Malakoutikhah et al., 2020).

3.3 RESULTS

3.3.1 Field surveys for ascertaining musk deer distribution

3.3.1.1 Questionnaire surveys

I conducted questionnaire-based survey in 57 valleys of the known musk deer range. Musk deer occurrence was confirmed in 49 valleys, by 356 respondents who reported 504 sightings at 62 different locations. Majority of sighting were claimed in valleys of Kala Pani, Minimerg, Bubind, and Qamari. A decline in the musk deer population was reported in 41 valleys, increase in eight, and local extirpation in eight valleys. Respondents in 32 valleys considered poaching to be the highest threat, followed by climate change in 12 valleys, and habitat loss/degradation in 7 valleys. Valleys of local extinctions fall in districts of Skardu (Basho Bara Jungle, Kharmang, Hoo, Skoro, Shigar, Kharpocho, Sorparanga) and Ghanche (Hushey valley).

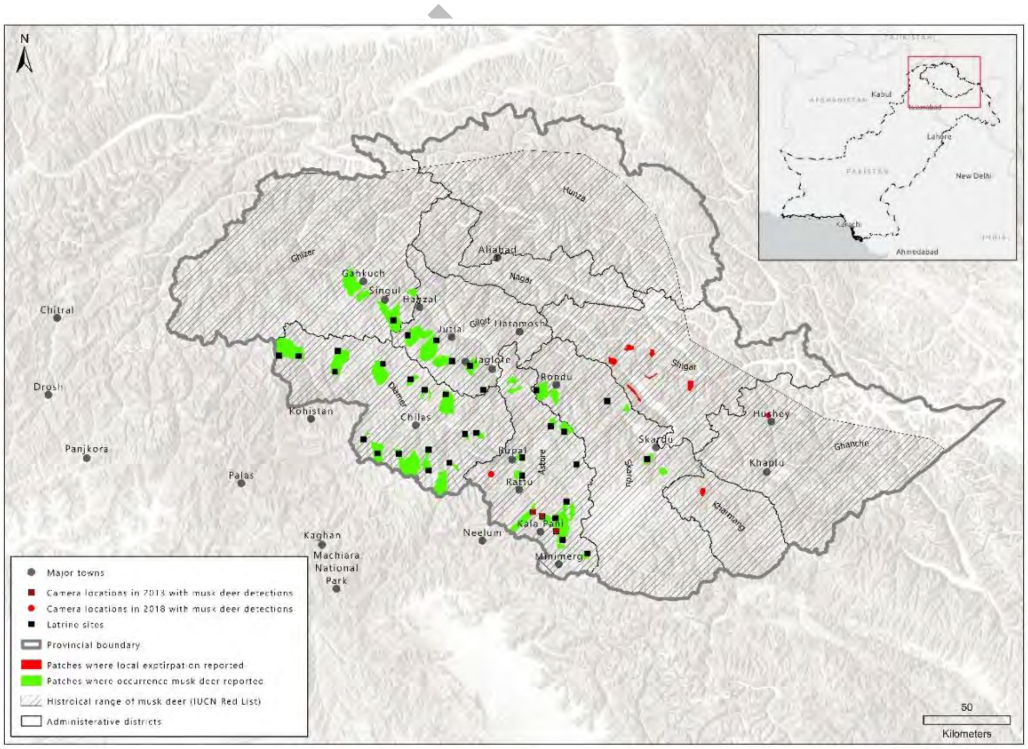

Figure 3.1. Details of occurrence points used in the MaxEnt model from reported locations (green polygons), latrines locations (pink squares), and camera locations where musk deer

were trapped in 2013 (red dotted squares) and camera locations where musk deer were trapped in 2018 (red circles).

3.3.1.2 Sign surveys

During the sign surveys 34 latrine sites (Figure 3.2) were encountered at 35 locations (Figure 3.1). Most of latrine signs were encountered in the districts of Diamer (16) followed by Astore (9), Gilgit (5), Skardu (2), and Ghizer (1) at elevations of 2,556 – 4,107 m, no signs of musk deer were found in the districts of Karmang, Shigar, and Ghanche.

Figure 3.2. Musk deer latrine sites in the study area in Kala Pani Valley.

3.3.1.3 Camera trapping

During the first camera trapping survey the 25 cameras were remained active for 375 trap-nights and three musk deer (Figure 3.1 and Figure 3.3 A, B, and C) along with many other wildlife species, including brown bears *(Ursus arctos isabellinus),* red foxes *(Vulpes vulpes),* and golden marmots *(Marmota caudata)* were photographed.

In the second camera trapping survey the 38 cameras were remained active for 4,638 trap nights, during which musk deer (Figure 3.1 and Figure 3.3 D) was trapped in Rupal Valley. Other wild species trapped included snow leopards *(Panthera uncia),* grey wolves *(Canis lupus),* Himalayan ibex *(Capra ibex sibirica),* red foxes *(Vulpes vulpes),* and stone martens *(Martes foina).*

Figure 3.3. Musk deer trapped during 2013 camera trapping (A, B, and C); and 2018 camera trapping (D).

3.3.2 Model performance

The ROC curve showed high accuracy with an AUC value of 0.91 ± 0.46. The high value proved that it was an excellent model with high discrimination power (Figure 3.4 A and B). The model achieved a 1.60 regularization gain value on occurrence data, which indicated that it was the best-fit model. The TSS score was also high, i.e., 0.67 + 0.289.

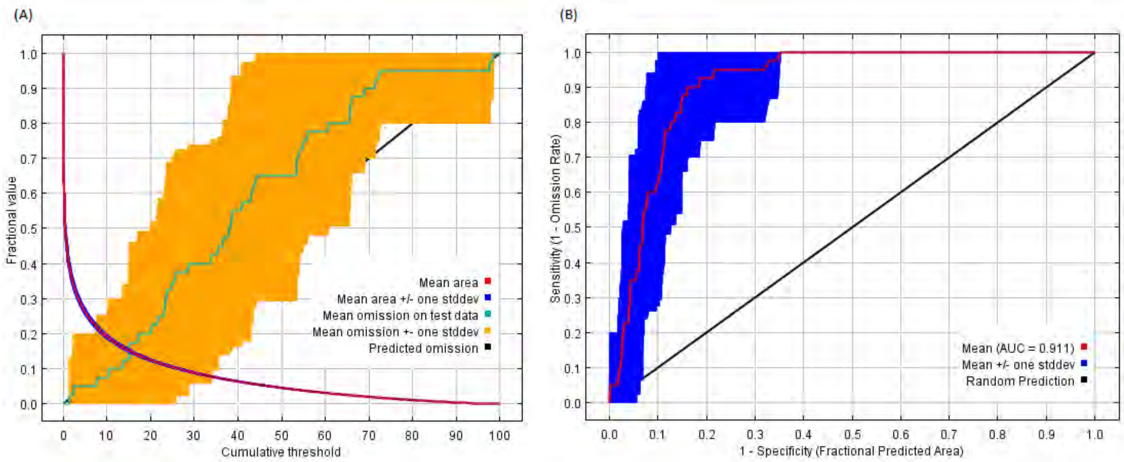

Figure 3.4. MaxEnt model evaluations: (A) averaged omission rate and predicted area as a function of cumulative threshold; and (B) the ROC curve by defining specificity using predicted area rather than true commissions. The averaged AUC value for musk deer was 0.911.

3.3.3 Determinants of habit suitability

The top four environmental variables (Figure 3.5) contributing to the musk deer model were bio_12 (annual precipitation) (63.2%), bio_15 (precipitation seasonality) (11.4%), bio_01 (annual mean temperature) (10.3%), and landcover (6.4%). The probability of suitable musk deer habitat was high in areas with an annual precipitation of 300–1,000 mm (Figure 3.6 A). The model reported that areas with 40–45% variation in monthly precipitation were highly suitable for musk deer (Figure 3.6 B). Areas with an annual mean temperature range of -5–20°C were preferred by musk deer, while areas with an annual mean temperature of -5–10°C had a high probability for suitable musk deer habitat (Figure 3.7 A). The response graph of land cover showed that musk deer were most likely to occur in mixed forests, which, in the case of the study area, were mostly birch and *Juniperus* ssp (Figure 3.11) (Figure 3.7 B).

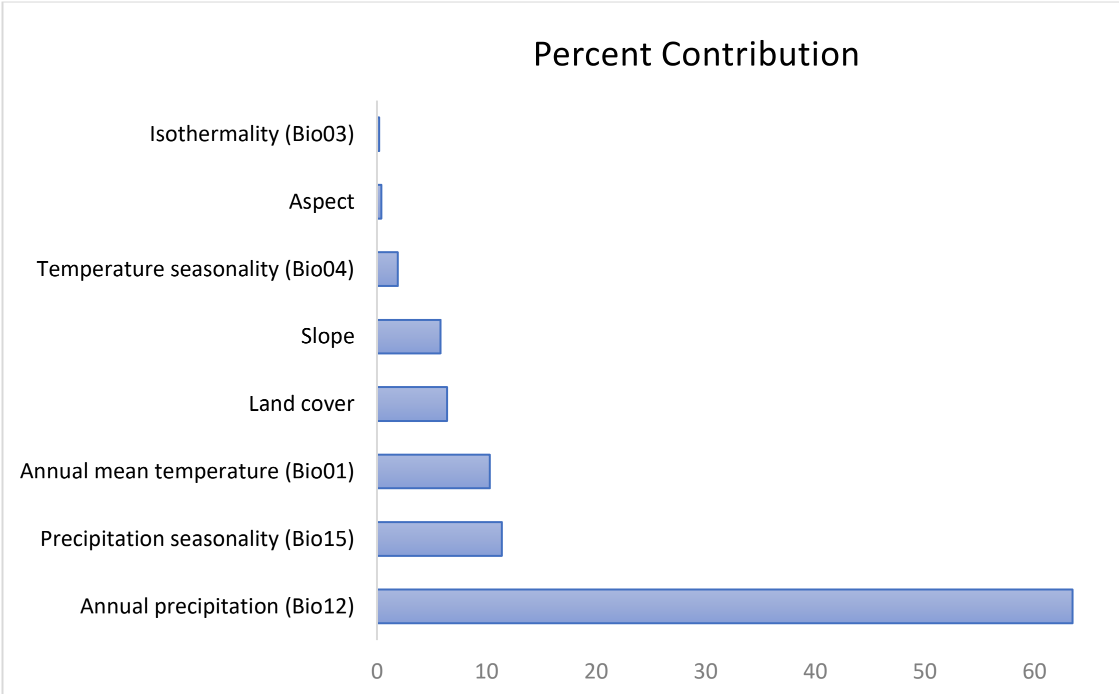

Figure 3.5. Contribution of each variable in the habitat model for musk deer

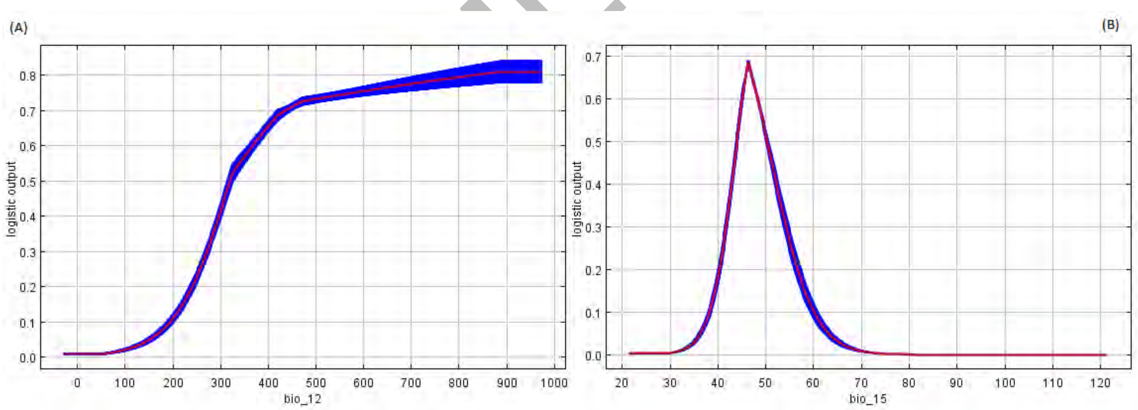

Figure 3.6. Effects of (A) annual precipitation (bio_12); and (B) precipitation seasonality (bio_15) in selection of habitat by Musk deer. The red line is the mean value, while the cobalt blue shades show standard deviations from the mean value of the variable

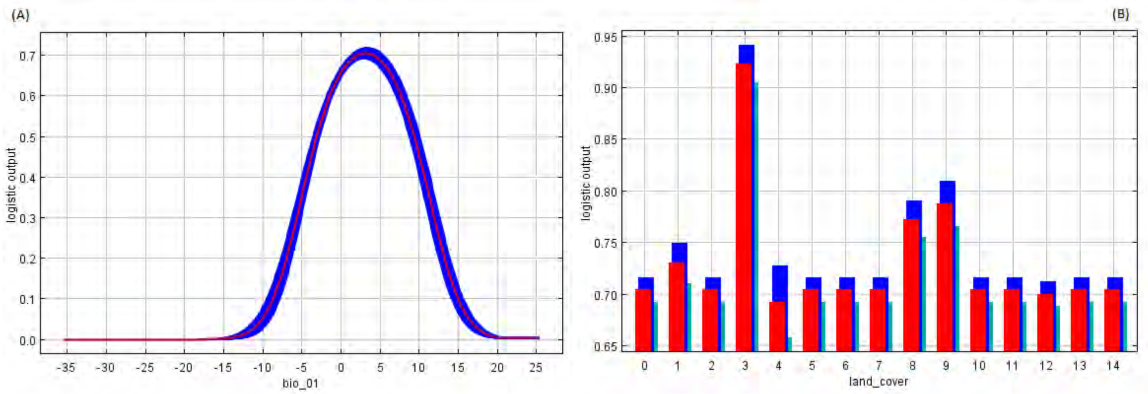

Figure 3.7. Effects of (A) annual mean temperature (bio_01); and (B) land cover in selection of habitat by Musk deer. The red line is the mean value, while the cobalt blue shades show standard deviations from the mean value of the variable

The Jackknife rest of regularization revealed that annual precipitation (bio_12) was the most important environmental variable as it had the highest gain when used in isolation—because of having the most useful information. When it was omitted, the gain decreased as it had the most important information that other variables were lacking (Figure 3.8).

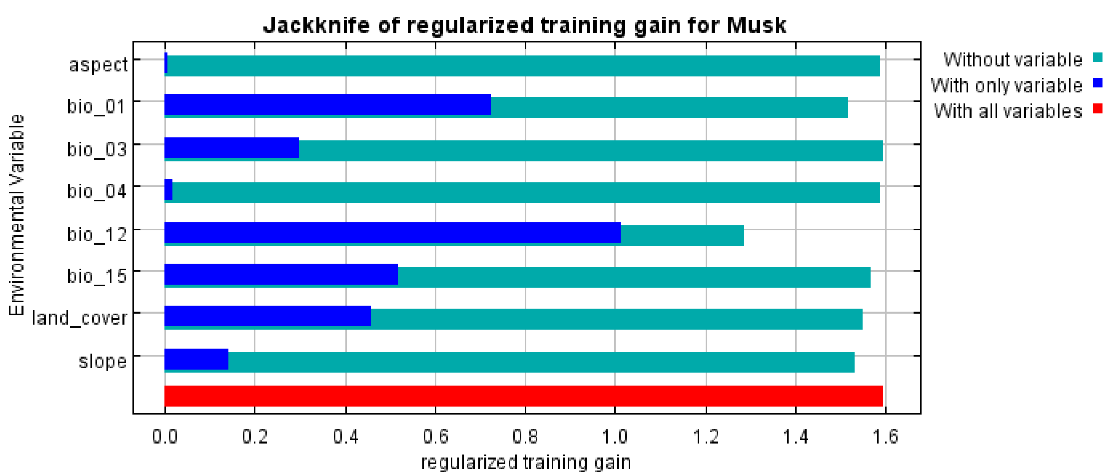

Figure 3.8. Jackknife analysis of variable importance showing the importance of each variable in predicting musk deer presence: 1) how the model's training gain was affected when each variable was omitted (aqua blue); 2) how it affected the training gain (cobalt blue) when each variable was used separately; and 3) total model gain (red)

3.3.4 Predicted suitable habitat for musk deer

The MaxEnt model predicted large areas of suitable habitat for musk deer in the districts of Astor and Diamer, overall, the model predicted 9,115.52 km^2 suitable habitat for muck deer which is 12.52 % of total study area (72,971 km^2). A contiguous suitable habitat was present in valleys on either side of the Indus River in Diamer district (from Goherabad to Tangir and from Raikot to Diong valley) (Figure 3.9). In Astor district, suitable habitat began at the ridgeline from the Daskin-Musking Valleys and ended in the valleys of Rupal, Rattu, Kalapani, Minimerg, and Parishing. From Minimerg Valley, the suitable habitat continued in an easterly direction along the Shingo River and continued in India. In Gilgit district, suitable and connected habitat patches existed in the west and south of Gilgit river from Sai Jaglote nullah to Kargah nullah that continued into Ghizer district, where there were highly suitable areas on the right side of the Gilgit river up to Hundarap nullah. A moderately suitable habitat continued from the Bonji Valley of Astor district and entered Skardu district, following the ridgeline along the Indus River up to Sadpara Valley. The model predicted low quality habitats in the Nalter and Haramosh valleys of Gilgit district and Bar Valley of Nagar district. Districts of Hunza, Kharmang, and Ghanche constituted unsuitable habitats (Figure 3.9).

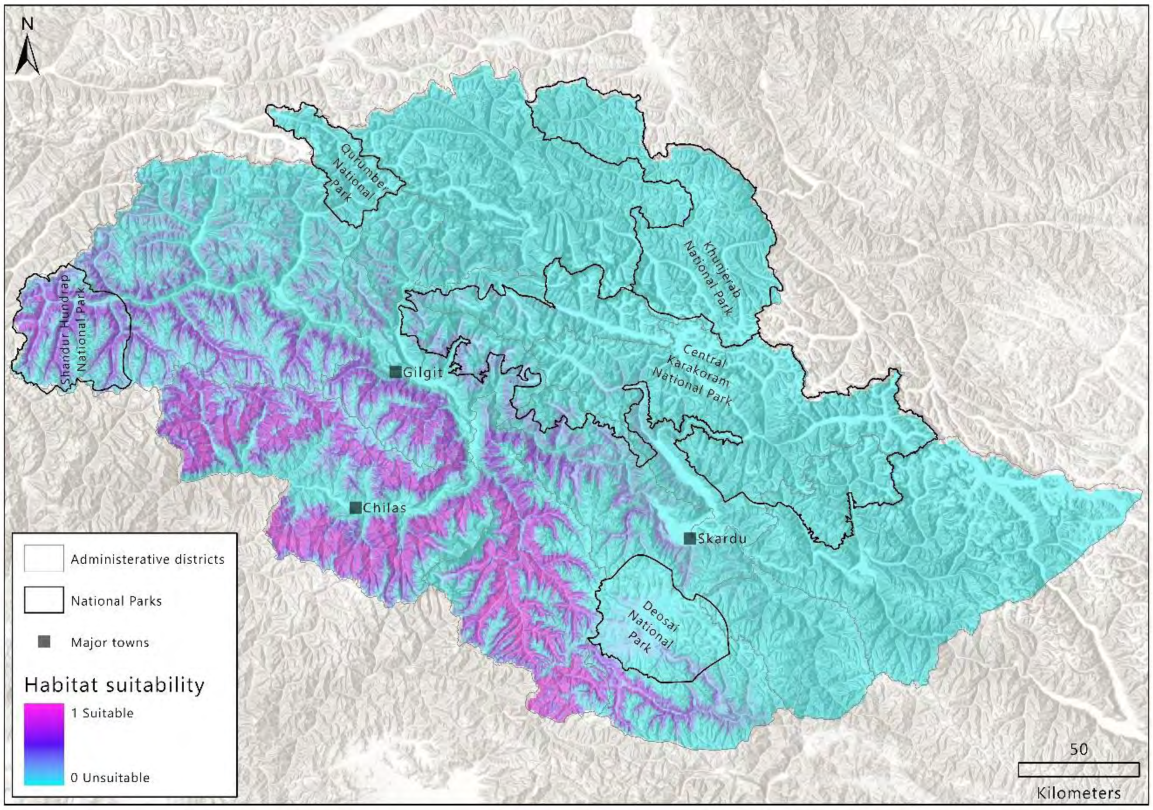

Figure 3.9. Suitable musk deer habitat predicted by the MaxEnt model in GB. The scale shows the probability of presence ranging from 0 to 1

3.3.5 Connectivity among patches

The maps of current flow density suggested a strong connectivity among 4-5(Dumot-Gais valleys patches, similarly in 11 – 12 (Rupal-Rattu valleys), and 19 - 20 (Basho-Sadpara) valleys (Figure 9). Populations in two valleys (Hushey (22), Biangsa (23) appeared to be isolated. Rest of all populations have weak to moderate connectivity (Figure 3.10).

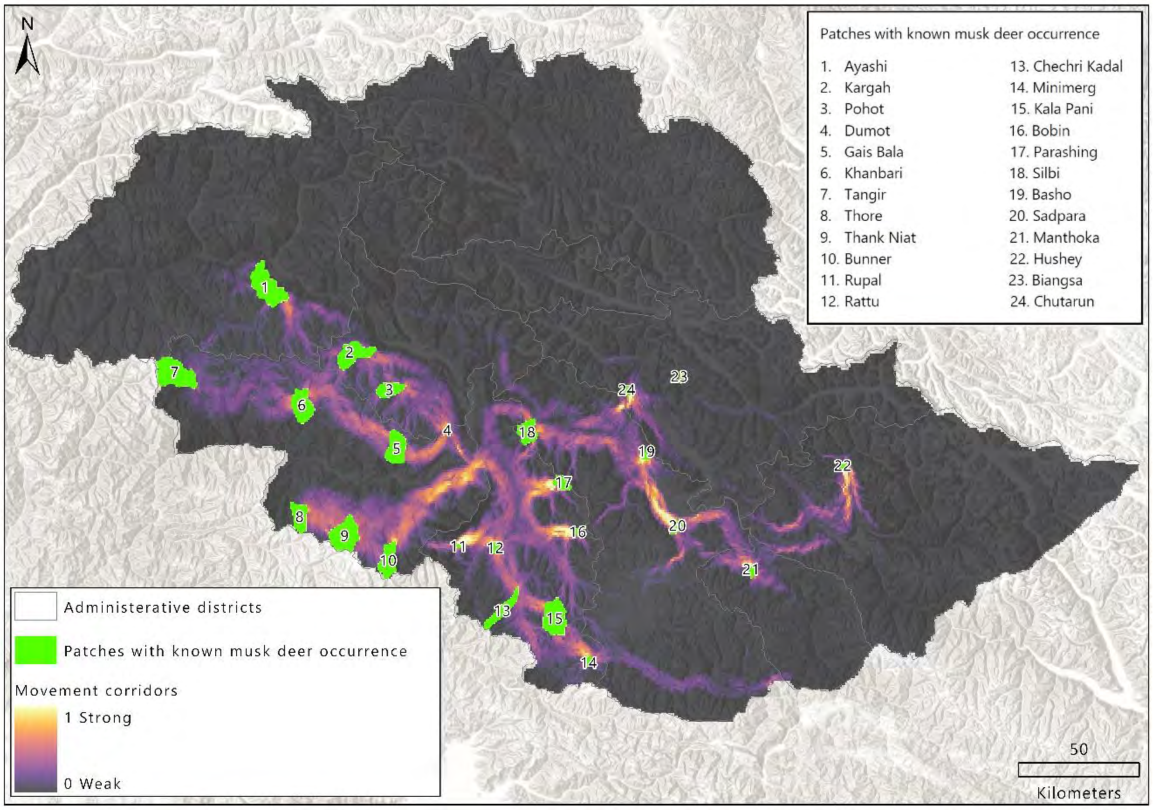

Figure 3.10. Predicted movement corridors of musk deer in GB. The scale ranges from 0 (low) to 1 (high) suitability for movement

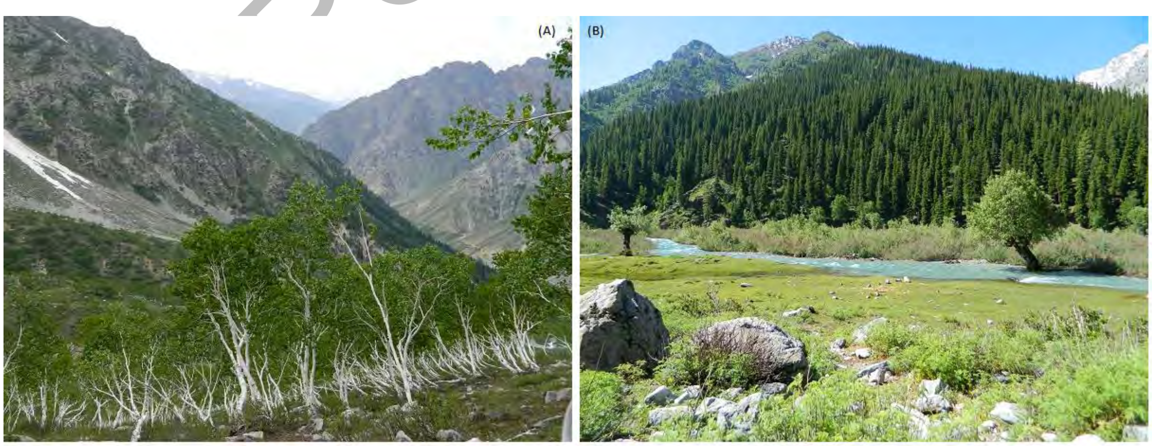

Figure 3.11. Typical musk deer habitat: (A) birch patch; and (B) closed patch with juniper trees.

3.4 DISCUSSION

The musk deer is a forest-dwelling species. Its numbers have depleted to a drastic level due to habitat modification and deforestation (Green, 1986; Singh et al., 2020). In addition, the use of musk in high-grade perfumes and medicine has made musk deer a highly coveted species, which has further decreased its population (Khan et al., 2006; Sathyakumar et al., 2012). To conserve musk deer, many valleys in the musk deer habitat range were notified as Community Controlled Hunting Areas (CCHAs). The establishment of protected areas (PAs) bring many incentives to custodian communities and resultantly they agree to decrease their dependency (Din et al., 2020) on musk deer habitat for agropastoral practices, but lack of PAs with strict laws (national parks or wildlife sanctuaries) enable overexploitation of resources from these PAs, like collection of herbs and poaching of animals especially musk deer (Qureshi et al., 2013). To assess the effectiveness of these conservation interventions, population monitoring is a prerequisite, as it provides information about the current distribution and emerging threats (Singh and Milner-Gulland, 2011) to improve management measures.

Musk deer's preference for dense forest has made this species difficult to count using direct count methods (Ostrowski et al., 2016). Therefore, their numbers and distribution have generally been reported via questionnaire surveys and indirect signs like latrines and pug marks (Abbas et al., 2015; Ilyas, 2015; Khalid et al., 1995; Qureshi et al., 2004; Singh et al., 2020). However, in a few instances, advanced techniques like camera trapping have also been employed (Pal et al., 2021). This study merited with the application of all the three methods to collect robust information on musk deer distribution and abundance.

The locations where the presence of musk deer was reported in this study included the districts of Astor, Diamer, Ghizer, and Baltistan division (districts of Skardu, Shigar, Karmang, and Ghanche) (Figure 3.1). The distribution of musk deer was reported in all these districts by (Abbas et al., 2015; Green, 1986; Roberts, 1997; Schaller, 1980).

Most of the musk deer latrines were in the districts of Diamer and Astor, followed by Gilgit, Skardu, and Ghizer. No latrines were found in Shigar, Kharmang, and Ghanche. A good population of musk deer was reported for Diamer, Astor, Ghizer and Baltistan division in old and recent literature (Abbas et al., 2015; Green, 1986; Roberts, 1997; Schaller, 1980)

Earlier, Roberts, (1997) reported a good population of musk deer in Hushey valley of Ghanche district of Baltistan. However, despite the extensive efforts, I was unable to confirm the occurrence of musk deer in this region.

Musk deer signs were encountered at elevations of 2,556–4,107 m. Musk deer elevation preference in the study area was like that reported in earlier studies (Green, 1985; Qamar et al., 2008; Sathyakumar et al., 2012).

The high AUC value (> 9.0) suggested that our model had high discrimination power. The high TSS value of 0.677 further proved it as a model of high significance (Hanspach et al., 2010). Our model predicted good habitats not only in areas that were previously reported (Abbas et al., 2015; Green, 1986; Roberts, 1997; Schaller, 1980), but identified new potential sites. The new suitable patches lie along the Shingo River which originates from the Minimerg Valley in Astor, and for the valleys from Gahkuch to Hundarap Valley on the left side of the Gilgit river (Figure 8). Although musk deer were not reported in the valleys along the Shingo River, existence of good patches of *Juniperus spp.,* blue pine *(Pinus Wallichana)* suggest suitability of this area. Similarly, good forest patches where musk deer could subsist were reported in the Singul, Gitch, Gulapur, and Sher Qilla valleys along the Gilgit river in Ghizer district by (Rao and Marwat, 2003). Schaller, (1980) quoting Raja of Gupis reported presence of musk deer in all ravines of the Gilgit river until 1947.

Annual precipitation (bio_12) was the environmental variable that contributed the most to the MaxEnt model. The only other study that predicted suitable Kashmir musk deer habitat based on a MaxEnt algorithm (Singh et al., 2020) found that the precipitation of the driest quarter (bio_17) was the most contributing environment variable. Bio_12 was followed in percentage contribution by bio_15, precipitation seasonality. A study that focused on Himalayan musk deer in Pakistan, found precipitation seasonality to be its second-most contributing environmental variable (Khadka et al., 2017). Tree species in musk deer habitat are limited by moisture availability in the pre-monsoon season (Dawadi et al., 2013). This highlights the importance of rainfall for forest-dwelling species like musk deer. Annual mean temperature (bio_01) was the third-most contributing environmental variable. Khadka et al., (2017) reported bio_01 as the most important environmental variable in their model. Sparse broad-leaved forests along with mixed forests were the most contributing land cover categories for predicting suitable musk deer habitat. These forest types included blue pine and birch (Figure 3.11), which are similar preferences reported for Himalayan musk deer in Nepal (Lamsal et al., 2018) and Pakistan (Qureshi et al., 2013).

The connectivity model (Figure 3.10) predicted connectivity corridors between the patches of Dumot Valley (4), and Gais Bala Valley (5), Rupal (11), and Rattu (12). The reported patches were separated by high elevations in the range of 4,500–8,000 m. Musk deer movement is possible among patches that are below 5,000 m—they are generally reported up to 4,500 m (Groves et al., 1995; Ilyas, 2015). Movement between many patches is constrained by mountains over 5,000 m that are either devoid of forest or remained snow-capped (Ali et al., 2014; Rao and Marwat, 2003). Similarly, movement is also constrained between patches at low elevations due to anthropogenic activities (Kabir et al., 2017). Therefore, in corridor modeling, high elevations, barren lands, glaciers, snow-capped peaks, and areas with high levels of anthropogenic activity are given high resistance values to train the model—the higher the value of the layer, the lower the chance of permeability for the specie (Poor et al., 2012; Zhang et al., 2021).

During the questionnaire surveys in eight valleys, it was suggested that musk deer numbers were increasing. Respondents in most valleys, however, thought musk deer numbers were decreasing mainly due to poaching followed by climate change and habitat degradation. This is also the case with other species of musk deer in Asia (Abbas et al., 2015; Green, 1986, 1985; Ilyas, 2015; Khalid et al., 1995; Khan et al., 2006; Qamar et al., 2008; Qureshi et al., 2004; Timmins and Duckworth, 2015b).

3.4.1 Management implications

This was the first extensive study in the region that yielded empirical data on musk deer occurrence and based on that constructed habitat suitability of the species. An overlay of existing PAs on musk deer habitat indicated that most of the highly suitable areas were unprotected, as they do not fall under any national parks. Hence, we recommend establishing new protected areas covering the *nullahs* (watersheds) from Minimerg to Zaipur, Rupal valley in Astor as a national park. The Nanga Parbat, Raikot, Fairy Meadows, Jalipur, Goner, and Bunner valleys in the Diamer district also require a PA status. Other candidate sites for inclusion in PAs are Kargah to Dumot valleys in Gilgit district, and Goherabad to Tangir in Diamer district.

Furthermore, as musk deer have a patchy distribution and very small home ranges, we suggest valley level conservation planning for effective recovery of musk deer populations. Localized actions may include protecting forest patches with known musk deer populations, motivating local communities for musk deer conservation, and hiring community wildlife wardens.

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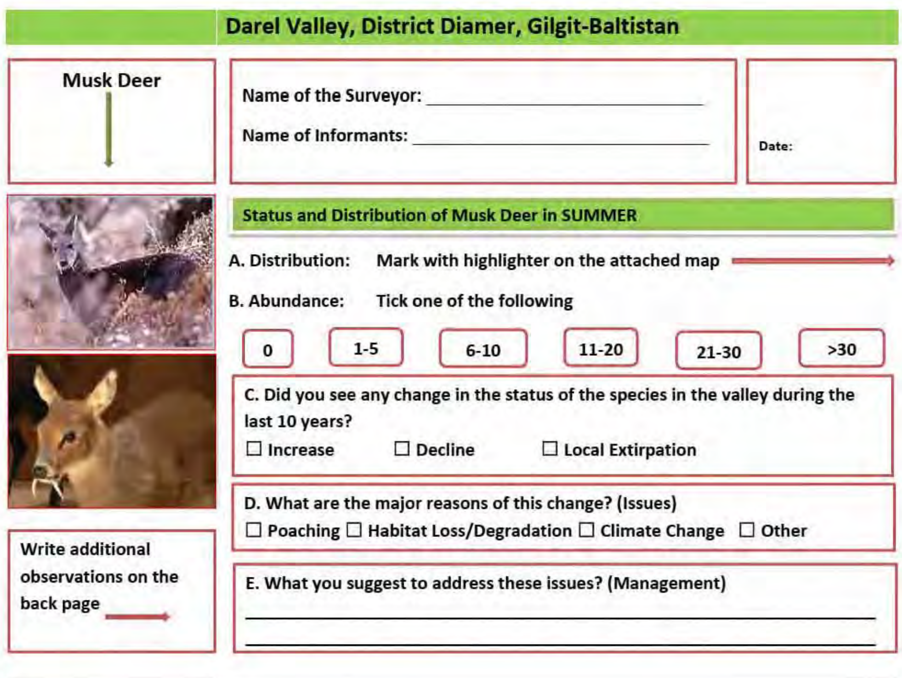
Appendix 3.1. Musk deer Questionnaire Survey format and GIS map to delineate location of musk deer.


Darel Valley, District Diamer, Gilgit-Baltistan

Musk Deer

Name of the Surveyor: ____________________

Name of Informants: ____________________

Date:

Status and Distribution of Musk Deer in SUMMER

A. Distribution: Mark with highlighter on the attached map

B. Abundance: Tick one of the following

0 | 1-5 | 6-10 | 11-20 | 21-30 | >30

C. Did you see any change in the status of the species in the valley during the last 10 years?

☐ Increase ☐ Decline ☐ Local Extirpation

D. What are the major reasons of this change? (Issues)

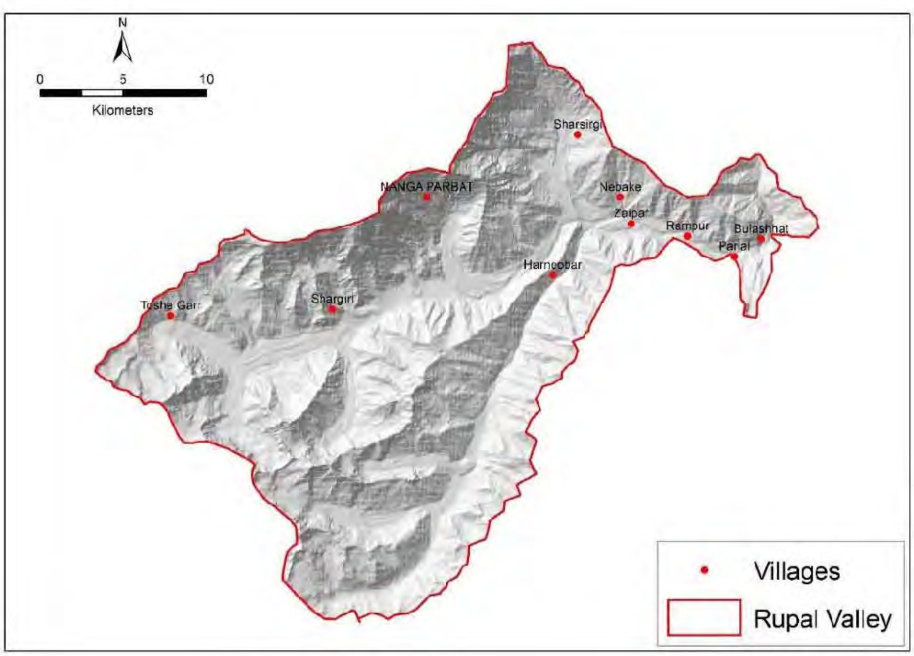
☐ Poaching ☐ Habitat Loss/Degradation ☐ Climate Change ☐ Other

Write additional observations on the back page

E. What you suggest to address these issues? (Management)

____

____



Appendix 3.2. Camera trapping field data collection sheet.

CAMERA TRAP STATION SHEET Set by: ____________

STATION ID	

e.g. Rupal 01

WATERSHED	

e.g. Rupal-WS1

Decimal degrees

N	□□.□□□□□□
E	□□.□□□□□□
ELEVATION	meters

CAMERA ID	

LURE TYPE	□skunk + fish oil	□castor + fish oil	□fish oil	□none		
HABITAT (in immediate surroundings)	□scrub	□forest	□pasture	□barren	□agric	
TERRAIN	□ridge	□cliff base	□draw	□valley	□saddle	□plateau
SUBSTRATE	□sand	□soil	□rock/gravel	□snow	□vegetation	

Station potential □good □medium □poor

STATION VISIT ⇩ **Sign in buffer area ⇨**

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

COMMENTS:
(use backside if needed)

CHAPTER FOUR

CURRENT DISTRIBUTION OF MARCO POLO ARGALI (OVIS AMMON POLII) IN PAKISTAN

4 CURRENT DISTRIBUTION OF MARCO POLO ARGALI (*OVIS AMMON POLII*) IN PAKISTAN

ABSTRACT

The distribution range of the Near Threatened Marco Polo argali, or Marco Polo sheep, *Ovis ammon polii* is restricted to the Pamir Mountains, spanning Afghanistan, Tajikistan, China, and Pakistan. Until the early 1970s the Marco Polo argali was abundant in northern areas of Pakistan, particularly in the Khunjerab and Misgar Valleys around the Pamir Knot, bordering China, Afghanistan, and Tajikistan. In Pakistan, the subspecies now occurs only in one small watershed, in Khunjerab National Park, bordering China, which it visits sporadically during summer. We used map-based questionnaire surveys, double-observer surveys, and camera trapping in a search for Marco Polo argali in the Pakistani Pamirs. We observed a herd of 19 individuals in Karachanai Nallah, in Khunjerab National Park, in 2012. The population that was formerly present in the Misgar Valley appears to have been extirpated, presumably because of anthropogenic factors such as poaching, competition with livestock, habitat disturbance, and the construction of a fence along the international border with China. Transboundary migration and range expansion into Pakistan could be facilitated by removal of the border fence adjacent to the Kilik–Mintika area and by limiting livestock grazing in former lambing areas.

Keywords: Anthropogenic effects, China, fencing, Marco Polo sheep, *Ovis ammon polii*, Pakistan, poaching, transboundary wildlife

4.1 INTRODUCTION

The argali *Ovis ammon* is categorized as Near Threatened on the IUCN Red List (Reading et al., 2020) but the Marco Polo argali (or Marco Polo sheep) *Ovis ammon polii* has not been assessed separately as a subspecies. However, a national assessment categorized the Marco Polo argali as Critically Endangered in Pakistan (Sheikh and Molur, 2004). The historical distribution of the subspecies includes Pakistan and other countries that share the Pamir Mountains (Russia, Afghanistan, China, Tajikistan, and Kyrgyzstan; (Fedosenko, 2000; Habib, 2006; Heptner et al., 1966; Petocz et al., 1978; Schaller, 1977, 1976; Schaller et al., 1987; Schaller and Kang, 2008). Throughout its range it is restricted to sparsely vegetated high-altitude environments (4,500 - 6,100 m) with harsh climatic conditions (Roberts, 1997; Schaller et al., 1987).

In Pakistan, the Marco Polo argali was reported historically from only three sites in the extreme north-west of Hunza District in Gilgit-Baltistan (Hess et al., 1997; Roberts, 1997; Schaller, 1977). Retrospective studies have shown that these valleys were once home to sizeable populations. Roberts (1997) quoted the Mir of Hunza's estimate of 1,000 Marco Polo argali in Khunjerab National Park. (Clark, 1964) reported the sighting of 65 male Marco Polo argali by an American tourist. (Rasool, 1981) reported populations of 300, 120, 160 and 100 in 1975, 1976, 1979 and 1980, respectively, but during December 1987–January 1988 the population was estimated to comprise only 20–25 individuals (Rasool, 1990). (Ahmad, 1996) reported 52 individuals from Karachanai Valley, and (Shafiq and Ali, 1998) reported 87 in Khunjerab National Park. Schaller et al. (1987) confirmed local extirpation on the Chinese side of the Khunjerab Pass and referred to the population in the Karachanai area as an isolated one. Schaller et al. (1987) found only a skull as evidence of the Marco Polo argali at the Kilik Pass on the Pakistani side in 1974 but observed 48 individuals on the Chinese side of the Mintika Pass.

Rasool (1990) linked the historical abundance of argali in Pakistan to the ban on hunting imposed by Mir Muhammad Nazim Khan of Hunza (1892–1935), with rampant poaching on the Chinese side forcing the species to take refuge in the Kilik, Mintika and Khunjerab Pass areas until 1949, when the Chinese government imposed a ban on the hunting of argali. Meanwhile the situation reversed in Pakistan following the death of Mir Nazim

Khan, and the Mir's and local poachers began hunting the species. The situation worsened during the construction of the Karakoram Highway during the 1960s and 1970s, when argali were poached to feed labourers. Observing the species' plight in 1975, George Schaller suggested that the government of Pakistan declare Khunjerab a protected area (Rasool, 1990). Khunjerab National Park was established in 1975, with the primary objective of protecting remnant populations of Marco Polo argali. However, no agency has monitored the argali population since 1998, and its status in Khunjerab and other parts of its historical range in Pakistan is unclear. Our study was motivated by this paucity of information about the species' current status in Pakistan.

4.2 MATERIAL AND METHODS

4.2.1 Study Area

The study was conducted in districts of Hunza and Nagar of Gilgit-Baltistan, because the literature that was conducted to ascertain the distribution of Marco Polo argali in Pakistan, the literature reported that Marco Polo argali was endemic to Gilgit-Baltistan and within Gilgit-Baltistan it was reported mainly in Misgar and Khunjerab Valley in the extreme north of district Hunza-Nagar. As both reported valleys were part of district Hunza but still the study included the watersheds of district Nagar due to its contiguity and possibility of move into district Nagar using movement corridors (Figure 4.1). Both the districts cover an area 14,305.67km^2. The area is dominated by rugged mountains, glaciers, alpine pastures, and forest patches at lower elevations (Khan et al., 2019). The areas mainly close to rivers beds are used by the inhabitants as arable land to cultivate wheat, maize, barley, potato. Both the districts are valued for the being the pioneers of social forestry in Gilgit-Baltistan. Apricots, cheery, apple and walnuts of the both the districts are famous all over the Pakistan for its best quality.

The first national of Gilgit-Baltistan i.e., Khunjerab National Park (KNP) was also established in the district Hunza on the recommendations of George B Schaller in 1975 (Rasool, 1990) and the largest national of Pakistan i.e., Central Karakoram National Park (CKNP) also falls in district Nagar. Bar Valley in the district Nagar was the first valley in the Gilgit-Baltistan where from the trophy program in Gilgit-Baltistan was initiated in 1993(Arshad et al., 2002) and now both the districts have a total of 17 Community Controlled hunting areas (CCHAs).

4.2.1.1 Flora

The flora of study area contains vegetations of mountain dry temperate coniferous forest (lower parts up to Minapin Valley in the district Nagar) and sub alpine all the valleys of both districts above Minapin Valley. Mountain dry temperate coniferous forests containing deodar (*Cedrus deodara*), blue pine (*Pinus wallichiana*), fir (*Abies spectabilis*), spruce (*Picea smithina*), chilgoza (*Pinus gerardiana*), juniper (*Juniperus* spp), Birch (*Betula* *utilis),* Bare Root Rose *(Rosa webbiana),* sea-buckthorns (*Hippophea rhamnoides)* and (*Artemisia* spp*)*. Sub Alpine zone is characterized by the highest snowfall in Northern Areas, ranging up to 3 meters, but with low rainfall. The prominent plant species of this zone include birch, willow, *juniperus*, *Ephedera, Artemisia Vibernum, Andropogon, Berbris, Lonicera* (Ali et al., 2015; Roa and Marwat, 2003).

4.2.1.2 Fauna

The districts of Hunza-Nagar are known for its gigantic wildlife species including; snow leopard (*Panthera unica*), Himalayan ibex (*Capra ibex sibirica*), blue sheep (*Pseudois nayaur*), brown bear (*Urus arctos*), red fox (*Vulpes vulpes*), stone martin (*Martes foina*), Altai mountain weasel (*Mustela altaica*), pika (*Ochotona* spp.) snow cock (*Tetraogallus himalayensis*), cape hare (*Lepus capensis*) and golden marmot (*Marmota caudata*), Marco Polo sheep (*Ovis ammon polii*), Astor markhor (*Capra falconeri falconeri*) and Ladakh urial (*Ovis vignei vignei*) (Khan et al., 2019).

4.2.1.3 Climate

The districts of Hunza-Nagar fall in Sub Alpine (upper valleys) and dry temperate zone (lower valleys, with dry cold winters and mild summers. During the month of January, the valleys remain covered with the snow and the temperatures falls below zero. During the summers the barren mountains absorb solar radiations, which are then converted to long wave heat, which rises the temperatures in the summers. Average temperature in summer rises from 17.5ºC to 29ºC (June- August), in autumn it varies from 6.6ºC to 25.3ºC (September-November), in winter -2.7ºC to 10.8ºC (December-February) and in spring (March-May) from 8.8ºC to 22.8ºC, the study area receives an annual rainfall from 100 to 300 mm (Khan et al., 2019, 2014).

4.2.2 Data Collection

We used three methods: (1) questionnaires to assess the species' status and guide subsequent field surveys; (2) double-observer surveys (Suryawanshi et al., 2012; Tumursukh et al., 2015) to estimate abundance, corrected for imperfect detection; and (3) camera trapping (Zaumyslova and Bondarchuk, 2015) for Marco Polo argali in historically occupied habitat in Hunza District. We also used questionnaires to identify potential factors responsible for local extinctions, and to delineate areas of potential occurrence of the species(Lee et al., 2006).

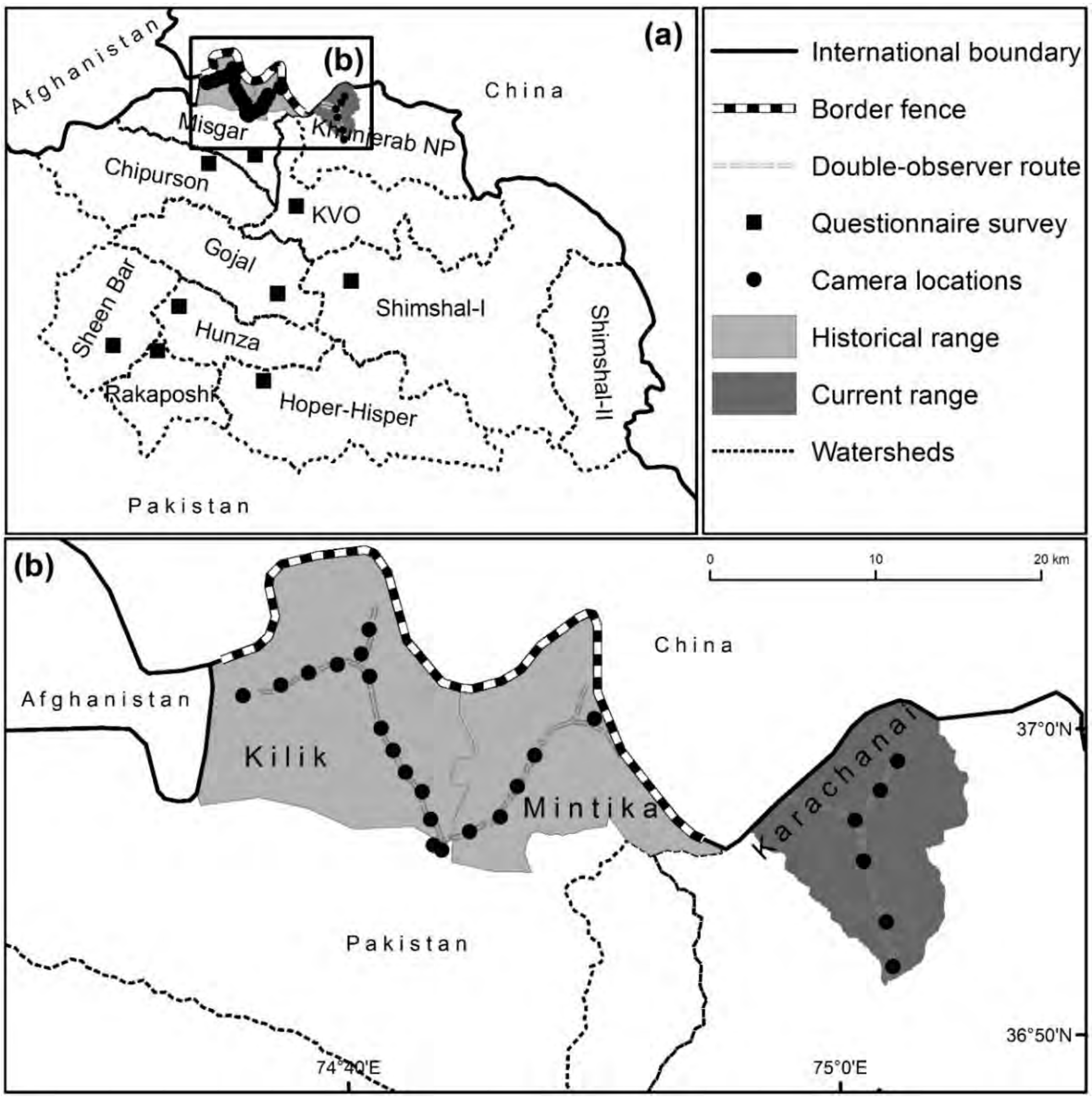


Figure 4.1. (a) Watersheds in the Hunza and Nagar Districts of Pakistan where local people participated in a questionnaire survey on the presence/absence of the Marco Polo argali Ovis ammon polii. (b) Locations of camera traps, and the routes of double-observer surveys.

4.2.2.1 Questionnaires Survey

Local knowledge can yield valuable insights into the status and ecology of wildlife (Gandiwa, 2012). For this reason, and to guide subsequent field surveys, in the first phase questionnaire surveys were undertaken during 19–23 March 2012 using the especially developed questionnaire formats that contained Geographical Information System (GIS) based maps (Appendix 4.1). The Hunza and Nagar Districts were divided into 11 watershed-based valleys (Figure 4.1), a total of 50 interviews targeting local hunters, herders and merchants were conducted in each watershed (9x50=450, watersheds KNP and Shimshal II were excluded as both have no settlements), to record any sightings during the previous 10 years. Reported observations helped guide the delineation of areas for the camera-trap and double-observer surveys.

4.2.2.2 Camera Trapping

A total of twenty trail cameras (Reconyx HC 500 and HC 900; Reconyx, Holmen, USA) were installed in areas where argali occurrence was reported by local people in the Kilik–Mintika area of Misgar and in Khunjerab National Park, each camera was apart at 1 km and at 1 meter from camera a lure station was established by levelling the gravel or sand into a circle with the help of foot, in the centre of the circle a plaster of pairs tablet soaked in the fish oil was placed to attract carnivores and herbivores (Bischof et al., 2014, 2013)

4.2.2.3 Double Observer Method

The double observer method modified by (Suryawanshi et al., 2012) was employed in different valleys of the study area by dividing the larger valleys into smaller blocks based on watersheds. These blocks were not larger than daily ungulate or human movement ability. Two observers separated by time (15 minutes), if only one trail was available, and space, if two trails were available, surveyed each watershed by walking along pre-determined routes. Both observers recorded any pellets, tracks and skulls of argali encountered during the survey (Tumursukh et al., 2015). The details of sighting were recorded on the double observer method's field data collection format (Appendix 4.2).

4.3 RESULTS

Argali presence was reported only by interviewees in the Khunjerab area. The most recent sighting reported by interviewees in Misgar Valley was from c. 2004. In Chipurson Valley, which is contiguous with Misgar Valley and the Wakhan corridor of Afghanistan (Figure 4.1 A), the map-based questionnaire did not yield evidence of Marco Polo argali. In Chipurson Valley a poacher produced the skull of a male argali, which allegedly had been killed illegally at the Pakistan–Afghanistan border in 2007 (Plate 4.1).

Plate 4.1. Skull of a Marco Polo argali *Ovis ammon polii* ram allegedly poached in 2007 near the Pakistan–Afghanistan border.

Double-observer surveys (Suryawanshi et al., 2012; Tumursukh et al., 2016) were conducted in the second phase of the study, during 25 June–13 July 2012, in the Misgar Valley (956.11 km^2) and Khunjerab National Park (1,178.87 km^2) areas. These areas were divided into smaller blocks, based on watersheds. In Misgar the surveys focused on Kilik

(207 km^2) and Mintika (120 km^2), and in Khunjerab National Park surveys were conducted in Karachanai (78.3 km^2) (Figure. 4.1). No sightings of Argali were recorded in the Misgar Valley while, in Karachanai Nallah, Khunjerab National Park, both observers encountered a single herd comprising five males, eight females and six lambs, owning small data size statistics employed by the double observer method to use estimated population was not applied (Plate 4.2).

Plate 4.2. Four rams, part of a herd of 19 individuals, sighted in Karachanai Nallah, Khunjerab National Park.

The third phase i.e., camera trapping took place during 11 May–17 June 2013. Twenty trail cameras were installed for 1 month in areas where argali occurrence was reported by local people in the Kilik–Mintika area of Misgar and in Khunjerab National Park. No Marco Polo argali were photographed by camera traps in either the Misgar Valley or Khunjerab National Park while during the one month monitoring the cameras trapped snow leopard

(*Panthera unica*), Himalayan ibex (*Capra ibex sibirica*), blue sheep (*Pseudois nayaur*), brown bear (*Urus arctos*), red fox (*Vulpes vulpes*), stone martin (*Martes foina*), Altai mountain weasel (*Mustela altaica*), pika (*Ochotona sp*.,) snow cock (*Tetraogallus himalayensis*), cape hare (*Lepus capensis*) and golden marmot (*Marmota caudata*).

4.4 DISCUSSION

Our surveys in Chipurson Valley, Kilik and Mintika found livestock grazing extensively. These areas lie above 4,000 m, and because of the short growing season for grasses and forbs there was considerable competition for resources, even among livestock. This may have been sufficient for exclusion of wild sheep from the area (Bagchi et al., 2004; Mallon et al., 2014; Mishra et al., 2004; Schaller and Kang, 2008), even in the absence of poaching. Fencing by the Chinese authorities at Kilik Pass may obstruct potential corridors by which argali could cross into Pakistan (Schaller and Kang, 2008). Snow-capped mountains hinder argali migration from Wakhjir Valley (Afghanistan) into Pakistan.

Hess et al. (1997) assumed that the extinction of the Marco Polo argali in the Pamir Knot occurred as a result of poaching; however, wildlife authorities did not allow local people to enter Kilik and Mintika prior to 2012. Local people suggested that the extirpation of the Marco Polo argali in the Kilik–Mintika area was a result of the Chinese fence. Similarly, (Fox et al., 2008) and (Luikart et al., 2011) cited fencing as a hurdle to the movement of the Tibetan antelope *Pantholops hodgsonii* in China, and there is increasing awareness of the negative ecological impacts of international border fences elsewhere (Lasky et al., 2011; Linnell et al., 2016).

In 1991, after meeting with the Khunjerab Village Organization, the Khunjerab National Park administration imposed a total ban on livestock grazing in the Walakdur area in Karachanai Nallah (Hess et al., 1997). The movement of Marco Polo argali has increased since then (Riaz & Akram, KNP watchers (2012, pers. comm.). However, herders and poachers who used to visit Karachanai prior to the establishment of the Park reported that movement and numbers had decreased despite improved monitoring and the livestock grazing ban.

It is likely that livestock grazing and fencing along the international border have had negative effects on the movement and persistence of Marco Polo argali in their historical range in Pakistan. The species now appears to be confined to a single watershed in Khunjerab National Park, which it visits only during the summer. We recommend implementation of more effective monitoring of argali at the Kilik and Mintika game reserves. This could be achieved by recruiting local people as game watchers and involving them in game reserve management planning, as well as convincing them to keep livestock away from core areas of the reserves. We also recommend that government authorities negotiate with their Chinese counterparts for the removal of the fence from the Kilik and Khunjerab passes. Studies to understand resource competition (Namgail, 2006) between the Marco Polo argali and the Himalayan ibex *Capra ibex sibirica* in Karachanai Nallah are required, as the ibex population is increasing. Cross-border cooperation could also improve the chance of long-term survival of the Marco Polo argali in the Pamirs. Such efforts could include joint studies, for example using camera trapping and faecal DNA analysis to monitor space use and migratory movements by transboundary herds. Since the completion of our study the Parks and Wildlife Department in Gilgit–Baltistan has recruited local guards to protect wildlife in the Kilik–Mintika area but to date the guards have not reported the occurrence of argali there. Neither the Pakistani nor Chinese authorities have initiated discussion regarding the removal of the border fence from the Kilik–Mintika area.

4.5 ACKNOWLEGMENTS

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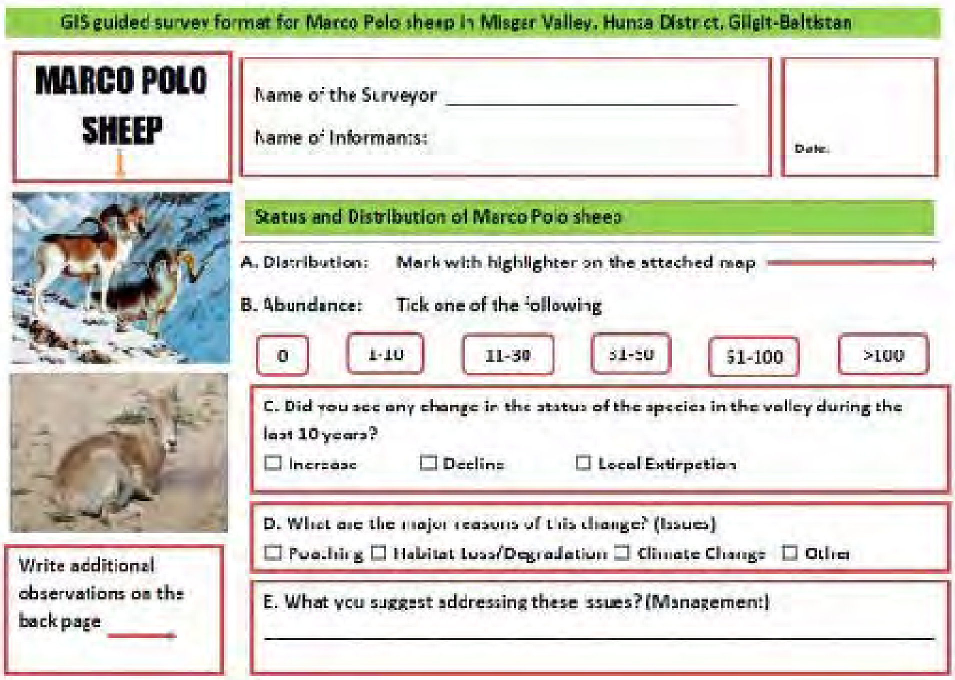
Appendix 4.1. GIS guided questionnaire survey form for Misgar Valley.



GIS guided survey format for Marco Polo sheep in Misgar Valley, Hunza District, Gilgit-Baltistan

MARCO POLO SHEEP

Name of the Surveyor ______________________

Name of Informants:

Date:

Status and Distribution of Marco Polo sheep

A. Distribution: Mark with highlighter on the attached map

B. Abundance: Tick one of the following

0 | 1-10 | 11-30 | 31-50 | 51-100 | >100

C. Did you see any change in the status of the species in the valley during the last 10 years?

☐ Increase ☐ Decline ☐ Local Extirpation

D. What are the major reasons of this change? (Issues)

☐ Poaching ☐ Habitat Loss/Degradation ☐ Climate Change ☐ Other

E. What you suggest addressing these issues? (Management)

Write additional observations on the back page

Appendix 4.2. Double Observer Survey filed data collection form.

Data Recording Format for Ungulate Survey using Double Observer Method

Survey Area/ ________________ Survey Block/ : ________________ Date/ : ________ Observer (A)—— or (B)—— Number: ______

Start GPS Readings: N ______________________ E ______________________ End GPS Readings: : N______________________ E ______________________ GPS ID: ___________

Herd #	Herd Size	Herd Type[1]	Age and sex classification: Female > 2 Year	Young < 1 Year	Yearling > 1 < 2 Years	Class I (2½) years	Class II (3½) Years	Class III (4½) Years	Class IV (5½) Years	Trophy Size in Class IV above 38 inches	Name of Herd Location	Please encircle location on the Map where herd is present — GPS Readings of Observer: N	E	Elevation	Time	Habitat type[2]	Herd Distance to Observer (m)	Slope Face[3]	Slope Angle[4]	Other Wildlife[5]	Herd Activity[6]
1																					
2																					
3																					
4																					
5																					

[1]Herd types: female herd (female and Young) =1, male herd (only males) =2, Mix herd (Males, Females and Youngs) =3
[2]Habitat types: Snow/برف=0, Bare Rock/ =1, Glacier/گلیشیئر =2, Rangeland/ = 3, Shrubs/جھاڑیاں =4, Mix Forest/ =5
[3]Slope Face: North (N), South (S), East (E), West (W) (use GPS compass)
[4]Slope Angle: < 45 (1), < 60 (2), < 90 (3)
[5]Leopard/ (L), Wolf/ (W), Bear/ریچھ (B), Jackal/گیدڑ (J), Fox/لومڑی (F), Wild boar/سور (WB)
[6] Feeding (FD), Walking (WK), Running (RN), Resting (RT)

Representative of (SLF/PSLEP): Name: ______________________ Signature: ______________
Representative of (MoCC): Name: ______________________ Signature: ______________
Representative of (Community): Name: ______________________ Signature: ______________

Both Observers should sit at the end of day to identify same herds, if the number of herd is the same and the location on map is also very close- but herd classification noted different by both observers- in that case the team that had most experience persons identification should be considered as authentic and this inform should be mentioned on back side of format that either observer A or observer B classification is authentic.

CHAPTER FIVE

GREENERY OR FEAR: SITE USE OF HIMALAYAN IBEX IN A PREDATOR-DOMINANT LANDSCAPE

5 GREENERY OR FEAR: SITE USE OF HIMALAYAN IBEX IN A PREDATOR-DOMINANT LANDSCAPE

ABSTRACT

The Himalayan ibex *(Capra ibex sibirica),* the largest and most populous wild ungulate of Pakistan, is a source of economic uplift for mountainous communities, a coveted trophy for game hunters, and the main prey base for the elusive snow leopard *(Panthera uncia).* Conservation incentives increased the number of ibex by reducing poaching incidents, but ample food supply also increased the number of its apex predator. No study thus far has focused on the strategies ibex use to survive in the rugged mountains of Pakistan, which are abundant with carnivores but devoid of vegetation to feed the increasing number of ungulates. I examined the co-occurrence of ibex and snow leopards in Hunza and Nagar Districts using an occupancy modeling approach. I checked the influence of roads, rivers, elevation, ruggedness, and normalized difference vegetation index (NDVI) using separate single-species occupancy models. I then used multi-species occupancy models to assess how these two species influence each other's distribution. Elevation influenced ibex distribution positively but had no effect on snow leopard distribution. In the case of snow leopards, NDVI influenced snow leopard distribution positively, but had a negative effect on ibex distribution. Similarly, ibex preferred areas close to rivers, while snow leopards had no preference for areas close to rivers. In the interacting state, snow leopards were found preferring elevated areas and areas close to rivers. The results of this study imply that ibex and snow leopards have clear preferences for habitat features, but snow leopard change their habitat preferences in relation to prey availability. These results suggest that ibex prefer safety over food.

Keywords: Himalayan ibex, snow leopard, co-occupancy, Hunza-Nagar, Pakistan.

5.1 INTRODUCTION

Space determines the nature of interaction between predator and prey. Prey species live in areas or patches with the maximum availability of food, protection, and fitness. Predator species, on the other hand, choose areas with the maximum opportunities to find and kill prey. But in the natural settings, habitat patches do not provide the same amount of food resources and physical features required for successful hunting due to their heterogeneity, hence restricting both prey and predators from using their home ranges uniformly (Althoff et al., 1997; Constible et al., 2006; Fortin et al., 2005; Orians and Wittenberger, 1991; Werner et al., 1983). This phenomenon is more pronounced in herbivores facing a continuous choice between foraging and escaping predation—as prey, herbivores live in a landscape of fear, avoiding areas of high forage if a perceived predation risk exists. However, these associations are not static and may change markedly under different conditions (Riginos, 2015). The environmental constraints in any landscape play a pivotal role in the formation of predatory and anti-predatory strategies. This results in a partial separation of prey and predator across landscapes and provides patches of relative safety for prey, but sufficient areas of overlap for predators to be successful (Arias-Del Razo et al., 2012).

There is well-documented evidence that interspecific interactions provoke spatial or temporal avoidance in carnivores (Parsons et al., 2019). Ungulates have their own strategies to avoid interspecific competition mostly in the form of niche overlap (Namgail, 2006), as both taxa have preferences for certain varieties of food. In some instances, animals are prey and predator at the same time. In such conditions, these animals have to make temporal and spatial adjustments to avoid predators and be successful predators (Bischof et al., 2014).

Prey species like ungulates modify their temporal and spatial activity patterns to avoid predation and other disturbances (Berger, 2007; Theuerkauf et al., 2003). They may make altitudinal migrations, especially when pregnant and lactating, or by making large-scale migrations by moving beyond the ranges of non-migratory predators (Hebblewhite and Merrill, 2009). That way, they sacrifice quality forage for protection from predators, (Behaviour and Mar, 1998; Festa-Bianchet, 1988; Namgail et al., 2007). Predation imposes strong selective and demographic effects on ungulates by decreasing their population sizes—ultimately leading to extinction given certain simultaneous environmental factors (Osmond et al., 2017). Predators with specialized morphology to hunt particular prey (Schmitz, 2017) require unique habitat features (like concealing cover) (Balme et al., 2007) and similar activity patterns to make successful kills (Theuerkauf et al., 2003). Models suggest that carnivores that do follow areas/patches where prey resources congregate have an advantage over predators that track higher densities or numbers of prey (Flaxman and Lou, 2009).

Among environmental forces, weather is the major force that drives prey-predator interactions. Prey begin foraging in risky areas during cold weather when fewer food resources are available and (Cresswell et al., 2010) and starvation risk outweighs predation risk—they seek risky areas profitable in food that are at minimal distances from escape cover (Yasué et al., 2003). In some situations, predators change or adjust their distribution in response to prey habitat choices, in such situations prey does not opt for relative resource availability to maximize fitness (Hugie and Dill, 1994).

Prey-predator interactions are explained by the optimal foraging model (Emlen, 1966; MacArthur and Pianka, 1966) or the game model (Smith, 1974). The optimal foraging model is based on the assumption that predators' primary goal is to maximize energy or protein intake (Pyke et al., 1977). The game model predicts that predators and prey move at similar spatial and temporal scales, i.e., predators are distributed uniformly when prey are (Luttbeg et al., 2020). In many cases, including in intraguild predation (IGP), predators are able to modify their distribution in relation to that of their prey such that actual predation risk is not fixed (Heithaus, 2001).

Many studies on prey-predator interactions are from Yellowstone National Park where the highly heterogeneous landscape provides prey with opportunities to escape predation (Kauffman et al., 2007). Conversely, homogenous landscapes with concentrated food resources lack distinct refuges due to being devoid of vegetation, and do not provide prey with opportunities of escape due to high accessibility to predators (Schmidt and Kuijper, 2015).

The Himalayan ibex is a large goat that lives in Central and South Asian landscapes that are rugged and devoid of vegetation, and where food is usually present in small patches along riverbeds (Roberts, 1997; Schaller, 1977). These landscapes are shared by the snow leopard as the apex predator that hunts with stealth like many other large predators (Pembury Smith and Ruxton, 2020).

Ibex prefer to graze close to steep cliffs to escape approaching predators. However, cliffs are also barriers to long-range migrations to avoid predators (Fox et al., 1992). Only a few studies have focused on species of similar size, habitat preference, and behavior to ibex, e.g., the Nubian ibex *(Capra ibex Nubian)* that lives in barren landscapes with homogeneous habitat features and concentrated food resources (Iribarren and Kotler, 2012). Measuring the impact of manmade stressors (poaching, competition with livestock, and anthropogenic actives in or around the habitats of wild animals) and natural stressors (harsh weather and threats of perceived predation that force prey species to live in a 'landscape of fear') can be useful in the management and conservation of wildlife populations. This is because the impact of predators is governed by the amount and configuration of risky habitat. Thus, quantifying and possibly changing the landscape of fear could benefit species or help assess the adequacy of an area before reintroducing species, e.g., bighorn sheep *(Ovis canadensis)* (Arias-Del Razo et al., 2012; Laundré et al., 2001).

To fill this gap in prey-predator interactions, this study was conducted to report novel insights into prey-predator relationships using the occupancy model (MacKenzie and Nichols, 2004; Rota et al., 2016). This model predicts habitat use by treating habitat features as explanatory variables and the presence of snow leopards as a pre-established threat for site selection by Himalayan ibex in landscapes where food is low, the weather is harsh, and habitat features provide camouflage.

5.2 MATERIALS AND METHODS

5.2.1 Study area

This study was conducted in different valleys of the districts of Hunza and Nagar, viz., Khunjerab, Misgar, Shimshal, Khudabad, Khyber, Hussaini, Gulmit, Ghulkin, Ahmedabad, Hassanabad, Nagar Khas, Hopper, and Hisper. These valleys all lie in the extreme north of Pakistan adjacent to the Chinese border and extend between 74°E to 76°E and 36°N to 37°N (Figure 5.1). The study sites covered an area of 14,826 km^2, which is dominated by rugged mountains with elevations of 1,695–7,889 m. The climate is cold and dry, with an average monthly temperature of -1°C during the coldest months (November–February). The average maximum temperature rises to 23.3°C during the warmest months (June–August) and the average annual precipitation is 149.7 mm, mainly as snowfall (November–February). There is a higher percentage of rainfall during March and April (Ali et al., 2015). The barrier effect of the Himalayas and Hindu Kush curtains the study area, restricting any benefit from the monsoons (Li et al., 2016). Due to this barrier effect, the Karakoram range maintains its aridity in the form of alpine steppes, (Schaller, 1977) providing suitable habitat for many important species of flora (*Primula macrophylla*, *Potentilla desertorum*, *Gentiana* spp., *Anemone* spp., *Plantago lanceolata*, *Saxifraga sibirica*, *Artemisia* spp*., Juniperus excels, Rosa webbiana, Myricaria germanica, Hippophae rhamnoides, Populus nepalensis*, *Salix* spp., *Betula utilis, Lonicera quinquilocularis, Setaria* spp., *Poa bulbosa*, *Poa sinaica*, *Phleum* spp., and *Carex* spp.) and fauna—the snow leopard *(Panthera uncia),* Himalayan ibex *(Capra ibex sibirica),* brown bear *(Ursus arctos isabellis),* grey wolf *(Canis lupus),* red fox *(Vulpes vulpes),* stone martin *(Martes foina),* Altai mountain weasel *(Mustela altaica),* pika *(Ochotona roylei),* Marco Polo sheep *(Ovis ammon polii),* and blue sheep *(Pseudois nayyaur)* (Qureshi et al., 2011).

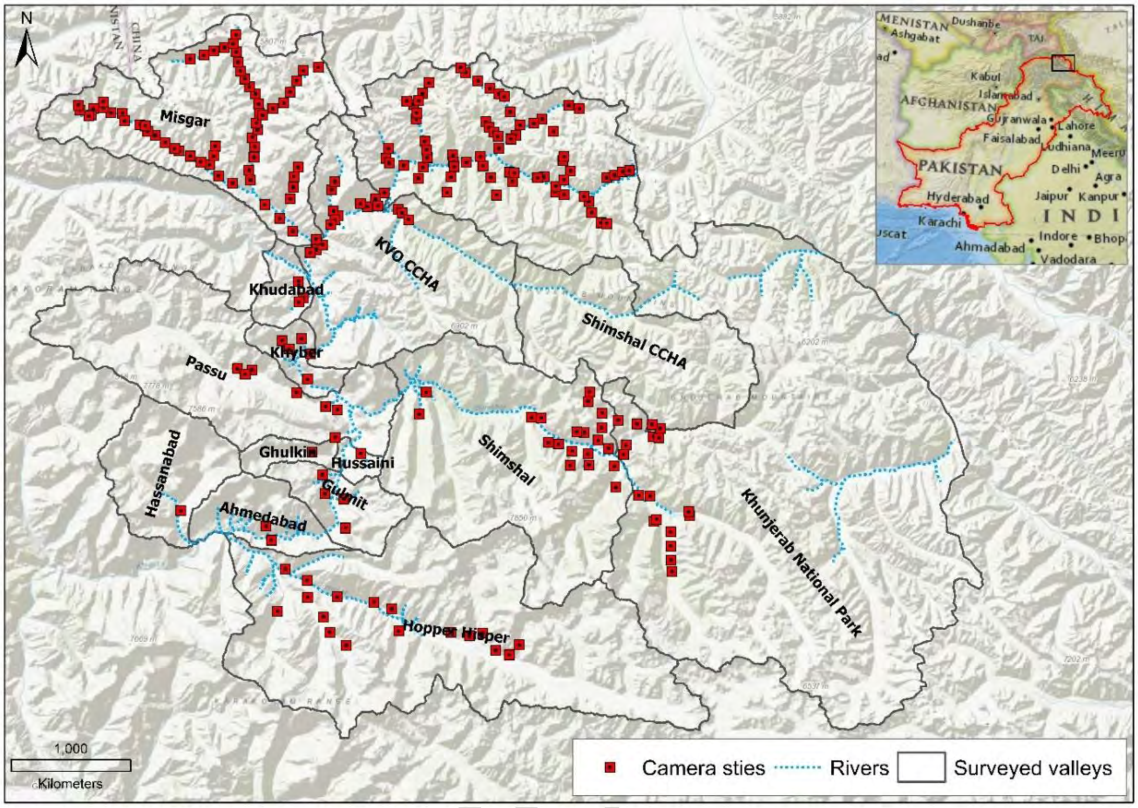


Figure 5.1. Study area showing locations of locations of camera sites in northern Pakistan**.**

5.2.2 Methodology

5.2.2.1 Species trapping

A total of 224 infrared/motion-triggered cameras (Reconyx HC 500 and HC 900; Reconyx, Holmen, USA) were installed, each separated by one kilometer (km) and mounted on specially designed 40–60 cm iron stands (Bischof et al., 2013). The presence of any indirect animal signs, e.g., scats, scrapes, pugmarks, chin rubs, and pellets (Karanth et al., 2011), and habitat features like ridges, cliff bases, and draws were considered important locations for camera installation (Bischof et al., 2013). To increase the detectability of target species, lure stations were established one meter away from each camera pole in view of the camera. These stations were established on leveled ground (done by foot) using plaster of Paris tablets soaked in fish oil. A boulder or vegetation was used to apply caster or skunk (Bischof et al., 2014, 2013). Using camera trapping survey formats, information like GPS coordinates of camera locations, type of lure, camera site potential, and signs of animals in a 20-meter buffer, were recorded.

The cameras were operational for 15–80 days. Trap histories of Himalayan ibex and snow leopards were developed when the cameras were taken down. We assigned ‘0’ for absence and ‘1’ for the presence of animals at the site (Alexander et al., 2016).

5.2.2.2 Covariates

Animals inhabit sites based on features. Therefore, I hypothesized the influence of certain landscape variables on the presence and absence of ibex and snow leopards. These included both natural (elevation, slope, aspect, distance to rivers, distance to glaciers, and normalized difference vegetation index (NDVI) and manmade variables (distance to roads). Shuttle Radar Topography Mission (SRTM) data was downloaded from (https://earthexplorer.usgs.gov/). The Terrain Ruggedness Index (TRI) was derived from the slope and aspect (Bragin et al., 2017). The Euclidean distances of rivers, glaciers, and roads (vehicular roads) and NDVI were calculated using Band 04 and Band 05 of Landsat 8 (downloaded from (https://glovis.usgs.gov/), while slope and aspect dervied form STRM using the differents tools for each operation in the spatial analyst tool in ArcGIS 10.8.1 (ESRI, Redland, USA).

I performed a statistical analysis at the camera station level (Alexander et al., 2016) using a circular buffer of 1,000 m around each camera station (Ladle et al., 2018). The average value of each variable was extracted using the zonal statistics tool in ArcGIS 10.8.1. The values were standardized at the zero mean and standard deviation of 1 (Zipkin et al., 2012) using the standardized function of the psycho package in R (R Core Team, 2021). I did not use any two variables that were correlated > 0.70 using the Pearson correlation test to avoid the problem of multi-collinearity (Dormann et al., 2013).

5.2.2.3 Occupancy modeling

We first ran a single-season, single-species occupancy model developed by (MacKenzie et al., 2002), as I hypothesized the need for a different set of habitat covariates as the species under consideration have different evolutionary lineages and dietary requirements.

Therefore, I first checked the effect of different habitat covariates on the detection probability of ibex and snow leopards—the covariates from the best detection model were kept constant when running models for estimating occupancy (Jones et al., 2016) using the occu function of the unmarked package in R (Fiske and Chandler, 2011). I then selected habitat covariates to use in multi-species models from the best detection and occupancy model using the Akaike Information Criteria (AIC) (Burnham and Anderson, 2002). We used a multi-species occupancy model developed by (Rota et al., 2016) which was adopted as a generalization of the single-species occupancy model of (MacKenzie et al., 2002). This was done to assess how the Himalayan ibex and snow leopard interact while accounting for imperfect detections (Parsons et al., 2019) using the occuMulti function of the unmarked package in R (R Core Team, 2021). Multi-species models are powerful as they can estimate the impact of Himalayan ibex and snow leopard on each other's occupancy against the impact of different covariates. I kept the detection and occupancy state covariates taken from single-species models fixed, while the impact of different covariates was tested on the interaction terms. I then ranked the multi-species models using AIC to find the best model (Burnham and Anderson, 2002).

5.3 RESULTS

The dataset used consisted of 224 camera trap sites and 6,074 camera trap nights. I recorded 65 snow leopard observations at 44 camera trap sites (19.64% of total camera trap sites) and 73 Himalayan ibex observations were recorded at 40 camera trap sites (17.85% of total camera trap sites). Both species were trapped at ten sites. Other species trapped included the red fox, stone martin, weasel, blue sheep, pika, golden marmot, and snowcock. The largest number of captures occurred in Khunjerab National Park—20 camera trap sites for snow leopards, 22 for ibex, and 4 for both species. In Misgar valley, snow leopards were captured at 14 sites, ibex at 12 sites, and both species at 4 sites. In Hunza-Nagar, snow leopards were captured at ten sites, ibex at six, and both species at two sites.

Table 5.1. Summary of model selection results indicating the role of covariates in determining the probabilities of step 1: Single-species occupancy (ibex and snow leopard), and step 2: Co-occupancy of ibex and snow leopard.

Model	AIC	Delta	AIC weight	Cumulative weight	K
Step 1: Ibex					
1. ψ (Elevation) p (RGN)	696.28	0.00	0.552	0.55	4
2. ψ (NN) p (RGN)	698.45	2.17	0.187	0.74	4
3. ψ (DISRV) p (RGN)	699.20	2.92	0.128	0.87	4
4. ψ (.) p (RGN)	700.81	4.53	0.057	0.92	3
5. ψ (NDVI) p (RGN)	702.29	6.01	0.027	0.95	4
6. ψ (DISRNE) p (RGN)	702.48	6.20	0.025	0.98	4
7. ψ (RGN) p (RGN)	702.59	6.31	0.024	1.00	4
Step 1: Snow leopard					
1. ψ (NDVI) p (RGN)	695.03	0.00	0.429	0.43	4

2.	ψ (.) p (RGN)	697.28	2.26	0.139	0.57	3
3.	ψ (RGN) p (RGN)	697.35	2.32	0.134	0.70	4
4.	ψ (DISRNE) p (RGN)	697.49	2.46	0.125	0.83	4
5.	ψ (NN) p (RGN)	698.72	3.70	0.068	0.89	3
6.	ψ (DISRV) p (RGN)	699.17	4.15	0.054	0.95	4
7.	ψ (Elevation) p (RGN)	699.28	4.26	0.051	1.00	4
Step 2: Co-occupancy						
1.	ψ (Elevation + NDVI + DISRV) p (RGN + RGN)	1389.69	0.00	0.366	0.37	10
2.	ψ (Elevation + NDVI +.) p (RGN + RGN)	1390.90	1.22	0.199	0.57	9
3.	ψ (Elevation + NDVI + elevation) p (RGN + RGN)	1391.86	2.17	0.124	0.69	10
4.	ψ (Elevation + NDVI +NN) p (RGN + RGN)	1392.71	3.02	0.081	0.77	10
5.	ψ (Elevation + NDVI + RGN) p (RGN + RGN)	1392.77	3.09	0.078	0.85	10
6.	ψ (Elevation + NDVI + NDVI) p (RGN + RGN)	1392.78	3.10	0.078	0.93	10
7.	ψ (Elevation + NDVI +DISRNE) p (RGN + RGN)	1392.88	3.20	0.074	1.00	10

Covariates: Elevation = elevation; RGN = ruggedness; NN = northness; DISRV = distance to rivers; NDVI = normalized difference vegetation index; DISRVE = distance to roads

In the first-step modeling (Table 5.1), detection (p) was best explained by the model that included ruggedness (AIC weight = 700.81). The probability of detecting Himalayan ibex increased in rugged areas (β = 1.05 ± SE 0.26). Occupancy (ψ) was best explained by the model that included elevation (AIC weight = 696.28). The occupancy of Himalayan ibex increased at higher elevations (β = 0.85 ± SE 0.36).

In the case of the snow leopard (Table 5.1), the best detection model included ruggedness (AIC = 696.28). The probability of detecting snow leopards was higher in rugged areas (β = 0.50 ± SE 0.23). Snow leopard occupancy was best explained by the model that contained NDVI (AIC = 695.03). Snow leopard occupancy decreased with NDVI (β = -12.91 ± SE 6.93).

In the multi-species models (Table 5.1), detection was best supported by the model that included ruggedness for both species (AIC weight = 1389.69). The probability of detecting ibex and snow leopards was high in rugged areas (β = 1.08 + SE 0.25 and β = 0.489 ± SE 0.23, respectively). While occupancy was best explained by the model that included elevation, NDVI, and distance to rivers, high elevations were more likely to be occupied by ibex (β = 0.984 + SE 0.37). NDVI was the variable that best explained snow leopard occupancy. Snow leopard occupancy decreased with NDVI (β = -11.507 + SE 6.704). Distance to rivers was the variable that best explained the occupancy of both species in the interacting state. The occupancy of both species was high close to rivers (β = -3.248; SE 3.353).

In the single-occupancy state, ibex showed a preference for areas close to rivers (Figure 2a), while snow leopards had no response to river distance (Figure 5.2 b). However, in the interacting state, snow leopards preferred areas close to rivers (Figure 5.2 c and Figure 5.3).

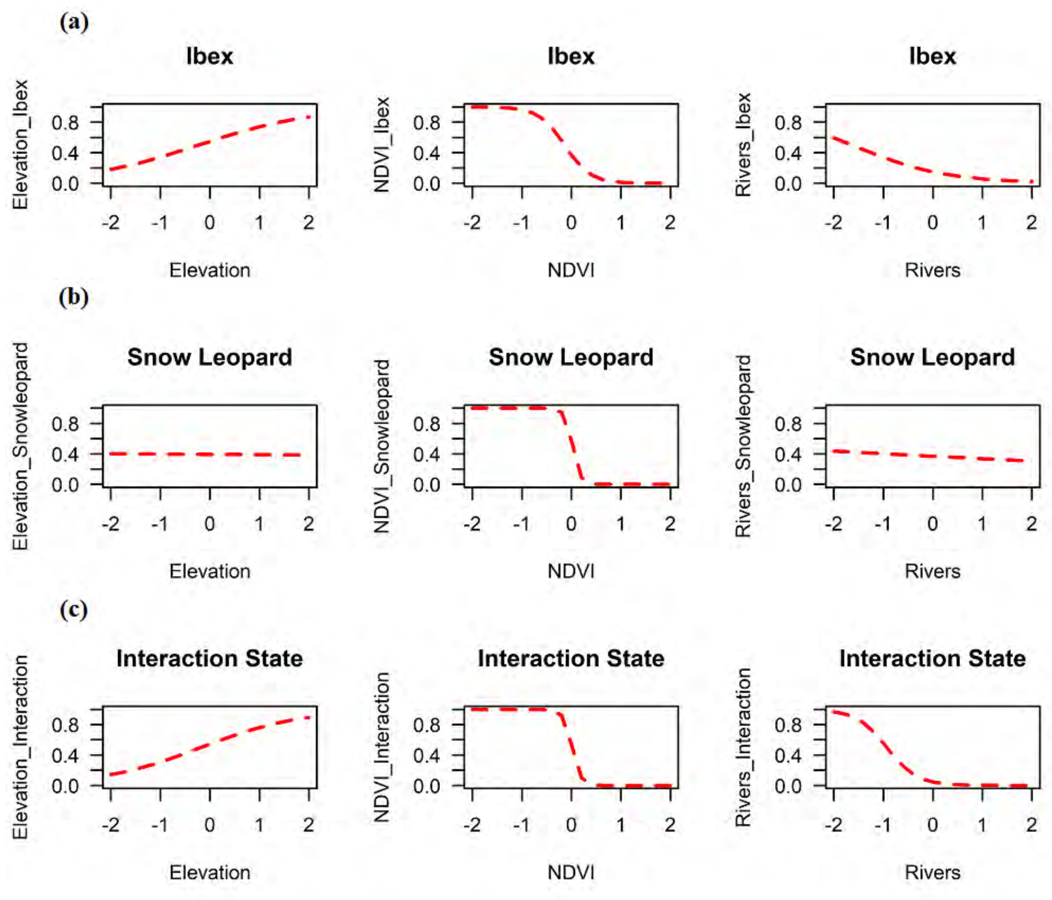


Figure 5.2. (a) Himalayan ibex response to elevation, NDVI, and distance to rivers in the best single-species model; (b) Snow leopard response to elevation, NDVI, and distance to rivers in the best single-species model; (c) Himalayan ibex and snow leopard responses to elevation, NDVI, and distance to rivers in the best multi-species model.

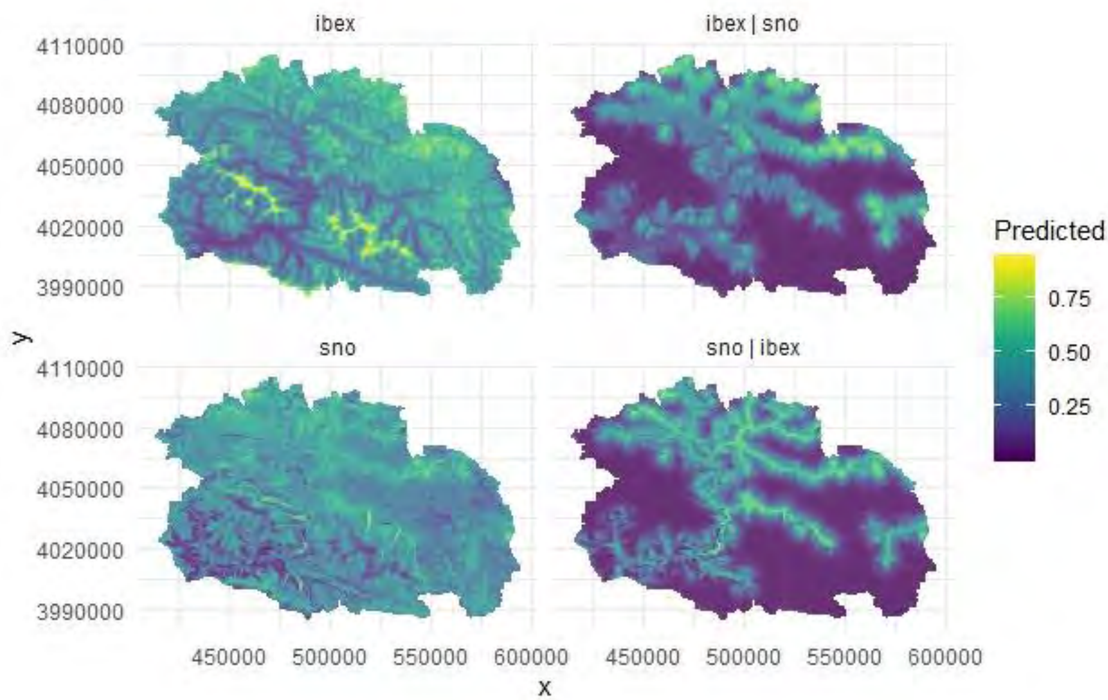


Figure 5.3. Himalayan ibex and snow leopard response in the single and interacting occupancy states.

5.4 DISCUSSION

In the high, arid mountains of Asia roams the ghost of mountains—the snow leopard (Schaller, 1980, 1977) an elusive and stealthy predator that preys on blue sheep and Himalayan ibex (Fox et al., 1992; Mallon et al., 2016). The prey species on these mountains negotiate rugged cliffs when they perceive approaching predators or human presence (Fox and Jackson, 2002; Namgail, 2006; Schaller, 1977). The 'landscape of fear' hypothesis proposes that prey species avoid energy-rich patches in favor of safety (Laundré et al., 2014), while predators forage free from predation risk—prey distribution determines their habitat (Mukherjee et al., 2009; Rosenzweig, 1973).

I found higher Himalayan ibex occupancy in elevated areas—it is reported that ibex prefer high elevations of 2,500–5,000 m (Fox and Jackson, 2002; Namgail, 2006; Salvatori et al., 2021; Schaller, 1977). These rugged mountains are devoid of dense vegetation—the floristic composition is dominated mainly by *Artemisia* spp. and *Ephedra* spp., and small shrubs (Schaller, 1977). In this study the negative association of ibex occupancy with NDVI, therefore, can be attributed to the bareness of the study area. The Karakoram-Pamir Mountain ranges usually receive precipitation in the form of snowfall that accumulates on the steep slopes, then melts or slips down in early summer. The water comes down through steams and grasses, shrubs, and trees growing along the streams and rivers. The riverbeds are usually a good source of forage for herbivores, and ungulates can be easily seen, especially during spring and autumn. I found that Himalayan ibex preferred areas close to rivers, which validates the findings of other authors (Han et al., 2021; Schaller, 1977).

Areas with high ruggedness (broken areas) had a higher rate of ibex and snow leopard detection. This was because the study area has a high proportion of ruggedness, and most cameras were in areas with a high ruggedness index. Snow leopards occupancy was negatively related with high NDVI values, which is consistent with the findings of (Bayandonoi et al., 2021; Lovari et al., 2013) that have showed that snow leopards avoid forested and non-mountainous areas, and prefer rugged terrain.

The snow leopard was found to prefer elevated areas and areas close to rivers, while Himalayan ibex retained their preference for elevated areas and areas close to rivers, even in the co-occupancy state. These findings validate (Alexander et al., 2016) work who found that prey presence was the main determinant of snow leopard site use. Prey use certain anti-predatory strategies to escape predation, but in certain instances, they have been observed foraging in riskier areas to avoid starvation (Cresswell et al., 2010). This study highlighted, that in our study area ibex had the opportunity to forage in quality food patches which were usually present at low elevated flat areas, but ibex avoided those patches (perceiving the risk of being preyed) and preferred to search for food close to escape terrain by balancing food requirement with risk avoidance. Some predators do not fix their distribution in relation to prey so that prey start perceiving those areas as risky for feeding (Heithaus, 2001).

5.4.1 CONCLUSION

The study demonstrates the opportunity of having prey determines the possibility for snow leopard presence, while the Himalayan ibex usually in the pursuit of safety in the habitats where they live, but as its habitats are devoid of uniform vegetation cover, but are in patches close to riverbanks which force Himalayan ibex to comprise safety over food, the study also concludes that multi-species model is a good approach to understand the site requirements of prey-predator, at single species level and on their spatial interactions level.

5.4.2 RECOMMENDATIONS

The green patches along the riverbanks are often grazing sites of livestock in the summers, this study recommend (1) the protected areas managers and shepherds should map the important patches where the ibex come to feed during the winters and avoid taking livestock to those patches to facilitate wild ungulates that they should get food at the risk of safety (2) Ban the shepherds to construct their traditional corrals on these grassy patches.

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CHAPTER SIX

CONCLUSION, FUTURE IMPLICATIONS AND RECOMMENDATIONS

6 CONCLUSIONS

This study confirms that all mountain ranges in GB host mountain ungulates, though each species occupies specific niche in relational to environmental covariates. The Himalayan ibex had the widest distribution among the four study species, though its major concentration was in the Karakorum range. Blue sheep had major stronghold in the Shimshal and Sockterabad valleys. Marco polo sheep is currently confined to one valley in Khunjerab National Park, while musk deer's prime habits exist in the Himalaya range.

Under climate change, ibex range is expected to shrink towards north, while that of blue sheep will extend towards east. We also found that ibex generally avoid areas occupied by the predator (however), however it may compromise security in favor of food.

6.1 FUTURE IMPLICATIONS

Conservation programs including the successful trophy hunting has resulted in increase of population of ungulate species especially that of ibex, blue sheep, and markhor. Economic befit gained by the community through these conservation programs, has inculcated a sense of ownership in the communities for these wild ungulates. However, communities appear to own and protect only those species which are part of the trophy hunting program. Consequently, species like carnivores and ungulates that are not part of the trophy hunting programs due to small populations like Ladakh urial and musk deer are often ignored.

Though ungulate actively migrate between summer and winter habitats, but climate change is severally impacting quality of their habitat as it does for majority of animals and plants in mountain ecosystems. Control on carbon emissions is critical for maintaining integrity of mountain ecosystems in future. The rapid population increase and demand of timber for construction and as fuel wood may also negatively affect the patches suitable for the musk deer. If deforestation is not controlled survival of musk deer remains questionable.

The border infiltrations by humans or livestock from one country to other is a common phenomenon, which forces countries to opt for border fencing, these fencing usually fragments the wildlife populations. One of such case is that of Marco Polo sheep at Kilik-Mintika of Misgar Valley and at Khunjerab top of KNP.

The barren habitat of ibex has not much to offer as food, the ibex negotiates on cliffs in search of protection from carnivores most of the time but the areas close to rivers for which it surrenders its security are heavily grazed by livestock's.

6.2 RECOMMENDATIONS

1) Areas identified as climate refugia in this study should be declared as legally protected by the Parks and Wildlife department.
2) New protected areas need to be created in prime habitats of musk deer in Astore and Diamer districts, and wildlife department need to increase staff in this area to control poaching of musk deer and monitor deforestation.
3) Connectivity of Marco Polo sheep population with China needs to be promoted through transboundary conservation.
4) The trophy hunting agreements need to be revisited to make the communities realize that trophies are allocated to them to utilize it for their social development but in return, it is mandatory for them to protect wildlife and their habitats.
5) The construction in, around protected areas, and core wildlife habitats need to be regulated through clear policy and law enforcement.
6) The livestock grazing should be regulated in all those valleys where high number of ungulates exist by introducing rotational gazing practices.

Do Marco Polo argali *Ovis ammon polii* persist in Pakistan?

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Richard Bischof and Muhammad Ali Nawaz

Abstract The distribution range of the Near Threatened Marco Polo argali, or Marco Polo sheep, *Ovis ammon polii* is restricted to the Pamir Mountains, spanning Afghanistan, Tajikistan, China and Pakistan. Until the early 1970s the Marco Polo argali was abundant in northern areas of Pakistan, particularly in the Khunjerab and Misgar Valleys around the Pamir Knot, bordering China, Afghanistan and Tajikistan. In Pakistan the subspecies now occurs only in one small watershed, in Khunjerab National Park, bordering China, which it visits sporadically during summer. We used map-based questionnaire surveys, double-observer surveys and camera trapping in a search for Marco Polo argali in the Pakistani Pamirs. We observed a herd of 19 individuals in Karachanai Nallah, in Khunjerab National Park, in 2012. The population that was formerly present in the Misgar Valley appears to have been extirpated, presumably as a result of anthropogenic factors such as poaching, competition with livestock, habitat disturbance, and the construction of a fence along the international border with China. Transboundary migration and range expansion into Pakistan could be facilitated by removal of the border fence adjacent to the Kilik–Mintika area and by limiting livestock grazing in former lambing areas.

Keywords Anthropogenic effects, China, fencing, Marco Polo sheep, *Ovis ammon polii*, Pakistan, poaching, transboundary wildlife

The argali *Ovis ammon* is categorized as Near Threatened on the IUCN Red List (Harris & Reading, 2008) but the Marco Polo argali (or Marco Polo sheep) *Ovis ammon polii* has not been assessed separately as a subspecies. However, a national assessment categorized the Marco Polo argali as Critically Endangered in Pakistan (Sheikh & Molur, 2004). The historical distribution of the subspecies includes Pakistan and other countries that share the Pamir Mountains (Russia, Afghanistan, China, Tajikistan and Kyrgyzstan; Heptner et al., 1966; Schaller, 1976, 1977; Petocz et al., 1978; Schaller et al., 1987; Fedosenko, 2000; Habib, 2006; Schaller & Kang, 2008). Throughout its range it is restricted to sparsely vegetated high-altitude environments (4,500–6,100 m) with harsh climatic conditions (Schaller et al., 1987; Roberts, 1997).

In Pakistan, the Marco Polo argali was reported historically from only three sites in the extreme north-west of Hunza District in Gilgit-Baltistan (Schaller, 1977; Hess et al., 1997; Roberts, 1997); retrospective studies have shown that these valleys were once home to sizeable populations. Roberts (1997) quoted the Mir of Hunza's estimate of 1,000 Marco Polo argali in Khunjerab National Park. Clark (1964) reported the sighting of 65 male Marco Polo argali by an American tourist. Rasool (1981) reported populations of 300, 120, 160 and 100 in 1975, 1976, 1979 and 1980, respectively, but during December 1987–January 1988 the population was estimated to comprise only 20–25 individuals (Rasool, 1990). Ahmad (1996) reported 52 individuals from Karachanai Valley, and Shafiq & Ali (1998) reported 87 in Khunjerab National Park. Schaller et al. (1987) confirmed local extirpation on the Chinese side of the Khunjerab Pass and referred to the population in the Karachanai area as an isolated one. Schaller et al. (1987) found only a skull as evidence of the Marco Polo argali at the Kilik Pass on the Pakistani side in 1974 but observed 48 individuals on the Chinese side of the Mintika Pass.

Rasool (1990) linked the historical abundance of argali in Pakistan to the ban on hunting imposed by Mir Muhammad Nazim Khan of Hunza (1892–1935), with rampant poaching on the Chinese side forcing the species to take refuge in the Kilik, Mintika and Khunjerab Pass areas until 1949, when the Chinese government imposed a ban on the hunting of argali. Meanwhile the situation reversed in Pakistan following the death of Mir Nazim Khan, and the Mirs and local poachers began hunting the species. The situation worsened during the construction of the Karakoram Highway during the 1960s and 1970s, when argali were poached to feed labourers. Observing the species' plight in 1975, George Schaller suggested that the government of Pakistan declare Khunjerab a protected area (Rasool, 1990).

Khunjerab National Park was established in 1975, with the primary objective of protecting remnant populations of Marco Polo argali. However, no agency has monitored the argali population since 1998, and its current status in Khunjerab and other parts of its historical range in Pakistan is unclear. Our study was motivated by this paucity of information about the species' current status in Pakistan.

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RESEARCH ARTICLE

Expanding or shrinking? range shifts in wild ungulates under climate change in Pamir-Karakoram mountains, Pakistan

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Abstract

Climate change is expected to impact a large number of organisms in many ecosystems, including several threatened mammals. A better understanding of climate impacts on species can make conservation efforts more effective. The Himalayan ibex (*Capra ibex sibirica*) and blue sheep (*Pseudois nayaur*) are economically important wild ungulates in northern Pakistan because they are sought-after hunting trophies. However, both species are threatened due to several human-induced factors, and these factors are expected to aggravate under changing climate in the High Himalayas. In this study, we investigated populations of ibex and blue sheep in the Pamir-Karakoram mountains in order to (i) update and validate their geographical distributions through empirical data; (ii) understand range shifts under climate change scenarios; and (iii) predict future habitats to aid long-term conservation planning. Presence records of target species were collected through camera trapping and sightings in the field. We constructed Maximum Entropy (MaxEnt) model on presence record and six key climatic variables to predict the current and future distributions of ibex and blue sheep. Two representative concentration pathways (4.5 and 8.5) and two-time projections (2050 and 2070) were used for future range predictions. Our results indicated that ca. 37% and 9% of the total study area (Gilgit-Baltistan) was suitable under current climatic conditions for Himalayan ibex and blue sheep, respectively. Annual mean precipitation was a key determinant of suitable habitat for both ungulate species. Under changing climate scenarios, both species will lose a significant part of their habitats, particularly in the Himalayan and Hindu Kush ranges. The Pamir-Karakoram ranges will serve as climate refugia for both species. This area shall remain focus of future conservation efforts to protect Pakistan's mountain ungulates.

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