ECOLOGY AND CONSERVATION OF THE SNOW LEOPARD (*Panthera uncia*) IN THE PAMIR MOUNTAIN RANGE, CENTRAL ASIA

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FACULTY OF SCIENCE
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ECOLOGY AND CONSERVATION OF THE SNOW LEOPARD (PANTHERA UNCIA) IN THE PAMIR MOUNTAIN RANGE, CENTRAL ASIA

ABSTRACT

The snow leopard *(Panthera uncia)* is a vulnerable umbrella species that thrives in the mountains of Central and Southeast Asia. Its population is declining globally due to both conventional and emerging threats. Despite the iconic status of the species and the enormous importance of its ecosystems, knowledge gaps in relation to species ecology and management are widely acknowledged. This study investigated snow leopard ecology in the transborder region of the Pamir and recognized conservation measures based on the knowledge gained on snow leopard ecology, conflicts with humans, and the economic potentials of the ecosystem services. Sign-based site occupancy surveys conducted from 2010-2012 across a 2,725 km^2 area confirmed the presence of snow leopards across the Pamir-Karakoram mountains. Occupancy was the highest in Khunjerab National Park ($\psi = 0.57 \pm 0.03$) followed by Qurumbar National Park ($\psi = 0.46 \pm 0.05$), the Misgar-Chipursan valleys ($\psi = 0.42 \pm 0.03$), and Broghil National Park ($\psi = 0.35 \pm 0.04$). The presence of predators, such as snow leopards, means inevitable conflicts with the pastoralist communities. The questionnaire surveys of 182 agropastoral households conducted in 2013 revealed an explicit seasonal and spatial variation in livestock depredation in the transborder region. Predation incidences were higher in the evening, and sheep and goats accounted for 92% of offtake. Overall, 315 heads of livestock were reportedly killed by snow leopards (47%) and wolves (53%) in the study sites, per year. This serious livestock loss was further aggregated by the disease-caused mortality, which was even imparted two-fold damage of the predation. The collective economic burden of predation and diseases was US$543 per household per year, which explains the low public tolerance for predators in the region. The low public acceptance of the predators triggered poaching and facilitated trade in snow leopards. An investigation of the dynamics of poaching and trade in snow leopards in Pakistan revealed that a total of 101 snow leopards were killed and traded during 2005–2017. Reported poaching incidents varied spatially ($\bar{x} = 9 \pm 2.6$ [95% Cl: 3–15]) and temporally ($\bar{x} = 7.8 \pm 1.09$) and accounted for a 2–4% annual population loss (n = 200–420) over 13 years. The average base and end prices for each pelt were US$ 245 ± 36 and US$ 1,736 ± 520, respectively. The ecosystems inhabited by snow leopards are of immense value for the survival of millions of human beings. The economic worth of ecosystem services assessed in Khunjerab and Qurumbar national parks measured at US$ 4.6 million and US$ 3.8 million annually, which translates into US$ 5955 and US$ 8912 per household per year. The findings of this study underpin improved management of protected areas to ensure the protection of wildlife in the study sites. Moreover, tangible conservation measures to offset predator-induced economic losses and the development of a multi-stakeholder coordination mechanism to curb poaching and trade in wildlife are essential. The worth of the ecosystem services should also be considered in future planning and investments in these landscapes.

Keywords: Ecosystem services, conservation, human-carnivore conflict, occupancy, poaching and trade, snow leopard

EKOLOGI DAN KONSERVASI HARIMAU BINTANG SALJI (PANTHERA UNCIA) DI BANJARAN PERGUNUNGAN PAMIR, CENTRAL ASIA

ABSTRAK

Harimau bintang salji (*Panthera uncia*) adalah spesies paying terancam yang hidup di pergunungan Asia Tengah dan Asia Tenggara. Populasinya merosot di peringkat global diakibatkan kedua-dua ancaman konvensional dan yang baru muncul. Walaupun spesies ini berstatus ikonik dengan tahap ekosistemnya yang sangat penting, namun terdapatnya jurang pengetahuan berkaitan biologi, habitat, dan pengurusan spesies ini adalah rata-rata diakui. Penyelidikan ini mengkaji ekologi harimau bintang salji dalam wilayah rentas sempadan Pamir dan mengenalpasti langkah konservasi/pemuliharaan berdasarkan penemuan ekologi, konflik dengan manusia dan potensi ekonomi khidmat ekosistemnya. Kaedah tinjauan penghunian di lokasi berdasarkan tanda mengesahkan kewujudan harimau bintang salji merentasi banjaran bersejarah di pergunungan Pamir-Karakoram. Penghunian tertinggi adalah di Taman Negara Khunjerab ($\psi = 0.57 \pm 0.03$) diikuti dengan di Taman Negara Qurumbar ($\psi = 0.46 \pm 0.05$), di lembah Misgar-Chipursan ($\psi = 0.42 \pm 0.03$), dan di Taman Negara Broghil ($\psi = 0.35 \pm 0.04$). Dengan kehadiran pemangsa, seperti harimau bintang salji ini, maka tidak dapat dielakkan timbulnya konflik dengan komuniti penternak. Tinjauan soal selidik mendedahkan adanya variasi musim dan ruang yang khusus terhadap pemangsaan ternakan di wilayah rentas ini. Insiden pemangsaan adalah lebih tinggi pada waktu petang, dan biri-biri serta kambing merupakan 92% dari mangsa. Secara keseluruhannya, 315 ekor ternakan dilaporkan dimangsai setiap tahun oleh harimau bintang salji (47%) dan serigala (53%) di kawasan kajian. Kerugian serius ternakan ini menjadi lebih teruk dengan kematian akibat penyakit, yang mana adalah dua kali ganda daripada pemangsaan. Beban kolektif ekonomi disebabkan pemangsaan dan penyakit adalah US$543 bagi setiap isi rumah pada setiap tahun, dan ini menjelaskan toleransi masyarakat yang rendah terhadap pemangsa di kawasan ini. Penerimaan masyarakat yang rendah terhadap pemangsa adalah pencetus kepada pemburuan haram dan merangsang perdagangan harimau bintang salji ini. Kajian tentang dinamik pemburuan haram dan perdagangan harimau bintang salji di Pakistan mendedahkan sejumlah 101 ekor telah dibunuh dan didagangkan dalam tahun 2005 hingga 2017. Insiden pemburuan haram adalah pelbagai antara ruang ($\bar{x} = 9 \pm 2.6$ [95% CI: 3-15]) dan masa ($\bar{x} = 7.8 \pm 1.09$) serta melibatkan 2-4% kerugian populasi setiap tahum (n = 200-420) dalam masa 13 tahun. Purata harga asas dan harga di hujung untuk setiap kulit harimau ini adalah US$245 ± 36 dan US$1,736 ± 520, masing-masing. Ekosistem didiami harimau bintang salji ini adalah bernilai tinggi bagi kemandirian berjuta manusia. Nilai ekonomi khidmat ekosistem yang telah dikira untuk Taman Negara Khunjerab dan Qurumbar adalah masing-masing US$4.6 juta dan US$3.8 juta setiap tahun, serta boleh diterjemahkan kepada US$5,955 dan US$8,912 setiap tahun bagi setiap isi rumah. Keuntungan ekonomi daripada khidmat penyediaan adalah tertinggi untuk kedua-dua Taman Negara, diikuti oleh khidmat budaya dan pengawalseliaan. Penemuan dari kajian ini menyokong pengembangan dan pengurusan yang lebih baik untuk kawasan terlindung bagi memastikan perlindungan hidupan liar dalam kawasan kajian. Malah, apa yang lebih penting adalah langkah konservasi yang jelas untuk mengimbangi kerugian ekonomi yang diakibatkan oleh pemangsa dan pengembangan mekanisme koordinasi pelbagai pihak pemegang taruh untuk mengekang pemburuan haram serta perdagangan hidupan liar. Nilai perkhidmatan ekosistem perlu dipertimbangkan dalam perancangan masa hadapan dan pelaburan dalam persekitaran ini.

Katakunci: Perkhidmatan ekosistem, pemuliharaan, konflik manusia-karnivora, penghunian, pemburuan haram dan perdagangan, harimau bintang salji

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AKDN	:	Aga Khan Development Network
AIC	:	Akaike information criterion
AJ&K	:	Azad Jammu & Kashmir
β	:	Beta
BNP	:	Broghil National Park
CO_2	:	Carbon dioxide
CSI	:	Carbon Sequestration Index
°C	:	Celsius
CPEC	:	China-Pakistan Economic Corridor
$\chi 2$	:	chi-square
CMCA	:	Community Managed Conservation Area
CITES	:	Convention on International Trade in Endangered Species of Wild Fauna and Flora
df	:	Degree of freedom
DNA	:	Deoxyribonucleic acid
p	:	Detection probability
DOI	:	Digital object identifier

$	:	Dollar
ES	:	Ecosystem Service
EIA	:	Environmental Investigation Authority
ESRI	:	Environmental Systems Research Institute
FAO	:	Food and Agriculture Organization
Glmer	:	Generalized Linear Mixed-Effects Regression
GIS	:	Geographic Information System
GB	:	Gilgit-Baltistan
GPS	:	Global Positioning System
GSLEP	:	Global Snow Leopard and Ecosystem Protection Program
GCF	:	Green Climate Fund
HKH	:	Himalaya-Karakoram-Hindu Kush
HH/hh	:	Household
HWC	:	Human Wildlife Conflict
ICRAF	:	International Council for Research in Agroforestry
IUCN	:	International Union for the Conservation of Nature
KNP	:	Khunjerab National Park

KPK	:	Khyber Pakhtunkhwa
KW	:	Kruskal–Wallis
λ	:	Lambda
lme	:	Linear Mixed Effects
MEA	:	Millennium Ecosystem Assessment
mm	:	Millimeter
MOCC	:	Ministry of Climate Change
MC	:	Misgar-Chipursan
NP	:	National Park
NDVI	:	Normalized difference vegetation index
PKR	:	Pakistani rupee
PA	:	Protected area
ψ	:	Psi (Occupancy)
QNP	:	Qurumbar National Park
SL	:	Snow Leopard
SLF	:	Snow Leopard Foundation
SDMs	:	Species Distribution Models
km^2	:	Square kilometer

SD	:	Standard Deviation
SE	:	Standard Error
UNEP	:	United Nation Environment Program
USD	:	United State Dollar
USAID	:	United States Agency for International Development
WASP	:	Water and Sanitation Improvement Program
HO	:	World Health Organization
WWF	:	World Wide Fund for Nature
yr	:	Year

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CHAPTER 1: INTRODUCTION

1.0 Introduction

The accelerating biodiversity loss in the modern world is subjected to a myriad of anthropogenic and climate change induced threats and presumably paving way for the sixth mass extinction (Palombo, 2021). About one million species of plants and animals have become vulnerable to extinction in the recent past and human activities have altered up to 75% of land and 66% of ocean areas, until now (Tollefson, 2019). The IUCN Red List statistics describe, 40,000 species (28% of the species assessed) are facing extinction. Mammals alone form 26% of the species threatened with extinction (IUCN, 2022). Amidst mammalian species, large carnivores are exposed to solemn threats and resultantly many of these majestic creatures' face decline both in their numbers and distributional ranges across the world (Ripple et al., 2014).

1.1 Ecology and importance of large carnivores

Out of the 245 terrestrial species of carnivores, 31 species have a body mass of ≥ 15 kg on average and have subsequently been classified as large carnivores (Hunter, 2019). The large carnivores subsist largely on other animals, occur in low densities, and reside at the top of the food web (Ripple et al., 2014). Despite being reckoned as the top predators, many species are poorly understood in terms of their numbers, distributions, and status; thus, impeding biodiversity statistics (Tollefson, 2019).

Among the terrestrial large carnivores, the big felids and canids are comparatively imperiled and admired (Ceballos et al., 2005). These apex predators are presented as the guardians of biodiversity and regulators of the ecosystem's functioning and structure through the formation of trophic cascades (Kuijper et al., 2016). Besides controlling meso-predators through competition and predation (Prugh & Sivy, 2020), large predators also regulate the population and behavior of herbivores (Brose et al., 2019) and help in maintaining high global plant biomass (Wilkinson & Sherratt, 2016). Large carnivores also succor in reducing disease occurrence in ungulate populations, thereby extenuating agricultural costs by spillover effects on livestock (Packer et al., 2003). Moreover, due to their charismatic nature, these apex predators deliver direct monetary paybacks by fostering tourism (Richardson & Loomis, 2009).

Most of the large canids and felids have overlapping distributional patterns, occur in a wide array of ecosystems, and occupy large home ranges (Carbone & Gittleman, 2002). Many socioecological factors determine their distribution (Dalerum et al., 2008). Monitoring of large carnivores is difficult because of the remote and wide landscapes they occur, scarcity of resources, lack of social as well as political will, and support requires from different stakeholders (Karanth et al., 2011). Many large carnivores have suffered significant range contractions, especially in Southeastern Asia where populations of humans, numbers of livestock, and crop densities are higher as compared to other regions (Wolf & Ripple, 2017). Despite being rich in species diversity, South Asia is more vulnerable to human-induced modification of ecosystems and the knowledge gap about species' ecology (Thatte et al., 2021).

Among the South Asian countries, Pakistan harbors 36 species of carnivores, and 18 of these occur in the northern mountainous belt of Karakoram, Himalayas, Hindu Kush, and Pamir (Roberts, 1997; Sheikh & Moular, 2003). The iconic carnivores of the north include the snow leopard (*Panthera uncia*), common leopard (*Panthera pardus*), brown bear (*Ursus arctos*), Himalayan lynx (*Lynx lynx isabellinus*), Asiatic black bear (*Ursus thibetanus*), wolf (*Canis lupus*), fox (*Vulpus vulpus*) and jackal (*Canis aureus*). These sympatric carnivores share the alpine ecosystems with their wild prey such as markhor (*Capra falconeri*), ibex (*Capra ibex siberica*), Marco Polo sheep (*Ovis ammon polii*), blue sheep (*Pseudois nayaur*), musk deer (*Moschus cupreus*), and other lesser felids and canids (Poore, 1992; Roberts, 1997). This charismatic megafauna is threatened due to overexploitation, and lack of methodical and systematic baselines hindered by scarcity of financial as well as human resources (Sheikh & Moular, 2003). Many of the large carnivore species, such as the threatened snow leopard, are keystone species across their range. Understanding the ecology and conservation need of the indicator species guarantees ecosystem conservation (Li et al., 2013).

1.2 Global distribution of snow leopard and conservation challenges

Snow leopards inhabit the alpine and sub-alpine regions of the high mountain ranges of south and central Asia, distributed across twelve range countries including Pakistan, Afghanistan, China, India, Bhutan, Mongolia, Kyrgyzstan, Nepal, Kazakhstan, Tajikistan, Russia, and Uzbekistan (Figure 1.1) with altitudes ranging from 5200m in summer to a minimum of 1500m in winter (Mahmood et al., 2019; Roberts, 1997). The potential range of the cat also reportedly extends to Myanmar (Jamtsho & Katel, 2019). A large part of its range has yet to be surveyed due to inaccessible and challenging terrain and the secretive nature of the species (McCarthy et al., 2016).

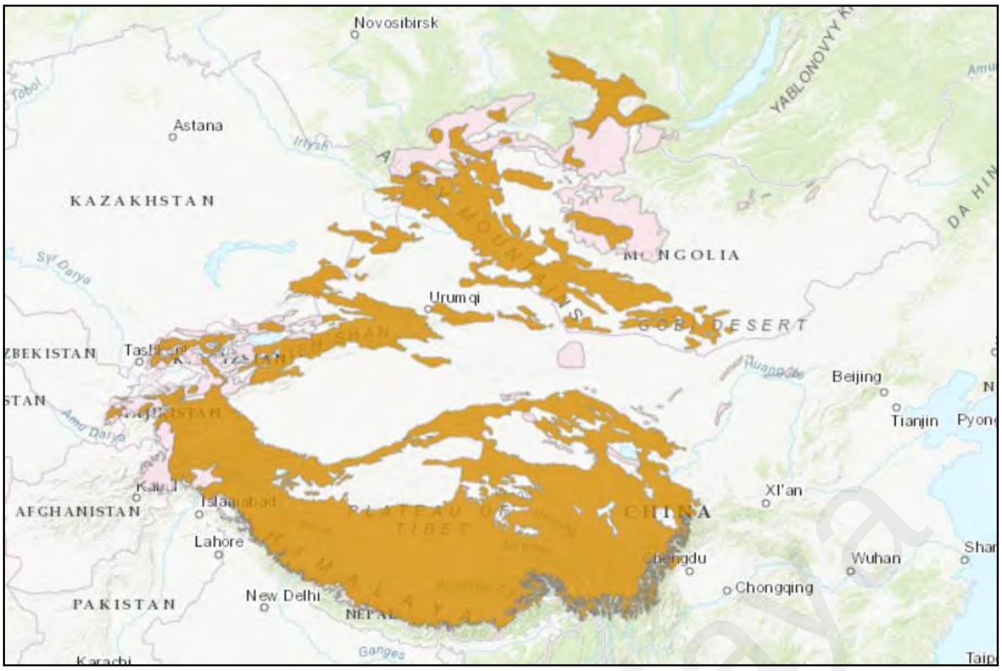

Figure 1.1: Global distributional range of snow leopard (IUCN, 2022)

The key parameters of snow leopard ecology such as occupancy, abundance, population, conflict with agropastoral communities, and interaction with sympatric carnivores are poorly understood, mainly due to the geopolitical barriers inflicted by its range being falling along the international borders (Hameed et al., 2020; Kabir et al., 2017). Globally, the snow leopard population is estimated to be between 5329-6140 individuals with a potential habitat of 1.245 million km^2 (Mahmood et al., 2019). However, range-wide estimates of the snow leopard are between 7463-7980 inhabiting a large geographical range of about 1.6 million km^2 (McCarthy et al., 2016; Maheshwari & Niraj 2018). The distribution range could be even larger i.e., 3,024,728 km^2 (McCarthy & Chapron, 2003; Valentova, 2017). Among the range countries, China reportedly hosts the largest population of snow leopards (2,000-2,500 individuals) followed by Mongolia (500-1000 individuals), Nepal (300-500 individuals), and India (200-600 individuals) (Valentova, 2017). The population is yet to be determined in Pakistan, Afghanistan, and Tajikistan (Valentova, 2017).

The snow leopard is listed in the Appendix-I of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) (Snow Leopard Network, 2014). Tajikistan has to sign off the CITES but has shown determination to conserve snow leopards and their habitat by endorsing the "Bishkek Declaration" in 2013 (Jackson et al., 2010; Snow Leopard Working Secretariate, 2013). Despite being protected by laws across its range, the snow leopards are subjected to poaching and trade, especially in China, Afghanistan, Pakistan, and the border regions of Mongolia (Jackson et al., 2010). The fur and other body parts of snow leopards have a high price in the black market and there is a shift towards luxury products, though traditional use of snow leopard parts is now strictly prohibited (Li & Lu, 2016). Almost one-third of the range of snow leopards lies in sensitive international boundaries where disputes continue to exist; thus, making conservation initiatives difficult to implement (Jackson et al., 2010; Nowell, 2016).

The conservation efforts are compromised most of the time, due to the lack of will to maintain protocols, low public tolerance, and lack of funds and expertise (Jackson et al., 2010).

The snow leopard population is reportedly dwindling due to the human-snow leopard conflict over livestock depredation, illegal hunting, habitat degradation, and fragmentation of most of its range (Devkota et al., 2017). Poaching of wild prey and increased anthropogenic movement in the snow leopard landscapes for medicinal or aromatic plant collection are damaging fragile ecosystems (Forrest et al., 2012). The influx of developmental projects, that foster human encroachment into the snow leopard habitats (Chen et al., 2016), and climate change (Forrest et al, 2012) have appeared as emerging threats to snow leopards and the mountain ecosystems they occupy. The mountain ecosystems are extremely fragile to climate change and the snow leopard habitat might reduce under the predicted climate change scenario (Aryal et al., 2016;

Forrest et al., 2012). The temperature in South Asia and Tibet is projected to increase up to 3 to 4°C by 2080-2099, along with an increase in the annual precipitation rate (Forrest et al., 2012). This change will result in the shift of the tree line into alpine areas, the species' preferred habitat (Forrest et al., 2012).

1.3 Snow leopard distribution and conservation status in Afghanistan and Tajikistan

Afghanistan falls in the west of the global snow leopard distribution range and the Wakhan corridor that connects Afghanistan with Pakistan, China, and Tajikistan along with some portion of the Nooristan Province constitutes the prime snow leopard range in the country (NEPA, 2014). About 100 snow leopards are found in the Wakhan corridor (Snow Leopard Network, 2014) but robust population estimates are still lacking (NEPA, 2014).

The snow leopard is threatened in Afghanistan due to the conflict with pastoral communities over livestock killing, poaching, and trade, reduction of natural prey (Moheb & Paley, 2016). About 119 snow leopards were reportedly traded between 2003–2012 in Afghanistan which constitutes 25% of the overall recorded cases across all range countries (Maheshwari & von Meibom, 2016).

Tajikistan forms another important snow leopard range country with a population of cats falling between 250-280 as opined by local experts (Government of Tajikistan, 2013). The snow leopard range in Tajikistan forms the center of the snow leopard distribution range and the Pamir and Pamir-Alai ranges are the main link between the southeastern part of the global range of the species (particularly the Hindu Kush and the Karakoram ranges) and the Tien Shan system and the northern part of the range (Saidov et al., 2016). Lack of conservation capacity, conflict with humans, loss of prey, and illegal trade have been acknowledged as major threats to snow leopards within Tajikistan (Saidov et al. 2016).

1.4 Snow leopard distribution and conservation needs in Pakistan

In Pakistan, the snow leopard range lies in ecologically rich but climate change sensitive landscapes (Khan et al., 2021). Pakistan's total snow leopard range spreads across an 80000km^2 area in the Hindu Kush, Himalaya, Karakoram, and Pamir Mountain ranges (Figure 1.2) which supports a reported population of about 250-400 individuals (Din & Nawaz, 2016; Hussain, 2003; Khan et al., 2021). Overall, about 30% of the snow leopard range has been explored, so far, using robust assessment tools such as sign-based occupancy surveys, camera trapping, and molecular genetics (Ale & Mishra, 2018). Most of these studies were undertaken in promising and comparatively accessible habitats (Hameed et al., 2020; MOCC, 2103).

There is a genuine need to expand the research agenda into the remote landscapes falling in the transborder regions to have a holistic overview of snow leopard distribution and conservation issues (Snow Leopard Working Secretariate, 2020).

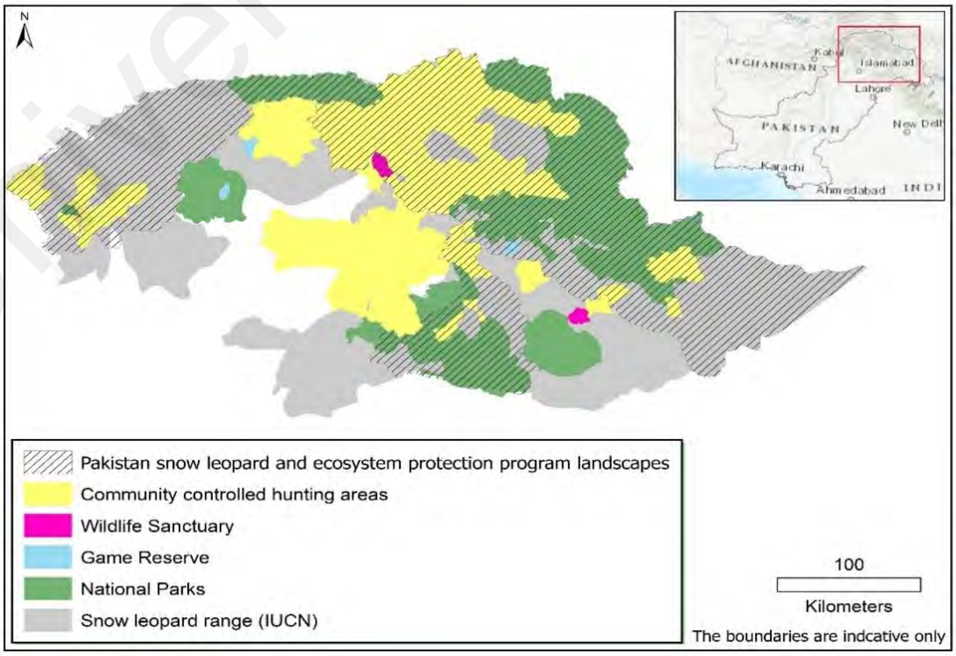

Figure 1.2: Snow leopard range in Pakistan showing the protected area network (SLF, 2021)

Mountain ungulates and livestock and even smaller mammals and gamebirds have been identified in the diet of snow leopards (Mallon et al., 2016). In the Pamir, mountain sheep and goats including ibex (*Capra ibex*), blue sheep or bharal (*Pseudois nayaur*), argali or Marco Polo sheep (*Ovis ammon polii*) and markhor (*Capra falconeri*) (Anwar et al., 2011; Devkota et al., 2013; Shehzad et al., 2012) aside from smaller mammals such as long-tailed marmot (*Marmota caudata*) (Jumabay-Uulu et al., 2014) have been reported in the snow leopard diet. However, the human-carnivore conflict is a major conservation challenge in the snow leopard range (Hussain, 2003). In Pakistan, more than nine million agropastoral communities share mountain ecosystems with snow leopards and sympatric predators (Nawaz & Hameed, 2015).

Studies (Chen et al., 2016; Chetri et al., 2020; Maheshwari & Sathyakumar, 2020) conducted in the snow leopard range estimate losses of 1.3 (range 0.7–3.3) animals per household per year due to snow leopard and wolf, which forms up to 30% of the family income earned by selling their livestock (Snow Leopard Network, 2014). Livestock mortality due to diseases is another serious issue in the snow leopard range, which is mostly not measured in studies focusing on the drivers of human-livestock-carnivore interaction (Dar et al., 2009; Habib, 2008; Li et al., 2013; Ostrowski, 2007) and makes the efficacy of the conservation initiatives indeterminate. These conservation challenges have led to the low tolerance of large carnivores in the public and triggered retaliatory killing (Din & Nawaz, 2011).

Expert surveys estimate that up to 23-53, snow leopards are annually poached in Pakistan, which is significant when considered together with the available population estimates and the spread of the snow leopard range in the country (Hussain, 2003; Nowell & Jackson, 1996). Human-snow leopard conflict and resultant retaliatory killing account for 55% of the overall snow leopard poaching incurring across its range and over 65% in

Pakistan (Nowell, 2016). The majority of the snow leopard poaching and trade remained unnoticed due to the secretive nature of the business (Khan, 2002a). The snow leopard pelts and body parts were noticed even in big cities and towns (Khan, 2002b). In nutshell, the snow leopard is facing multifaceted threats ranging from the knowledge gap about its distributional pattern even in the well-established PAs, reduction in natural prey-base conflicts with grazer communities, poaching, and trade (Ahmad et al., 2016; Anwar et al., 2011: Hussain, 2003; Khatoon et al., 2017). Apart from this, the mountain ecosystems, inhabited by snow leopards, have been supporting socially secluded and diverse human cultures as well as livelihoods for centuries (MOCC, 2013). These ecosystems are essential for the co-existence of humans and wildlife.

A few studies (Morali et al., 2017; Saeed et al., 2022) have been conducted to understand the worth of the services provided by the snow leopard ecosystems to the mountain communities across the snow leopard range so that holistic conservation management measures are formulated and implemented.

Finally, field-based research on snow leopards is logistically expensive and physically demanding due to the vast, rugged, inaccessible terrain, and lack of human and financial resources. Resultantly, a major portion of the snow leopard range in Pakistan, especially the Pamirs remains unexplored (MOCC, 2013) like many other portions of its range (Weckworth, 2021). Survey efforts at the landscape level are needed to document the distribution and density of snow leopards and the effectiveness of protected areas using robust scientific tools (Alexander et al., 2016). Since the majority of the snow leopard habitat across its range, in general, and Pakistan, in particular, falls in the transborder areas, making survey efforts challenging due to geopolitical barriers and require special attention (Kandel et al., 2016). Understanding all these socioecological, economic and geographical information gaps is a prerequisite to ensure the conservation of the apex predators such as snow leopards in the future (Inskip & Zimmermaan, 2009). The current study is undertaken to fulfill the research gaps identified and improve our understanding of snow leopard survival needs in Pakistan and adjoining transborder areas.

1.5 Aim and objectives of the study

The major aim of this project was to investigate snow leopard distribution, human-snow leopard conflict dynamics, poaching and trade, and valuate ecosystem services through robust field-based studies in the Pamir Mountain range and adjoining landscapes along with the transborder regions with Afghanistan, Pakistan, and Tajikistan.

Flanked by the Hindukush, Himalayas, Karakoram, and Kunlun Mountain Ranges, the Pamirs form one of the most spectacular mountain ranges in the world and are recognized as the ‘roof of the world’ (Bliss, 2006). The Pamir Mountain range is listed among the world's 200 eco-regions (Olson et al., 2001) and is considered a biodiversity hotspot (McGinley, 2008) due to its extraordinary geographic position and socio-cultural (Kreutzmann, 2003) and ecological diversity (WCS, 2006). This study was designed to help achieve the national as well as the range-wide goals of the Global Snow Leopard and Ecosystem Protection Program (GSLEP) endorsed by the twelve range countries by adopting the Bishkek Declaration in 2013 (Snow Leopard Working Secretariate, 2013). The specific objectives of the study include the following.

1. Assess occupancy patterns of the snow leopard based on the circumstantial evidence;
2. Evaluate the spatial and temporal pattern of livestock predation by snow leopards;
3. Examine the value of livestock and economic impacts of livestock predation and public tolerance of snow leopards;
4. Investigate the drivers of snow leopard poaching and trade;
5. Evaluate the economic value of ecosystem services in the Pamir.

1.6 Description of the objectives and methodological approach adopted

The first objective of the study aimed to assess the occupancy of snow leopards at the large landscape scale (>10,000 km²) in the Pamir range. Since snow leopards are solitary and territorial animals and mark their territory through scrapes and scent marks (Jackson & Hunter, 1996), these traits were considered to assess the occupancy and detection probability of snow leopards by conducting grid-based sign surveys. The environmental and anthropogenic factors that influence the occupancy of snow leopards in northern Pakistan were also investigated.

The findings of the study threw light on the coverage and effectiveness of protected areas to protect large-ranging species such as snow leopard and can be translated into strategies pertaining to protected area management.

The second objective measured the patterns of conflict between humans, snow leopards, and wolves (major sympatric carnivores) in the periphery of Pamir Knot- encompassing Afghanistan, Pakistan, and Tajikistan Pamir Mountain Range- using questionnaire survey data (n = 182). The Pamir Mountains account for 3.5% (120,996 km²) of the total snow leopard range (3,438,909 km²) and are mostly constituted of remote and rugged terrain (Nyhus et al., 2016). This study revealed the occurrence of large carnivores including snow leopard, wolf, lynx, and brown bear based on a direct sighting by the pastoralists during the study period of five years. The human-carnivore conflict was associated with the snow leopard and wolf only across the study sites. This is the first transboundary study of human-carnivore conflict in the Pamir and intends to quantify the temporal (i.e., year, season, and time) and spatial (i.e., valley) predation trends and prey (i.e., livestock) preferences (i.e., sex and age) by the snow leopard and wolf. This study envisages that patterns in livestock depredation by the snow leopard and wolf across the geopolitical areas would likely be influenced by predator abundance, behavior, seasonality, livestock holding, and herding practices. The understanding of these underlying factors is essential for identifying conservation hotspots and developing workable conservation management strategies to safeguard threatened wildlife species such as the snow leopard and wolf.

Under the third objective, human attitudes and perceptions about large carnivores were addressed. Public tolerance of predators constitutes one of the key parameters of human-carnivore conflict (Røskaft et al., 2007) and is considered among the decisive factors in formulating conservation management strategies (Wechselberger & Leizinger, 2005).

An attempt was made to estimate the economic value of livestock belonging to pastoralist communities in the periphery of Afghanistan, Pakistan, and Tajikistan Pamirs—and their perceptions, attitudes, and tolerance of snow leopards and wolves in light of livestock losses to predation. To understand how relevant is the predation-induced loss as compared with other types of livestock losses, the disease-caused mortality of livestock and associated economic liability were also evaluated and the significance of each to the region's overall economy was compared.

The fourth objective aimed to investigate the dynamics and drivers of snow leopard poaching and trade in Pakistan. This constitutes the first-ever detailed assessment of the problem using multipronged strategy and assessment tools. The spatial and temporal distribution of snow leopard poaching and trade along with poaching methods and intentions are addressed and discussed in detail. The study also focused on the possible routes and destinations of snow leopard products during a period of 13 years (2005-2017). The efficacy of the existing laws and management measures are also discussed at the end.

The fifth objective of this Ph.D. project attempted to quantify and compare the provisioning, cultural, and regulatory services delivered by two high-elevation national parks (NPs) to buffer zone communities. The Qurumbar and Khunjerab national parks fall in the Pamir-Karakoram landscape, which is one of the three snow leopard landscapes in Pakistan selected for implementation of the Global Snow Leopard and Ecosystem Protection Program's goal to secure "20 landscapes by 2020" (Davletbakov et al., 2016). Megadevelopment projects, such as the China–Pakistan Economic Corridor, pass through the Karakoram–Pamir landscape, specifically through KNP. The findings of this study are expected to contribute to the economic analysis of such development projects in terms of their implications for the ecosystem services of associated landscapes.

More importantly, the outcomes of the study will help in developing better strategies for the conservation of protected areas that consider the desires of the native people, who depend on the resources of the protected areas. Last, but not least, the approach adopted herein and the findings of this study could serve as a reference for future endeavors across the unexplored snow leopard landscapes.

CHAPTER 2: LITERATURE REVIEW

2.1 Global status of snow leopard

With a wide but sparse distribution, snow leopards are found across 12 countries of South and Central Asia with core habitats falling in the Himalayan, Hindu Kush, Pamirs, Karakorum, Kun Lun, Tien Shan, and Altai ranges. Population trends and estimates vary among and within the countries (McCarthy et al., 2016). Although questioned (Ale & Mishra, 2018), based on expert reviews the IUCN status has been down listed to Vulnerable from Endangered (McCarthy et al., 2017). The main threats to the species are poaching and illegal trade for fur and bones (Watts et al., 2019), and conflicts with humans resulting in the decrease of available prey and retaliatory killing (Maheshwari & Niraj, 2018; McCarthy et al., 2017).

Considering the increased anthropogenic activities that result in continuous degradation and fragmentation of their natural habitat and prey base, information on the ecology of the snow leopard is crucial in devising conservation management plans (Watts et al., 2019). Snow leopard ecology has been studied in various contexts; including food habits (Chetri et al., 2017; Hacker et al., 2021; Khatoon et al., 2017; Lham et al., 2021; Weiskopf et al., 2016), habitats (Bocci et al., 2017; Kachel et al., 2017; Randeep et al., 2020; B. Shrestha & Kindlmann, 2020), population dynamics (Alexander et al., 2016; Chetri et al., 2019; Dyldaev et al., 2021; Mishra, et al., 2020), conflicts with humans (Bhatia et al., 2020; Hacker et al., 2020; Kusi et al., 2020; Lham et al., 2021; Maheshwari & Sathyakumar, 2020) and the emerging problems and possible solutions for the conservation of the species (Alexander et al., 2021; Chetri et al., 2020; Khan & Baig, 2020; Khan et al., 2021; Loch-Temzelides, 2021; Schutgens et al., 2019).

Contrary to other big felids, the study of the snow leopard ecology started relatively very late. For instance, when cougars were being collared in the USA (Seidensticker et al., 1973), National Geographic (1971) was just published the first photographs of snow leopards taken in the wild from Pakistan. The seminal studies undertaken by Schaller in the early 1970s in central Asia and Pakistan led to the introduction of the snow leopard to the world and the initiation of field research (Hunter et al., 2016). Almost eight years after that the first snow leopard was captured and radio-collared in Nepal (Jackson & Ahlborn, 1989). Despite, the technological loopholes associated with the radio collars used, a study of five collared snow leopards in four years revealed that home ranges of between 11.7 km^2 and 38.9 km^2 with substantial overlap both within and between sexes. In 1993, Tom McCarthy collared five snow leopards in Mongolia for five years which resulted in an estimation of the snow leopard home range of 140-1500 km^2 (McCarthy, 2000). This initial research work helped the ecologists to model snow leopard habitats across all 12 range countries, despite the shortcomings in the satellite image (Hunter & Jackson, 1997). The findings of these studies also suggested that signs such as tracks, scats, scrapes, and scent marks may be reliable indicators of snow leopard presence and relative abundance and this led to the adoption of the Snow Leopard Information Management System (SLIMS) which was adopted by range countries (Jackson & Hunter, 1996). Over time, snow leopard research upscaled with the introduction of more robust techniques such as molecular genetics (Zhang et al., 2007; Janecka et al., 2011), camera trapping (Jackson et al., 2006; McCarthy et al., 2008; Sharma et al., 2014) and GPS collaring (McCarthy et al., 2007). These techniques provided more reliable estimates of snow leopard abundance of up to 5–6 individuals/100 km^2 applying genetics (Janecka et al., 2011) as compared to camera trapping and sign surveys (1-3 individuals/100km^2). Similarly, the GPS collaring of a snow leopard in Pakistan collected about 842 locations and the home range of the cat was calculated home ~850 km^2.

Other studies undertaken in Magnolia estimated home ranges of 503 ± 286 km² (Johansson et al., 2015). The information on the snow leopard ecology collected across the range of counties helped model global snow leopard habitat suitability maps and identification of snow leopard Landscape Conservation Units (Snow Leopard Working Secretariate, 2013; Li et al., 2020).

Further detailed synthesis of snow leopard ecology with effects from 1904 to 2020 (Sharma & Singh, 2020) revealed a principal focus on surveying and monitoring with abundance & distribution, followed by food habit studies, habitat use and selection, molecular ecology, disease ecology, ethology, and physiological studies. These studies spread across only 22% of the global snow leopard range and roughly 3% has been surveyed using robust population-density estimation methods (Sharma & Singh, 2020). Resultantly, we do not have consistent estimates of snow leopard abundance and distribution across a major portion of the snow leopard range (Snow Leopard Working Secretariate, 2013). The available global estimates (3920–6390) estimates are outdated and derived based on indirect observations (Snow Leopard Network, 2014) with China having the highest reported population (2000-2500) followed by Magnolia (500-1000), India (200-600), Nepal (300-500), Pakistan (200-420), and rest having less than 200 individuals (Snow Leopard Working Secretariate, 2013).

2.2 Pakistan snow leopard range and conservation needs

Pakistan has an area of more than 80,000 km² of suitable snow leopard habitat in the north that spreads over Himalaya, Karakoram, Hindukush, and Pamir landscapes across three administrative areas Azad Jammu and Kashmir, Gilgit-Baltistan and Khyber Pakhtunkhwa (Fatima et al., 2019; Hameed et al., 2020; Khatoon et al., 2017; Network, 2014; Valentová, 2017).

Among the range countries, snow leopard ecology and conservation have comparatively least addressed in Pakistan (Nawaz & Hameed, 2015) due to the scarcity of human and financial resources and geopolitical barriers as most of the snow leopard range fall along international borders.

The species' range in Pakistan is ecologically rich with unique biodiversity but very sensitive to climate change (Khan et al., 2021). Along with snow leopard many other mammal species can be found in the area including grey wolf (*Canis lupus*), Eurasian lynx (*Lynx lynx*), Asiatic black bear (*Ursus thibetanus*), Pallas's cat (*Otocolobus manul*), common leopard (*Panthera pardus*), brown bear (*Ursus arctos*), Himalayan ibex (*Capra ibex sibirica*), markhor (*Capra falconeri cashmirensis*), blue sheep (*Pseudois nayaur*), Ladakh urial (*Ovis orientalis vignei*) and musk deer (*Moschus cupreus*) (Hacker et al., 2021; Hameed et al., 2020; Khan et al., 2021; Khatoon et al., 2017). The northern Karakorum and Hindukush range has a semi-arid environment while the western Himalayas are characterized by a moist temperate zone. Different vegetation zones identified across the range are alpine meadows, alpine dry steppes, permanent snowfields, and subalpine scrub zone (Fatima et al., 2019; Hameed et al., 2020; Khan et al., 2021).

Habitat degradation and fragmentation, reduction in natural prey base due to hunting disease and competition with livestock, retaliatory killing, poaching, and wildlife trade are the main threats to the survival of snow leopards (Snow Leopard Working Secretariat, 2013). Development projects like China-Pakistan Economic Corridor (CPEC) may further degrade and fragment the fragile habitat of the species and also increase wildlife trade (Farhadinia et al., 2019).

2.3 Estimation of snow leopard occupancy

One of the critical aspects for the successful conservation of species is the knowledge of their occurrence (Shrestha et al., 2020). This becomes more important in the case of large carnivores as they determine the overall ecosystem health. Various field and analytical techniques are used to model this (Bashir et al., 2018; Khatoon et al., 2019). The most widely used analytical techniques to answer some of these questions are species distribution models (SDMs) that provide a quantitative relationship between the landscape features; both biotic and abiotic, and the species relative occurrence. Information from SDMs on habitat suitability and key factors affecting species distribution can help in identifying and prioritizing areas for conservation (Shrestha et al., 2020). Occupancy modeling is one of the remote sensing techniques, that estimates species' space use and distribution based on the detection probability i.e., presence/absence while accounting for imperfect detection (Bashir et al., 2018). This is very useful for cryptic and elusive species, whose population dynamics cannot be reliably estimated (Banner et al., 2019). Occupancy modeling assumes demographic and geographic closure of the target species and requires multiple surveys to address imperfect detection by estimating the detection rate, given true presence. Although this sounds simple, it becomes difficult considering the landscape features and the behavior of target species that limit detection (Guillera-Arroita et al., 2014; Halstead et al., 2021) at the given time.

Common field methods to obtain detection data for occupancy modeling are remote cameras, acoustic, interviews, sign-based surveys, non-invasive genetic sampling, and snow tracking (Clare et al., 2017; Guillera-Arroita & Lahoz-Monfort, 2017; O'Connor et al., 2017; Seidlitz et al., 2021). Sign-based surveys are really helpful in investigating changes in site occupancy rates over time (Seidlitz et al., 2021).

They have been used in determining site occupancy of large felid species such as the African lion (*Panthera leo*) (Midlane et al., 2014), common leopard (*Panthera pardus*) (Gubbi et al., 2020; Thapa et al., 2021), tiger (*Panthera tigris tigris*) (Thapa et al., 2021) and snow leopard (Alexander et al., 2016; Hameed et al., 2020).

Although a keystone species, snow leopard occupancy has been poorly studied across its range because of geopolitical and ecological constraints like elusive behavior, remote and rugged habitats that hinder logistics, and trans-border issues (Hunter et al., 2016). Few studies are reporting the site occupancy for snow leopards across its range including Russia (Kalashnikova et al., 2019), China (Alexander et al., 2016; Bai et al., 2018), India (Randeep et al., 2020; Watts et al., 2019), and Nepal (Aryal et al., 2016; Poudyal, et al., 2020). Owing to this, the confirmed occurrence of the species has been reported for only 27% of its total range (Snow Leopard Working Secretariat, 2013).

2.4 Human-snow leopard conflict

Human-wildlife conflicts (HWC) are one of the key challenges to conservation efforts across the globe (Torres et al., 2018). It occurs when humans and wildlife compete for space and resources and negatively affects each other directly or indirectly (Karanth & Kudalkar, 2017). Cost to humans is loss of life and injuries, crops and property damage, and livestock depredation that disturb the food security, economic and psychological well-being, and livelihoods of communities (Sharma et al., 2020). The retaliatory killing of wild animals leads to biodiversity loss and ecosystem disturbance (Nyhus, 2016). Similarly, the need for food and space of the growing human population results in the shrinkage and degradation of habitat for wildlife (Acharya et al., 2016). The magnitude of conflict increases with large carnivores because of their large home ranges, physical size, and feeding behavior, associated with real or perceived livestock depredation (Holland et al., 2018; Montgomery et al., 2018; Redpath et al., 2013; Wang et al., 2019).

The result is a global phenomenon where carnivores kill livestock and in response get killed (Montgomery et al., 2018; Torres et al., 2018). A varying global pattern of complexity is observed in local perceptions and attitudes toward large carnivores (Chetri et al., 2020). These perceptions are usually based on the ethnicity of the local communities, and religio-cultural beliefs (Chetri et al., 2020; Mkonyi et al., 2017). Other factors that shape the perceptions include the nature of animal's behavior and negative encounters risk (Dressel et al., 2015), and socio-demographic variables (Caruso et al., 2020; Fort et al., 2018; Trajçe et al., 2019). Understanding these perceptions will aid in minimizing the conflict's magnitude and outlining long terms conservation goals (Chetri et al., 2020), in landscapes where the primary source of livelihood is animal husbandry (Dressel et al., 2015).

Snow leopard in competition with other sympatric carnivores like the Eurasian lynx (*Lynx lynx*) and wolf (*Canis lupus*) preys on wild ungulates and influences the underlying ecosystems (Hacker et al., 2020; C. Li et al., 2015). The increased anthropogenic activities and the growing human population have reduced both the natural prey base and available habitat. This, in combination with abundantly available domestic animals, results in increased livestock depredation (Hacker et al., 2020). The economic loss resulted due to this depredation fuels negative attitudes in the local communities and they try to manage it through the extirpation of the snow leopard (Chen et al., 2016). Predation frequency is dependent on local conditions and husbandry practices and is highly variable across its range (Suryawanshi, 2013). Studies on snow leopard diet reported that 15 to 70% of the diet was composed of livestock consumption (Bocci et al., 2017; Hacker et al., 2021; Lu et al., 2019; Shrestha et al., 2018; Tumursukh et al., 2016; Wang et al., 2014).

2.5 Poaching and trade in snow leopards

Wildlife usage has been reported for different purposes like medicines, food, trophies, clothing, pets, and talismans that create a global market in wildlife trade (Patel et al., 2015; Uprety et al., 2021). To meet the demands of the increasing human population for wildlife products, the market is rapidly expanding and is resulting in increased wildlife trade. For many wildlife species, the trade is regulated and legal. However, for other thousands of species, the illegal trade severely hinders conservation efforts and negatively affects the livelihoods of communities, food security, and sustainable development of the environment (Biggs et al., 2017). Illegal wildlife trade or trafficking also called green crime is defined as the capture, poaching, collection, smuggling, and trade of protected and endangered species, and their products and by-products (Uprety et al., 2021). According to some estimates, it is the third largest illegal trade following the drug and arms trade (Regueira & Bernard, 2012). The annual global demand for this illegal trade is estimated from 10 to 20 billion US dollars (Uprety et al., 2021).

This illegal trade is among the main challenges to conservation efforts across Asia (Esmail et al., 2020; Uprety et al., 2021) and poses different taxa under threat including but not limited to amphibians (Janssen & Shepherd, 2019; Rowley et al., 2016), reptiles (Janssen & Shepherd, 2019; Lyons & Natusch, 2011), birds (Burivalova et al., 2017; Mazumdar et al., 2014), and mammals (Li & Lu, 2014; Nijman, 2017; Pandit et al., 2014; Rooney et al., 2015). Although the leading cause of the illegal wildlife trade is the demand at the consumer level, the poverty of the concerned communities cannot be ignored while dealing with the illegal wildlife trade (Duffy et al., 2016; Uprety et al., 2021). Being a transboundary issue further complicates the matter and makes it difficult to devise and implement legislation (Patel et al., 2015; Uprety et al., 2021).

Snow leopards face the threats of poaching and subsequent trade across their range in South and Central Asia (Ale & Mishra, 2018; McCarthy et al., 2017). This had been a common practice for thousands of years along the Silk Road during trading activities. The costly products and high market demands determine the trade and poaching intensity of the cat. The most sought-after product is the skin for coats and decoration (Maheshwari & Niraj, 2018; Mccarthy, 2019). Other products include meat for eating as a delicacy, bones for use in traditional medicines, claws, teeth, taluses, penises as superstition accessories with good luck against evil spirits, and living cubs for exhibition and research (Maheshwari & Niraj, 2018; MaMing, 2012).

2.6 Ecosystem Services in the Mountain Ecosystems

Besides the conflicts, positive interactions also occur between humans and large carnivores (Kumbhojkar et al., 2020). Large carnivores can help people through Ecosystem Services (ES)- the gains of people from ecosystems- that range from livelihoods to cultural and spiritual values (Balasubramanian & Sangha, 2021; Notess et al., 2018; Reytar & Veit, 2017; Sangha et al., 2019) such as reducing economic and human health impacts from zoonotic diseases, by supporting agricultural production through preying on herbivores, create livelihood options through ecotourism for local communities (Braczkowski et al., 2018; Gilbert et al., 2017; O'Bryan et al., 2018; Penteriani et al., 2017; Verma et al., 2017; Young et al., 2020).

Ecosystem services play a vital role in human well-being and survival (Song & Deng, 2017). Estimates suggest that more than three-fourths of the world's poor people are dependent on ES for their survival and the demand is expected to increase subject to the rapidly increasing population (Paudyal, 2018).

Compared to the high-productivity ecosystems like mangroves, coastal deltas, and tropical forests (Szabo et al., 2016; Vo et al., 2012) few assessments of ES are available for low-productivity ecosystems i.e., semi-arid rangelands and deserts (Zoderer et al., 2016). These low-productivity systems are important as they support 33% of the world's population and cover 40% of the earth's land surface. The inhabitants of these systems mostly rely on agriculture and pastoralism for livelihood due to the lack of available alternatives (Murali, 2019).

Ecosystem services provided by carnivores are at risk as currently 61% of all large carnivores are threatened with extinction (Scullion et al., 2021). The ecosystems of the snow leopard range have been less studied compared to their ecological importance, and the services provided to the concerned communities and downstream inhabitants (Murali et al., 2017). The range is characterized by high mountains with the largest glaciers outside the polar region and provides invaluable ES to both the local communities and about one billion people downstream. These services include food, medicines, pastures, fodder, water, important minerals, timber, hydropower, and tourism (Murali, 2019). Understanding the importance of these services is necessary to devise strategies for ecosystem conservation and enhance management practices with a better decision-making framework. Thus, it is noteworthy, that in addition to its value as data for knowledge material, conservation, and management strategies, the findings reported from this research could serve as the basis for future similar studies in other geographic locations of the snow leopard range.

CHAPTER 3: METHODOLOGY

3.1 Study area

This study was undertaken in the Pamir Mountain Range covering the transborder regions of Afghanistan (Lower and Upper Wakhan Corridor), Tajikistan (Alichur, Tokhtamish, and Shymmak), and Pakistan (Khunjerab National Park [KNP], Misgar and Chipursan Valleys, Qurumbar National Park [QNP] and Broghil National Park [BNP]) around the Pamir Knot (Figure 3.1). Flanked by the Hindukush, Himalayas, Karakoram, and Kunlun Mountain Ranges, the Pamirs form one of the most spectacular mountain ranges in the world and are recognized as the 'roof of the world' (Bliss, 2006). The Pamir Mountain range is listed among the world's 200 eco-regions (Olson et al., 2001) and is considered a biodiversity hotspot (McGinley, 2008) due to its extraordinary geographic position and socio-cultural (Kreutzmann, 2003) and ecological diversity (Wildlife Conservation Society, 2007). The Pamir's grasslands and semi-deserts act as a major bio-geographic barrier between Mediterranean-influenced middle Asia, monsoonal South Asia, and the continental expanses of Central Asia. Being situated in the alpine zone, the winter is harsh, autumn is mild and summers are pleasant with annual temperature and precipitation ranging from -18°C to 23°C and 50mm to 300mm, respectively (Khan et al., 2014).

The Pamirians represent two major language groups, Iranian and Turkic, of this part of central Asia. Wakhi is a branch of the eastern Iranian languages within the Indo-Iranian group while Kirghiz is a Turkic language belonging to the Altaic group (Kreutzmann, 2003). The specific attraction of this altitudinal ecological belt is the availability of water stored in glaciers and snow that feeds irrigation systems. Though the Wakhis grow crops, the Kirghiz have traditionally refrained from any form of settled agriculture.

Both groups utilized high pastures where groundwater and runoff create seasonal meadows (Kreutzmann, 2003).

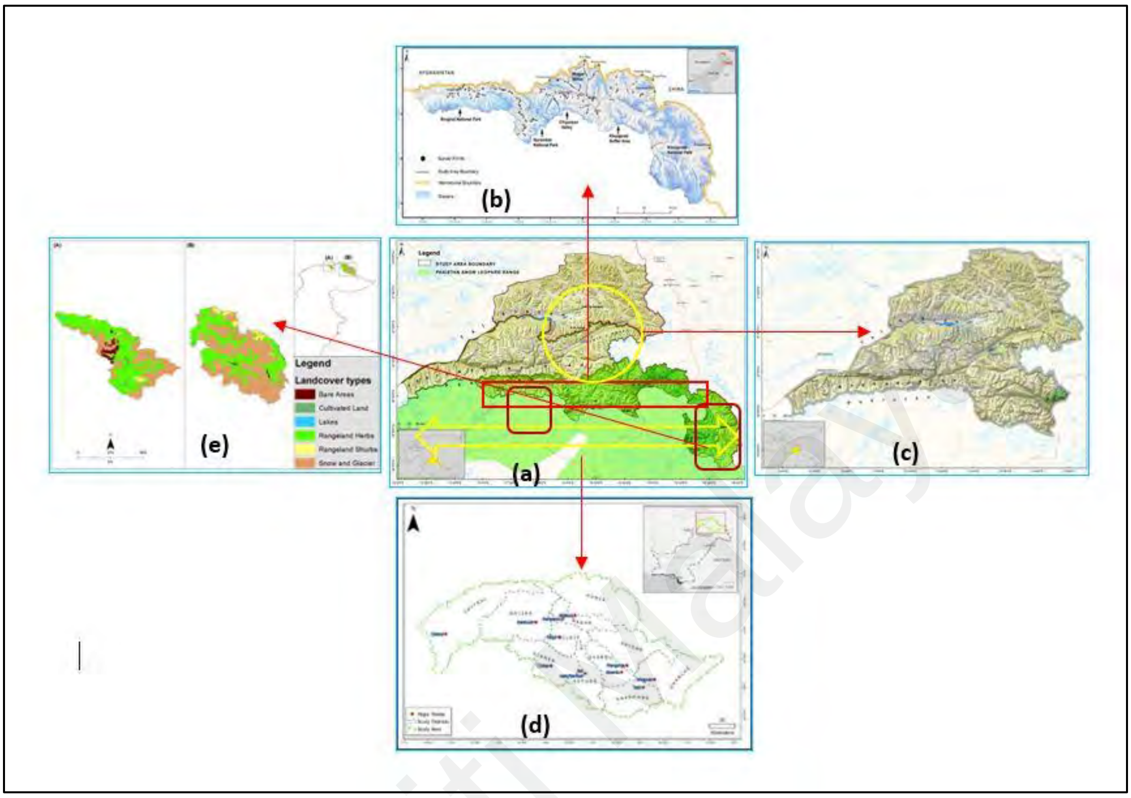

Figure 3.1: Map showing (a) the study area, (b) occupancy study sites, (c) human-snow leopard conflict study sites, (d) snow leopard poaching and trade study sites, and (e) sites for the ecosystem valuation study undertaken in this research

The mammalian fauna of the Pamirs includes iconic species like the Marco Polo sheep (*Ovis ammon polii*), Himalayan ibex (*Capra sibirica*), blue sheep (*Pseudois nayaur*), Ladakh urial (*Ovis orientalis*), snow leopard (*Panthera uncia*), the grey wolf (*Canis lupus*), and brown bear (*Ursus arctos*).

3.2 Estimation of snow leopard occupancy and detection probability

3.2.1 Study sites

Study sites encompassed three high-altitude National Parks (NPs) viz; the KNP, QNP, BNP, and Community Managed Conservation Areas (CMCAs) of Misgar and Chipursan Valleys falling in the Karakorum-Pamir and Hindu Kush-Pamir Mountain Ranges, respectively (Figure 3.2).

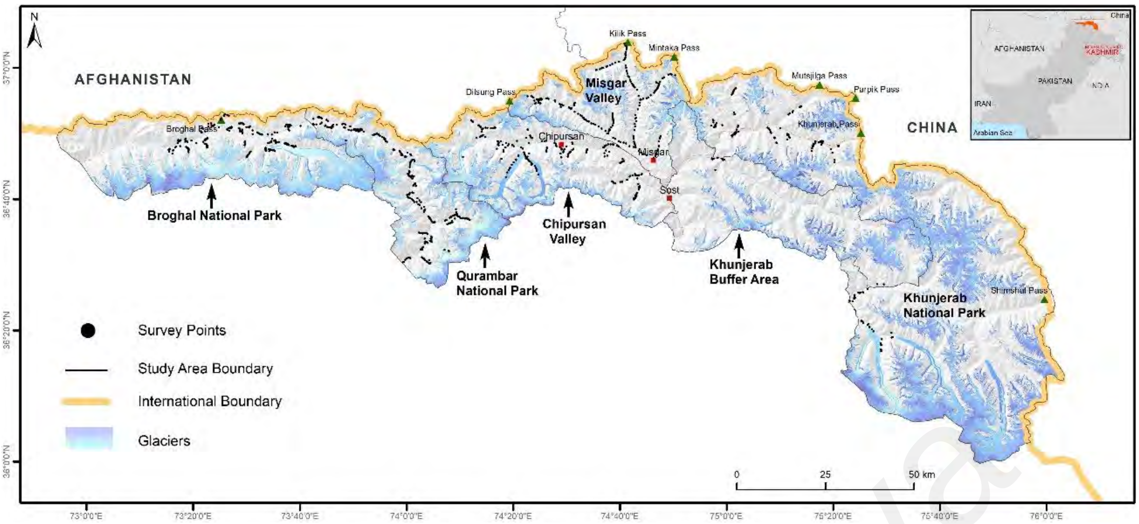

Figure 3.2: Map of the study site showing overall study units, survey blocks and occupancy points surveyed

The KNP (74° 52'- 76° 02′E, 36° 56'- 36°13′N) covers an area of 4,455km² and ecologically continues to Taxkorgan Nature Reserve, China. As a result of the preliminary surveys conducted by Schaller in the 1970s (Schaller, 1980), the watersheds of Khunjerab and Shimshal were notified as National Park in 1975, mainly to conserve Marco Polo sheep and the snow leopard. The KNP and its buffer zone also support a good population of ibex (*Capra sibirica*) and blue sheep (*Pseudois nayaur*), where a community-based trophy-hunting program is being implemented (Khan et al., 2014).

The BNP spread across 1,348 km² in Chitral District and lies between 73° 13′- 73° 52′E and 36° 42′- 36°55′N and was notified as a National Park in 2010 to safeguard high altitude (3,300-4300m) wetlands and associated wildlife. It borders the North and West with the historical Wakhan corridor of Afghanistan, in the East and South borders with Yasin valley and Qurumbar National Park of Gilgit-Baltistan (GB), respectively (Shah, 2012).

The QNP (73°40´-73°05´E, 36°40´-36°55´N) lies in the Ghizer District and borders the Wakhan Corridor of Afghanistan in the North, the Broghil National Park in the West, the Hunza Valley in the East, and Ghizar River in the South.

The Park extends over a 740km² area and was notified in 2011 to conserve the natural flora and fauna, and wetlands and improve the livelihood of the local people (WWF-Pakistan, 2016). The QNP and its buffer zone, the community-managed conservation area fall in the mountain desert ecosystem where the average rainfall rarely exceeds 150mm.

The CMCAs of Misgar and Chipursan Valleys (74° 0´-74° 5´E, 37° 0´-37° 5´) spread across 2,248km² in the Pamir and are surrounded by KNP in the Northeast, Afghan and Tajik Pamir in the North, and QNP in the West. The Pamir and the Karakoram Mountain ranges meet at Kilik Pass of Misgar Valley on the borders of China, Afghanistan, and Pakistan. The Kilik and Mintika watersheds used to be a potential habitat for Marco Polo sheep (Ali et al., 2019) which constitute one of the major wild prey of snow leopards in the region.

3.2.2 Study design and data collection

Snow leopards are elusive, solitary, and territorial animals and mark their territory through scrapes and scent marks. These traits were used to assess the site use and detection rate of snow leopards in this study, undertaken between the years 2010-12. Due to the logistic challenges imposed by the remote terrain, the landscape was divided into four (KNP, Misgar-Chipursan, KNP, and BNP) larger study units (survey blocks). Next, the study area was split into smaller sampling units by overlaying 5 x 5 km grid cells (sites) using ArcGIS v.10.7 and each survey block was surveyed discretely. In this study, the quadrat method was used instead of the line transect.

Grids are preferred over line transects in snow leopard occupancy studies as grids provide a more systematic approach to have a holistic overview of and scan the landscape under consideration (Alexander et al., 2016; Bayandonoi et al., 2021; Sharief et al., 2022). Within the grids then the microhabitats (points) are searched for snow leopard signs by walking through 5 x 100 long transects, 2 to 12 in each grid. In each accessible site, a team of two observers surveyed the most likely micro-habitats (points) such as ridgelines, saddles, gorges, and cliff-bases where snow leopards usually tend to leave signs. Since the snow leopard landscape restricts free movement, each point was confined to a rectangular route of 5 x 100 m to ensure uniformity of the survey effort across the study sites (Figure 3.3).

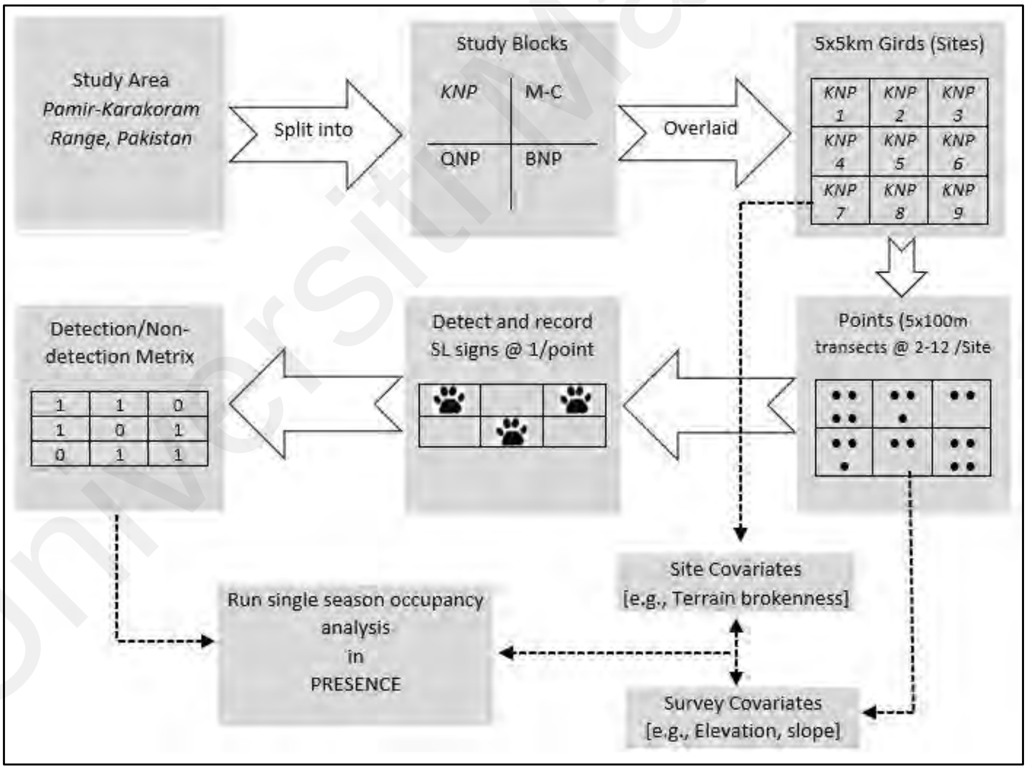

Figure 3.3: Schematic of the occupancy survey design

Snow Leopard signs are very prominent and researchers even with some training and skills can easily detect these signs in the field. Snow leopards' scent-spray or cheek rub on boulders along the treks or overhanging rocks that when fresh has a pungent smell.

Similarly, they scrape to mark their territory using their hind legs and most are revisited and refreshed (Jackson & Hunter, 1996). Only one fresh sign, scrape, or scent spray site (Jackson & Hunter, 1996) was recorded at each point, which resulted in a maximum of 12 points that were recorded at each site. Each point was marked with GPS and habitat attributes (survey covariates) were noted.

A total of 109 accessible grid cells (KNP=21, BNP=14, QNP=24, CMCAs=50) were surveyed, covering a 2,725 km² area, with altitudes ranging from 2,257m to 4,837m (average=3,737m). About half of the grid cells (n=533) in the study area fall in the high altitude (>5,000m) of cold desert glaciated terrain; hence, were therefore not accessible by people.

Based on the field observations and previous research (Ghoshal et al., 2019; Henschel et al., 2016), 11 sites and 7 survey covariates were hypothesized as predictors of snow leopard occupancy in the study area (Table 3.1).

Table 3.1: Eleven site and seven survey covariates hypothesized to affect snow leopard occupancy and detection probability across the study sites

Covariate	Data source	Likely effect on occupancy	Published evidence of the effect of the variable
Site Covariates			
Precipitation	www.worldclim.org (Hijmans et al. 2005)	−	Bai et al., 2018
Road	Spatial Analyst Tool in ArcGIS v.10.7. (ESRI, Redlands. USA)	−	Luo et al., 2019
Ruggedness	Geoprocessing script (Sappington, Longshore & Thompson, 2007)	+	Taubmann et al., 2016
River	Spatial Analyst Tool in ArcGIS v.10.7. (ESRI, Redlands. USA)	+	Aryal et al., 2016
NDVI	Spatial Analyst Tool in ArcGIS v.10.7. (ESRI, Redlands. USA)	+	Taubmann et al., 2016
Elevation/Altitude	www.earthexplorer.com	−	Taubmann et al., 2016
Temperature	www.worldclim.org (Hijmans et al. 2005)	−	Farrington and Li, 2016
Slope	www.earthexplorer.com (Derived from elevation)	+	Alexander et al., 2016
Settlements	Spatial Analyst Tool in ArcGIS v.10.7. (ESRI, Redlands. USA)	−	Luo et al., 2019

Table 3.1, continued.

Covariate	Data source	Likely effect on occupancy	Published evidence of the effect of the variable
Prey	Snow Leopard Foundation	+	Ghoshal et al., 2019
Staff	Collected in this study (Wildlife Department GB)	+	Henschel et al., 2016
Survey Covariates			
Pasture	Assessment of microhabitats in this study	−	Fox and Chundawat, 2016
Scrub	Assessment of microhabitats in this study	+	Fox and Chundawat, 2016
Barren	Assessment of microhabitats in this study	+	Snow leopard Network, 2014
Terrain	Assessment of microhabitats in this study	+	Snow leopard Network, 2014
Ridge	Assessment of microhabitats in this study	+	Snow leopard Network, 2014
Cliff base	Assessment of microhabitats in this study	+	Snow leopard Network, 2014
Plateau	Assessment of microhabitats in this study	−	Snow leopard Network, 2014

Topographic covariates such as elevation were downloaded from the website (www.earthexplorer.com) while slope was derived from the elevation.

The density of rivers (water) in the study sites was calculated using the Spatial Analyst Tool in ArcGIS v.10.7. (ESRI, Redlands, USA). Similarly, ruggedness was extracted using the geo-processing script (Sappington et al., 2007).

The climatic covariates (annual mean temperature and annual mean precipitation) were downloaded from www.worldclim.org developed by Hijmans et al. (2005). The anthropogenic covariates (density of roads and settlements) were extracted following Luo et al. (2019) and survey covariates were collected based on the pre-categorization of microhabitats and the observer's experience. The *topographic habitat variables* were categorized into the valley, ridgeline, cliff base, and plateau; *physiognomic vegetation variables* into the pasture, scrub, and barren; and *terrain brokenness* into flat, slightly, moderately, and very broken, respectively.

3.2.3 Data analysis

All the covariates were standardized to mean zero (0) and variance of one (1) using psycho package in R (R Core Team, 2019), before running the occupancy models. Pearson correlation test was used to exclude highly correlated ($r > 0.70$) variables (Schober & Schwarte, 2018) in the analysis (Alexander et al., 2016).

Having the data consolidated, detection histories as “1s” and “0s” in a matrix of sites vs. points (MacKenzie et al., 2002) were developed and analyzed using the software PRESENCE v.12.37 (Hines, 2006). Since each of the four study blocks was surveyed once to estimate the probability of site use rather than true occupancy of snow leopards, the single species single season occupancy model was considered (MacKenzie et al., 2002). On the onset, the null model was computed by keeping both detection (p) and occupancy (ψ) constant.

This study intended to model covariates that influence detection probability first, while, keeping occupancy constant and then to use the best detection model based on the AIC weight in further modeling aimed to investigate the significance of occupancy covariates (Henschel et al., 2016; Karanth et al., 2011). Next, the univariate, bivariate, and then multivariate modeling was run, unless the final model that best explained the variation in detection and occupancy (site use) of the snow leopard at the site level (Henschel et al., 2016) was secured. The best-fitting model was determined using the Akaike Information Criteria (AIC). The model that has the best fit (likelihood) obtains the minimum value of AIC value (Burnham & Anderson, 2002). Finally, the output of the best model was used to predict the probability of unconditional occupancy (site use) at the sites (girds) not sampled (Kshettry et al., 2017) to have a holistic overview of the study area. The occupancy values obtained for each site were pooled to calculate the average occupancy estimates with standard errors across the study blocks and study areas.

Since the study aimed to estimate and compare the snow leopard occupancy (site use) and detection probability in the entire study sites; therefore, analysis was run on the overall data collected. The study blocks in this study were merely to standardize the surveys as such a long and remote area cannot be surveyed simultaneously.

3.3 Spatiotemporal patterns of livestock predation

3.3.1 Study Sites

The study sites include the valleys of Afghanistan (i.e., Lower and Upper Wakhan corridor) Pakistan (i.e., Chipursan and Misgar Valleys), and Tajikistan (Pamir: Tokhtamish, Shymak, and Alichur) around the Pamir Knot covering ~2,770 km^2 area (Figure 3.4). A description of the sites is given above under the heading 3.1.

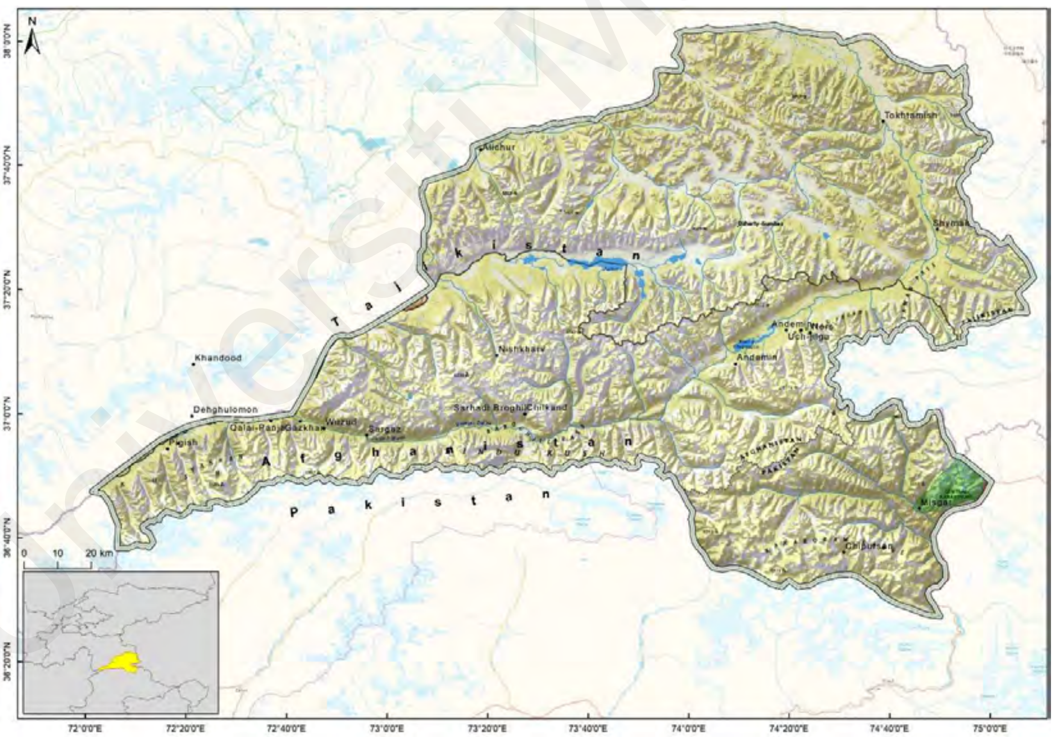

Figure 3.4: Map of the study sites showing the valleys sampled along the transborder region in the Pamir

3.3.2 Study design and data collection

The village men were approached in the remote village at the periphery of the Pamir Knot, in Afghanistan, Pakistan, and Tajikistan. Data was collected on human-carnivore conflicts using a structured questionnaire (Dar et al., 2009; Din et al., 2013), and one adult person, usually the head of the household among the agropastoral households was interviewed. Respondents were informed about the objectives of the survey before interviews to avoid exaggerated data.

Questions asked included the number and types of livestock owned, grazing patterns and knowledge of the occurrence of predators, predation details, and demographic information. The sightings of snow leopards and wolves as reported by the respondents were used as confirmation of predator occurrence in the study sites. The number of livestock owned and killed was grouped into categories like goat, sheep, cattle (cow, calf, and bull), and others (yak and equine). The pastoral communities have been living alongside the wildlife in these valleys for centuries and they easily differentiate between wolf and snow leopard kill. Felids suffocate the prey and canine punctures are visible on the neck region. While canids attack the hind limb of their prey. We recorded the incidences where the informants defined the predator correctly.

Livestock predation reports were reckoned very carefully and only those incidents where informants were able to identify the predator directly (sighting) or indirectly (signs of the predator and kill patterns) were recorded (Table 3.2).

Table 3.2: Explanatory variables used as predictors of the extent of livestock predation by the two predators (snow leopard and wolf)

Variable Name	Variable Description
Valley	Natural watersheds in the study sites approached to collect data
Season	Four seasons (Autumn [Sep-Nov], Spring [Mar-May], Summer [Jun-Aug], and Winter [Dec-Feb]) of the year
Time	Time of the predation incident. Morning (5 am to 2 pm), Evening (3 pm to 8 pm), and Night (9 pm to 4 am)
Year	2008-2012
Prey (Livestock) sex	Male, female, and both (where both sexes were killed)
Prey (Livestock) age	Adult and young/kid (juvenile)
Livestock owned by the respondents	Total livestock owned (T.o), Sheep owned (S.o), Goat owned (G.o), Cattle owned (C.o), and Other (yak, equine, etc.) owned (O.o). Each livestock type was summed up as low and high using the median.
Predator sighted	Wolf sighted and snow leopard sighted (yes or no) by the respondents during the study period.

In cases, where herders were unable to recall the information relating to the number, age, sex, and chronological evidence related to the livestock killed by snow leopards and wolves, the data were not considered in the analysis (Dar et al., 2009; Namgail et al., 2007). The questionnaire surveys were conducted in the last quarter of 2012 to collect data on the reported livestock predation incidences from January 2008 to June 2012. A total of 278 data points including 50 from Afghanistan, 185 from Pakistan, and 43 from Tajikistan were used to run the analysis.

Having taken into account important assumptions such as high dimensionality and multi-collinearity among the variables associated with multivariate modeling, in relation to the data structure, mixed-effect nested models using “lme4” package were run (Bates et al., 2015) by calling the function “glmer” with family “Poisson”.

Mixed effect models are more effective when there is non-independence in the data either due to the multicollinearity or grouping of the samples. These account for non-independence between the samples via random effects, where the random effects are particularly useful when there are lots of levels, comparatively little data on each level, and patchy sampling across levels (Hall & Wang, 2005).

Model selection was made through stepwise backward elimination and effects were plotted using package “effects” (Fox, 2016). Due to the limited data points, the data were pooled and analyzed for the entire study area.

3.4 Predation intensity and valuation of livestock losses and local consumption

3.4.1 Study sites

The study sites for this study are described under 3.3.1 (Figure 3.3) and include the valleys of Afghanistan (i.e., Lower and Upper Wakhan corridor), Pakistan (i.e., Chipursan and Misgar Valleys), and Tajikistan (Pamir: Tokhtamish, Shymak, and Alichur) around the Pamir Knot covering ~2,770 km^2 area.

3.4.2 Study design and data collection

Pretested structured questionnaires (Din & Nawaz, 2010; Din et al., 2013) covering important conflict-inducing parameters such as study site demographic features, pastoralism practices and herd dynamics, the status of large carnivores, predation intensity patterns with associated economic losses, human perceptions, attitudes, and tolerance of predators were used to collect data.

Informants included herders, farmers, wildlife guards, students, and teachers. One respondent per household was interviewed and a minimum of 10% of households in each village were reached. Survey objectives were explicitly communicated prior to survey initiation to avoid embellished information.

Predation incidences reported during the period January 2008–June 2012 were recorded. A total of 182 respondents from seven valleys were considered in this study.

The livestock types of the respondents were grouped into four categories, namely sheep, goat, cattle (bull, cow, and calf), and other (yak and equine). The economic return—marketing animals or consuming domestically—was calculated using the average price per animal in local markets with the total number of animals utilized. The variation in economic impact per household per year in each study site was tested statistically.

Livestock predation incidences were assessed very carefully. Only those reports were considered where informants were able to identify predators directly (predator sighted on the spot or previously near the predation spot). Indirect identification was restricted to signs left by predators or that the kill reflects the predation instinct of a particular predator (Din et al., 2013; Namgail et al., 2007). Furthermore, herders' reports were filtered (who generally differentiate between snow leopard and wolf kills based on carcasses) and did not include instances where herders were unable to recall the number, age, sex, and chronological evidence related to the livestock killed.

The livestock losses due to disease were also counted and compared with losses to predation and evaluated the economic loss associated with each type.

3.4.3 Data analysis

The statistical tests were used to evaluate the data and summarize variation among different factors in the computing software, R (R Development Core Team, 2015).

The lasso logistic regression in R using package "glmnet" (Friedman et al., 2010) was used to test the influence of social and demographic factors on human attitude towards large carnivores.

The public perception of carnivores, gauged through the question of, whether they want to increase or maintain the population of snow leopards or wolves (yes = 1 or no = 0), was used as a response variable. Then, effects of several factors, including education, income, occupation, land holding, type and number of livestock, valleys, countries, year, season, prey sex, age, and predation time were tested through logistic regression by;

$$\log \frac{p(PublicPerception)}{1+p(Public\ Perception)} = \beta_0 + \beta_1(Education) + \beta_2\,(Income) + \beta_3(Occupation) + \beta_4(Landholding) + \beta_5(Numberoflivestock) + \beta_6(Valley) + \beta_7(Country) + \beta_8\,(Season) + \beta_9\,(Prey\ sex) + \beta_{10}\,(Prey\ age) + \beta_{11}\,(predation\ time) + e \quad (3.1)$$

The logistic regression coefficients β present the change in log odds ratios with per unit change in the respective factor. The logistic regression assumes the explanatory factors to be linear and to address the potential risks of multicollinearity, lasso penalty (Chen et al., 1998; Tibshirani, 1996) was added to the logistic regression (Tong et al., 2009).

$$\lambda \sum_{j=1}^{10} |\beta j| \to 0 \quad (3.2)$$

The lasso penalty removes weak factors from the regression model through tuning constant λ (lambda), which shrinks the logistic regression coefficients (β) towards zero. The tuning constant λ was tuned through 10-fold cross-validation in simpler settings to find the best value of λ. The testing classification error for each test set was computed from the training set. A range of values of λ was used to determine its minimum. The percentage of correctly-identified samples was used to quantify model performance.

The data was split into two sets randomly in a ratio of 0.7. The largest set which takes 70% of the samples was used to train the model. Test data was used to assess model performance once the optimum model was selected. Separate models for each snow leopard and wolf were run.

3.5 Investigation of poaching and trade in snow leopards

3.5.1 Study sites

For the assessment of poaching and trade, the entire snow leopard range including Pamir was considered. The snow leopard range in the country spreads across an 80,000 km^2 area in the northern mountainous belt including Hindu Kush, Pamir, Karakoram, and Himalayas (MOCC, 2017). Administratively, the snow leopard range covers the entire Gilgit-Baltistan (GB) Province, Chitral, Kohistan, and Swat Districts of Khyber Pakhtunkhwa (KP) Province and Neelum District of Azad Jammu and Kashmir (AJ&K), respectively (Figure 3.5). The GB province contains the largest proportion (> 60%) of the country's snow leopard range (Hussain, 2003).

Pakistan's snow leopard range also borders India, China, and Afghanistan and constitutes an important corridor enabling genetic diversity. Apart from the snow leopard range, major cities including Rawalpindi, Islamabad, Lahore, Swat, and Peshawar were also surveyed to collect data on the snow leopard trade.

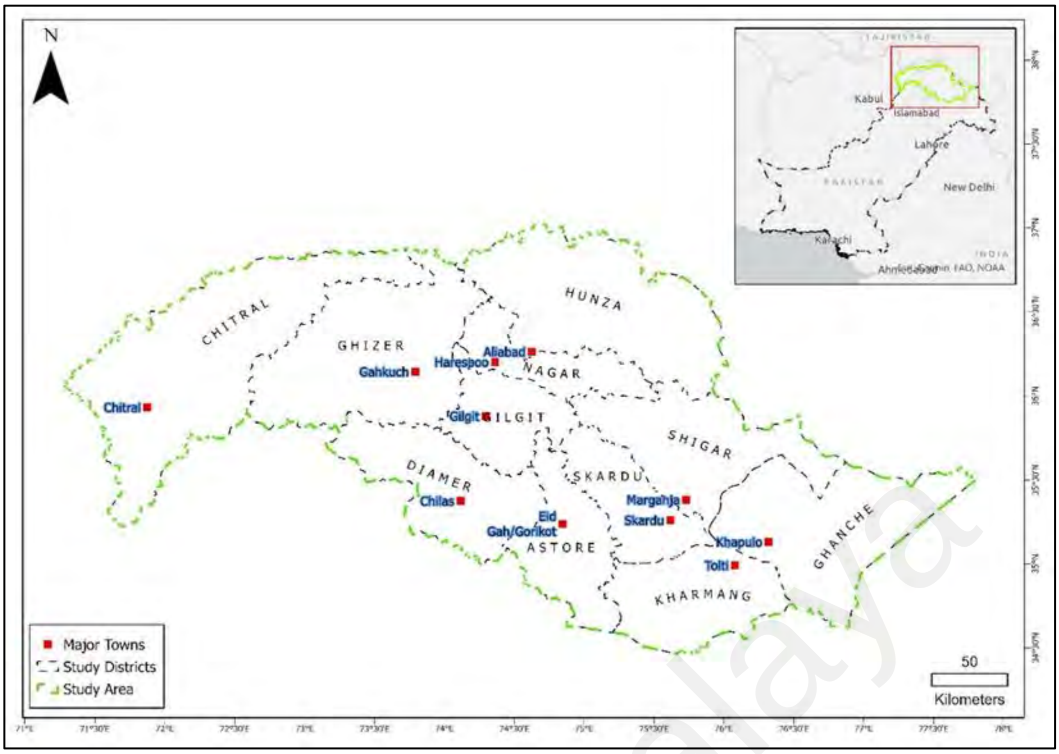

Figure 3.5: Map of the study sites showing the administrative units selected for data collection.

3.5.2 Study design and data collection

Since the investigation of wildlife poaching and trafficking is a sensitive issue and cannot be ascertained through a single method, a mix of investigative tools was used in this study (Figure 3.6). About 15 personnel from the wildlife department, Snow Leopard Foundation, and communities were engaged in the data collection process. Firstly, structured questionnaires were distributed to the wildlife staff in each district and provincial or regional headquarters to gather reported, pursued, and persecuted cases of snow leopards and other carnivores during the study period (i.e., 2005-2017). Data collection in studies like this one is highly challenging and thus requires longer study periods to enable sufficient time for data collection and to understand the temporal trend in poaching incidences. Other studies (Li & Lu, 2014; Maheshwari et al., 2016; Nowell, 2016) have reported their findings over an even longer study period.

The questionnaires were also shared with the non-governmental conservation organizations operating in the snow leopard range for information collection. The data involving the survey was collected in early 2018.

Next, potential pelt markets in major cities outside the snow leopard range including Swat, Peshawar, Rawalpindi, Islamabad, Lahore, and Karachi were surveyed at least twice. Thorough surveys were conducted in each district of the snow leopard range focusing on major markets in each town; i.e., district and tehsil (an administrative sub-division of a district) headquarters.

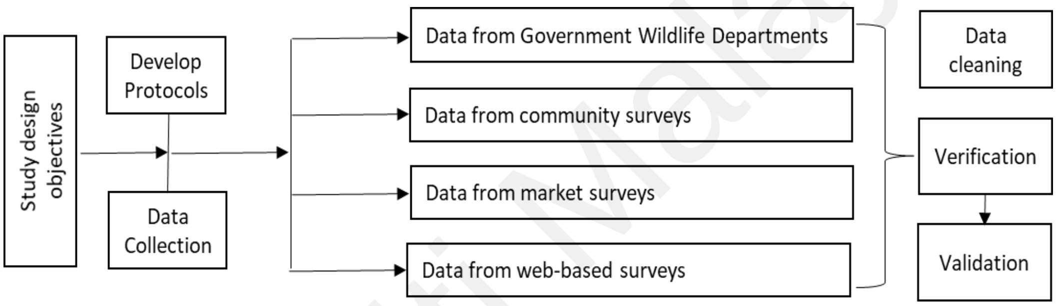

Figure 3.6: Schematic of methodological workflow adopted during the study

Subsequently, based on the information obtained thus far, a separate questionnaire was developed to collect poaching and trade data from local informants in the snow leopard range valleys. Herders, hunters, shopkeepers, local taxidermists, and other potential informants were approached covertly. Potential informants in the valleys were identified, trained in data collection, and engaged in the surveys.

Lastly, a desk review was conducted and the internet was browsed for news related to poaching, apprehending, prosecution, and smuggling related to snow leopards. Search engines such as Google and social media, like Facebook and Twitter, were searched for news related to snow leopards. Besides, the archives of major national and local online newspapers, both Urdu and English were also consulted.

3.5.3 Data analysis

Data collected from different sources and tools were decoded in excel sheets, cleaned, verified, and validated by filtering double counts and duplications. Data were reported using descriptive statistics. Mean, standard error, and confidence intervals were reported where required. The Chi-square test was used to measure variations in the poaching methods and intentions stimulating poaching. T-test was used to see whether the mean base price (price at the poaching site/location) varies from the end price (price offered in the markets at large cities). The worth of the trade was reported both in PRK and USD.

3.6 Valuation of the ecosystem services in the snow leopard landscapes

3.6.1 Study sites

Ecosystem services were assessed in the two high-elevation national parks (NPs), KNP and QNP, and their immediate buffer zones, notified as the community-managed conservation areas (CMCAs), in Pamir (Figure 3.7). A description of the two NPs is provided above under 3.2.1.

The Qurumbar valley (buffer of QNP) is subdivided into many villages, as are the buffer valleys of KNP. The buffer zone of QNP is more populated (~1,200 households) than that of KNP (~560 households). The Wakhi is a major ethnic group of the Pamir, along with the Kirghiz. The literacy rate in the communities of QNP is lower than in KNP, and the remote mountain communities lack basic civic facilities. Agropastoralism is the major source of livelihood. Sheep and goats constitute the bulk of the livestock, followed by cattle and yak (Din et al., 2017).

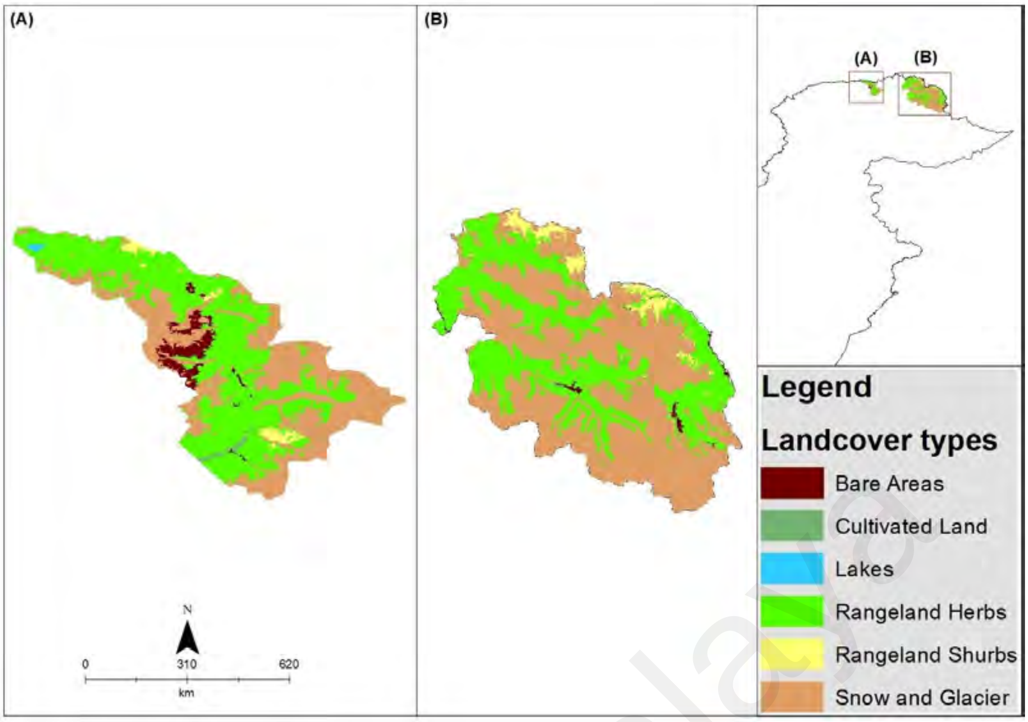

Figure 3.7: Map of the study sites showing major land cover types

Because of the mountainous terrain, the average landholding is less than 1 hectare per household, and cropping is mostly done on the irrigated alluvial fans. Both study sites fall in a single cropping zone because of the arid climatic conditions. An overview of the main characteristics of the 2 NPs is provided in Table 3.3.

Table 3.3: Major socioecological attributes of the 2 national parks.

Socioecological characteristics	KNP	QNP
Major ecosystem types	Alpine and cold desert ecosystem	High-elevation wetland ecosystem
Total core area in km^2	4455	740
Landcover types in %:		
- Rangeland herbs/shrubs	54.10	40.65
- Snow/glaciers	40.73	58.63
- Barren area	4.30	0.61
- Lakes	0.24	0.01
Cultivable land (buffer zone)	0.62	0.11
Average tourist flow/year	28,260	3,512
Dependent buffer households	1,200	560

Table 3.3, continued.

Socioecological characteristics	KNP	QNP
Total livestock heads	13,250	33,696
No. of trophy hunts (2014–15) of ibex + blue sheep in the buffer zone	21 + 5	5 + 0

3.6.2 Study design and data collection

This study relied on semi-structured questionnaire surveys of 190 households residing in the buffer zones of KNP (n=93) and QNP (n= 97) conducted between May–August 2016 to quantify and evaluate selected essential ecosystem services. The data were complemented by the socioeconomic baseline data reported in the management plans of KNP (Khan, 1996) and QNP (WWF-P, 2016). In addition, consultations were carried out to gain technical inputs and validation from experts representing both government and private institutions, including agriculture, livestock, rural development, forest, wildlife, and tourism departments, and conservation NGOs.

3.6.3 Data analysis

This study considered provisioning services (n = 9), cultural services (n = 2), and regulatory services (n = 1), following the MEA Report (2005). The main valuation tools used in this study were the market price method (provisioning services), the net revenue approach for cultural services (Sharma et al., 2015), and the benefit transfer (unit value transfer) method for regulatory services. A description of the services measured, data sources, and the methodology adopted is provided in Table 3.4.

Following Sharma et al. (2015), provisioning services were estimated using the equation:

$$\boldsymbol{TVP}_{\mathrm{i}} = \sum_{i=1}^{n} (\%hh_{\mathrm{i}} \times HH \times NV_{\mathrm{i}}) \tag{3.3}$$

where i represents the different ecosystem provisioning services; $\%hh_i$ is the proportion of overall households reliant on the i^{th} provisioning service (i.e., dependency weight); HH is the cumulative number of households living in the buffer zone; and NV_i is the annual average net benefit gained per household, calculated by deducting the annual price of the products from the respective gross value using the net benefit method (Sharma et al 2015; Viboonpun, 2000).

Table 3.4: **Description of the ecosystem services measured, data sources, and methodology adopted.**

Ecosystem service	Valuation method	Assessment description	Source
Provisioning services			
Crops	Market price	Net annual crop income/household = (crop yield/hectare × local crop price/kg) – input cost of 60% of gross income	Government of Gilgit-Baltistan (2014); Sharma et al. (2015); Murali, Mishra, et al. (2017)
Fruits	Market price	Net annual income per household = (fruit yield/bearing tree × local price/kg) – (losses 15–30% + input cost of 30% of gross income)	Government of Gilgit-Baltistan (2014)
Fodder	Market price	Net fodder value = (average fodder consumption per cattle and sheep/goat per year × market price per kg fodder × total number of livestock in the study sites) – input cost of 60% of gross value	Government of Gilgit-Baltistan (2014); Murali, Mishra, et al (2017); Livestock vaccination data of SLF (24/12/2015)

Table 3.4, continued.

Ecosystem service	Valuation method	Assessment description	Source
Medicinal plants	Market price	Net income per household = (average quantity of medicinal plants collected in kg × market price per kg) – collection/time cost	Government of Gilgit-Baltistan (2014)
Fuelwood	Market price	Average annual value = (average annual quantity in kg harvested per household per year × per kg price in local market × total households in the study sites) – input, ie labor or transportation cost	Sharma et al. (2015); Government of Pakistan (2015); Government Forest Department (personal communication, 15/06/2016)
Timber	Market price	Net annual value = timber (85 square feet) required to construct a traditional rural house with 11,000 square feet covered area × average number of new houses constructed in the study sites having took into account the annual population growth rate of 2.5% × market price of 1 square foot timber (500 PKR = US$ 4.76)	Unit values from Gilgit-Baltistan Planning and Development Department (2013)
Physical material (stone, sand, soil)	Market price	Net annual value = stone and soil or sand (1650 square feet) required to construct traditional rural house with 16,500 square feet of covered area × average number of new houses constructed in the study sites taking into account the annual population growth rate of 2.5% × market price of 1 square foot stone (50 PKR = US$ 0.47) and soil or sand (30 PKR = US$ 0.28)	Unit values from Gilgit-Baltistan Planning and Development Department (2013)

Table 3.4, continued.

Ecosystem service	Valuation method	Assessment description	Source
Domestic water consumption	Market price/ benefit transfer	Net value per year = (per capita water consumption per day of 15 liters × average household size of 8 × 365 days × total households [QNP = 1170, KNP = 560] × market price of locally produced 1 liter of water [6.5 PKR]) – input cost (project cost + tariff per household per year)	WHO (2013); Water and Sanitation Extension Program (WASEP) of AKDN, Gilgit (personal communication, 20/11/2015)
Electricity	Market price	Net annual value = average units consumed per household per month × 12 months × total households × per unit rate	Government Water and Power Department (personal communication, 14/07/2015)
Cultural services			
Tourism	Net revenue	Annual net revenue from tourism = (number of tourists × net tourist spending per trip) + revenue from tourist entry fee – tourism management cost • National visitor = US$ 50/day • International visitor = US$ 75/day	Sharma et al. (2015) for method; USAID Firms Project (2014) for daily tourist spending; National Park Directorates for tourist data (KNP 08/02/2016 and QNP 09/02/2016)
Sports (trophy) hunting	Net revenue	Annual net revenue from trophy hunting = (total number of hunts [ibex, blue sheep] made in each community-managed conservation area × fee per bag) – management fee collected	Parks and Wildlife Department, Gilgit-Baltistan (2015)

Table 3.4, continued.

Ecosystem service	Valuation method	Assessment description	Source
Regulatory services			
Carbon sequestration	Benefit transfer	Annual benefit = area under cultivation and grassland × corresponding carbon sequestration index (CSI) × price per unit of CSI	Sharma et al. (2015); Grace et al. (2006), area under rangeland; ICRAF (2006), area under cultivated land; Green Climate Fund (2017), CSI and unit value

The rangelands, herbs and shrubs, and cultivated area (QNP = 57,899 ha; KNP = 286,888 ha), which made up about 55% of the total area of QNP and 41% of that of KNP were considered to estimate carbon sequestration. The carbon sequestration values estimated by Grace et al. (2006) for temperate grasslands and the value of cultivated vegetation estimated by ICRAF (2006) were applied to calculate the total monetary value of the carbon sequestration potential of the study area by putting US$ 5 on 1 tCO_2eq (GCF, 2017).

KNP and its buffer zone harbor good populations of Siberian ibex and blue sheep, while QNP's only wild ungulate species is ibex.

Trophy hunting has emerged as a conservation tool over the years in Gilgit-Baltistan and has been practiced in the buffer zones of QNP and KNP in designated CMCAs. The annual net revenue generated was calculated by subtracting the management fee (20%) from the total amount secured from trophy hunting in each CMCA (Table 3.3). The remainder (80%) of the net revenues generated goes to the communities to spend on collective civic needs (Shackleton 2001; Zafar et al., 2014; Nawaz et al., 2016).

CHAPTER 4: RESULTS

4.1 Estimation of occupancy and detection probability (Paper I)

A total of 109 accessible grid cells (KNP=21, BNP=14, QNP=24, CMCAs=50) covering a 2,725 km² area, an altitude ranging from 2,257m to 4,837m (average=3,737m) were surveyed. About half of the grid cells (n=533) in the study area fall in the high altitude (>5,000m) cold desert glaciated terrain and hence, were humanly inaccessible. Out of the 822 points (5x100m transects), an average of 7 points/grid were surveyed, and snow leopard signs were detected in 413 points, corresponding to a naive occupancy estimate (proportion of sampled units in which signs were detected) of 0.39. Accounting for imperfect detection resulted in a mean detection probability (*p*) of 0.37 (SE = 0.005) and an average occupancy (Ψ) estimate of 0.57 (SE = 0.02), 18% higher than the naive estimate. Snow leopard occupancy was higher in KNP than in QNP, Misgar-Chipursan (MC) Valleys, and BNP, respectively (Figure 4.1 & 4.2).

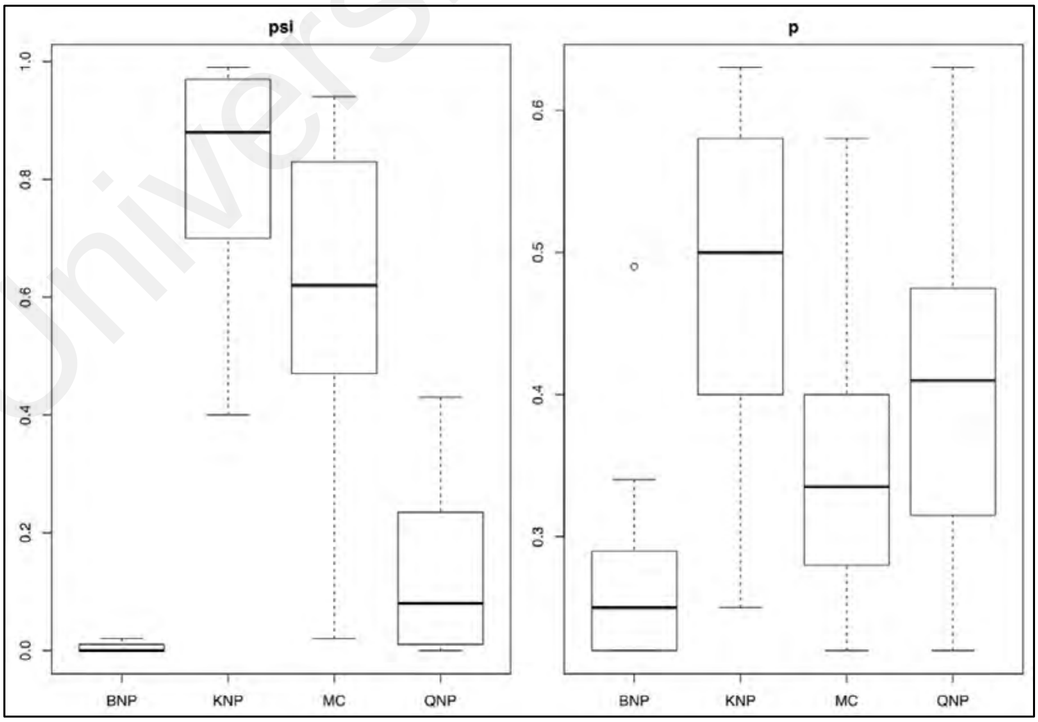

Figure 4.1: Average occupancy estimates and detection probability in different blocks of the study sites

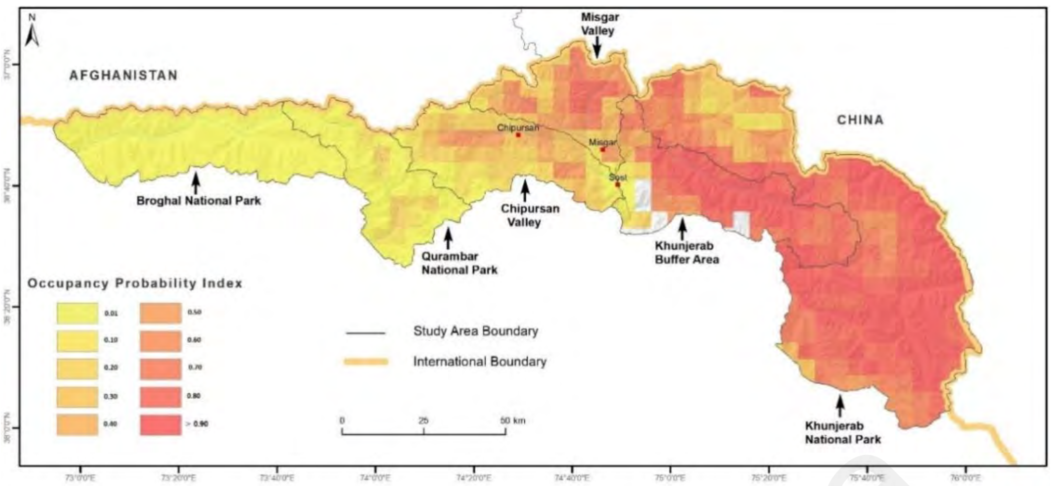

Figure 4.2: Distribution of snow leopard occupancy probabilities in the study sites

Out of the 11 site covariates and 7 survey covariates used to train the occupancy model, the effect of 4 site covariates and 2 survey covariates best explained the variations in snow leopard occupancy and detection probability across the study sites (Table 4.1).

Table 4.1: Results of multivariate model selection for estimating snow leopard occupancy (ψ) in the study sites

Model	K	AICc	ΔAICc	AIC wt	Model Likelihood	logLik
Ψ (Precipitation + Road + River + Ruggedness), p(Scrub + Barren)	8	558.78	0	0.28	1.00	542.78
Ψ (Precipitation + Road), p(Scrub + Barren)	6	559.68	0.9	0.18	0.64	547.68
Ψ (Precipitation + Road + Ruggedness), p(Scrub + Barren)	7	560.24	1.46	0.14	0.48	546.24
Ψ (Precipitation + Road + NDVI), p(Scrub + Barren)	7	561.34	2.56	0.08	0.28	547.34
Ψ (Precipitation + Road +Aspect), p(Scrub + Barren)	7	561.45	2.67	0.07	0.26	547.45
Ψ (Precipitation + Road + Altitude), p(Scrub + Barren)	7	561.6	2.82	0.07	0.24	547.6
Ψ (Precipitation + Road + Temperature), p(Scrub + Barren)	7	561.65	2.87	0.07	0.24	547.65
Ψ (Precipitation + Road + Settlement), p(Scrub + Barren)	7	561.67	2.89	0.07	0.24	547.67

The 2nd and 3rd best models also retained the same variables as that of the 1st model but with slightly different combinations. For instance, model 2 come up with Precipitation + Road as site covariates and Scrub + Barren as survey covariates. Similarly, model 3 retained 3 sites (Precipitation + Road + Ruggedness) and 2 surveys (Scrub + Barren) covariates. Since both the 2nd and 3rd models didn't come up with a new variable that was not present in the 1st model, the effect of the variables and their coefficients didn't change. Therefore, the first model is interpreted here. Snow leopard occupancy at the site level decreased with an increase in mean annual precipitation and mean density of roads, whereas increased with a corresponding increase in the availability of water sources. Similarly, the detection probability was higher in barren and scrub areas as compared to pastures and plateaus (Table 4.2).

Table 4.2: Estimates of β coefficient values for covariates (derived from the top model) assumed to influence snow leopard site use

Coefficients	β(s)	SE
ψ *(Intercept)*	-1.06	0.60
ψ (Mean annual precipitation)	-6.12	1.80
ψ (Mean density of roads)	-1.61	0.57
ψ (Mean density of rivers)	0.74	0.42
ψ (Mean ruggedness)	0.68	0.47
p *(Intercept)*	-1.25	0.24
p (Barren)	0.78	0.29
p (Scrub)	1.76	0.30

4.2 Spatial and temporal predation pattern and prey preferences (Paper II)

4.2.1 Predator occurrence and livestock holding

The snow leopard and wolf sightings by the respondents were used as validation of predator presence in the study sites.

This research took into account disease-caused livestock mortality and livestock losses to the wolf being the major sympatric species of snow leopard across its range. This helped to better understand the factors other than snow leopard that induce livestock losses and subsequent economic burden on the local communities. It is worth noting that the local communities attribute all livestock losses to snow leopards knowing that this is a species of conservation concern and they may get some compensation for their losses. Therefore, it was unavoidable to also consider other factors contributing to livestock losses in the study sites.

Average snow leopard sighting reports (number of sightings per year) were higher (1.6 ± 0.15) in Pakistan Pamir followed by Afghan Pamir (0.84 ± 0.20) and Tajik Pamir (0.40 ± 0.14), respectively. However, average wolf sightings across the three geopolitical regions had a comparatively reversed trend with the highest reports described from Afghan Pamir (13.3 ± 0.70), followed by Tajik Pamir (12.4 ± 1.31) and Pakistan Pamir (3.9 ± 0.32). Average livestock holding was higher in Tajik Pamir (92 ± 12.4) followed by Afghan Pamir (83 ± 10.6) and Pakistan Pamir (29 ± 2.5). Among livestock types, sheep and goats were preferred (83%) over large animals (17%).

4.2.2 Fixed and random effects retained by final model

The final nested-mixed effect model retained predator, time, prey sex, prey age and interaction of predator with time, total livestock owned, and wolf abundance (sighting) as the main effect (P-value = <0.05) to describe the predation patterns across the three geopolitical regions (Table 4.3). In addition, the standard deviations of random effects (season [SD= 7.35] and season-valley interaction [SD= 21.81]) were higher than that of the residual (SD = 4.91) explaining the random effects to be influential (χ^2=129.98, df= 1, P-value=<0.01) over predation count.

Table 4.3: Fixed effects of the final nested mixed effect model acquired through backward elimination at a significance level of <0.05.

	Df	Sum Sq	Mean Sq	F-value	P-value
Predator	1	9.101	9.101	9.101	<0.001
Time	2	132.19	66.096	66.1	<0.001
Prey. Sex	2	166.33	83.166	83.17	<0.001
Prey. Age	1	10.718	10.718	10.72	<0.001
Predator: Time	2	31.796	15.898	15.9	<0.001
Predator: Wolf	2	25.125	12.563	12.56	<0.001
Predator:Total Liv	2	34.38	17.19	17.19	<0.001

4.2.3 Spatial pattern of livestock predation

The data revealed considerable variation in the spatial pattern of livestock predation by wolves and snow leopards across the study sites. As illustrated by the model, the random intercept by valley significantly explained the variation in predation count.

Among the four valleys considered, the predation count in Wakhan valley (Afghanistan) was 20% higher than Misgar and Chipursan (Pakistan) and 43% higher than Tajikistan Pamir (upper left panel of Figure 4.3). Snow leopards as compared to wolves showed more variability of predation over the valleys (upper left panel in Figure 4.4) and maximum predation was detected in Wakhan valley followed by Chipursan, Misgar, and Pamir, respectively. In the case of the wolf, maximum predation was observed in Wakhan and minimum in Misgar valley.

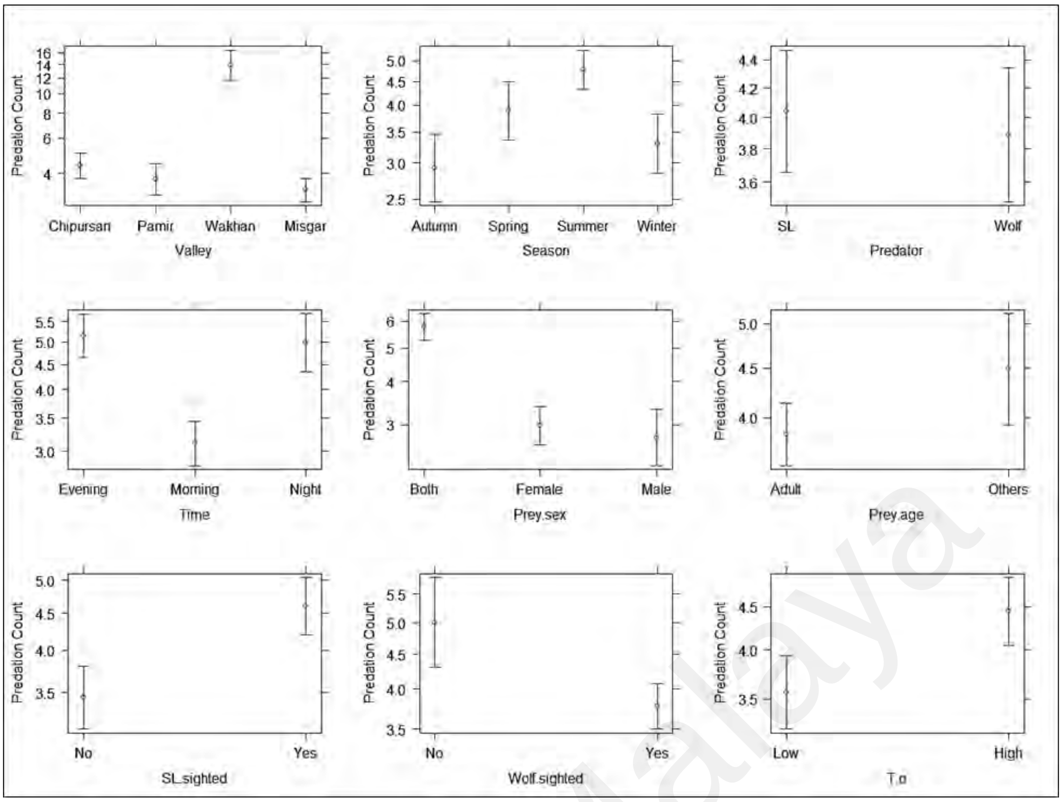

Figure 4.3: The distribution of considered factors in relation to predation count. The considered factors are valley, season, predator, time, prey sex, prey age, snow leopard sighting (SL.sighted), wolf sighting (Wolf.sighted), and total livestock owned (T.o) by respondents.

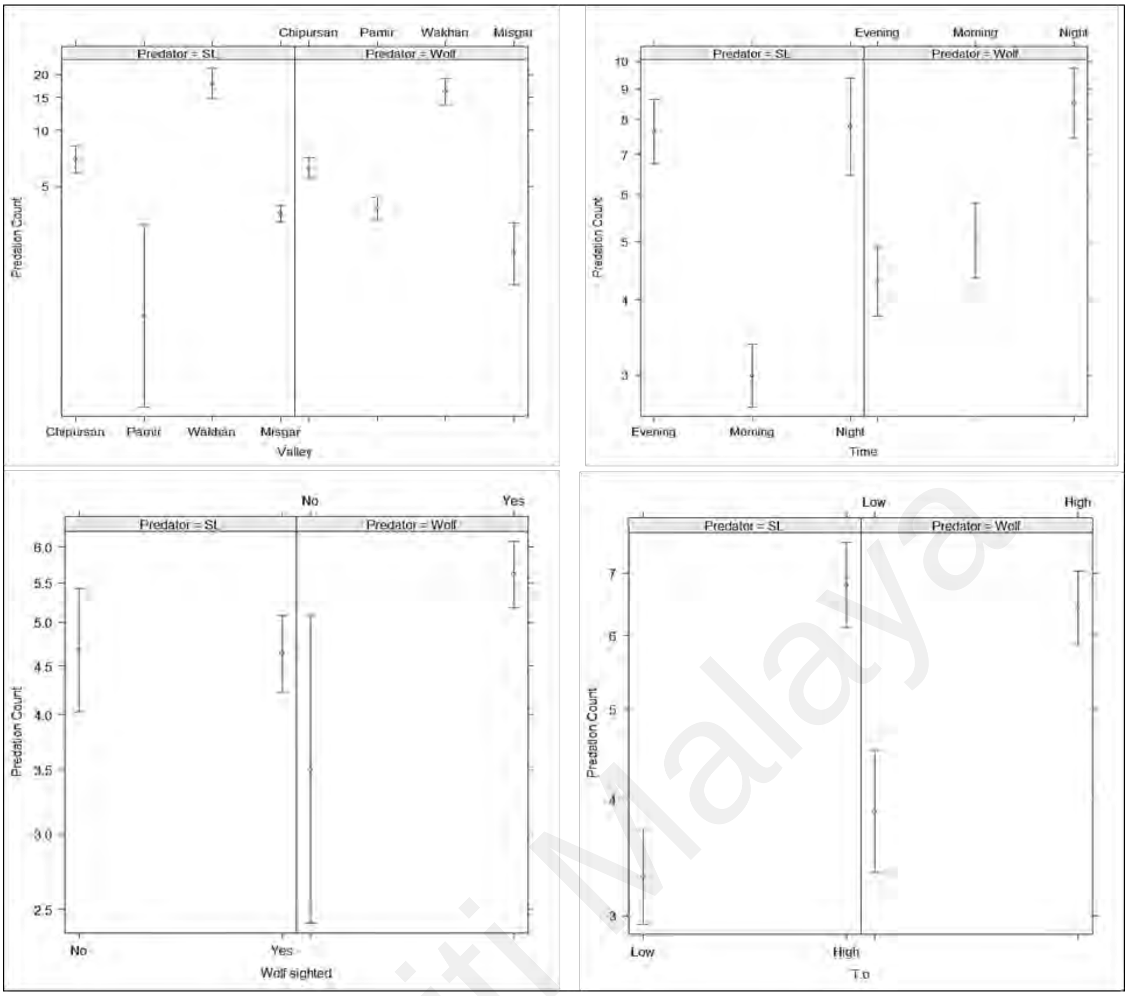

Figure 4.4: The influential interaction effect plot of predator and valley, predator and time, predator and wolf sighting, and predator and total livestock owned by the respondent.

4.2.4 Temporal predation trend

Livestock predation by snow leopards and wolves also varied temporally across the study sites (upper central panel of Figure 4.3). The predation incidences across the regions were high in winter than in spring, autumn, and summer seasons. However, the season and valley interaction plot (Figure 4.5) indicated that the predation rate changes across the valleys with seasons. Predation count was maximum in Wakhan valley during summer and minimum in spring. The predation trend found in summer was repeated in autumn. In the winter season, predation incidences were almost uniformly distributed across the valleys, as compared to spring, where Chipursan valley came up with the most predation count.

The distribution of time in relation to predation count is presented in the middle left panel of Figure 4.3. Most predation is observed at night time followed by evening and morning. The upper right panel of the influential interaction effect plot of predator and time (Figure 4.4) indicates that the snow leopard as compared to the wolf displayed more variability of predation over time. The number of predation events due to snow leopards was high in the evening and low in the morning. A different trend was observed in the case of the wolf, where a minimum predation count was observed in the evening.

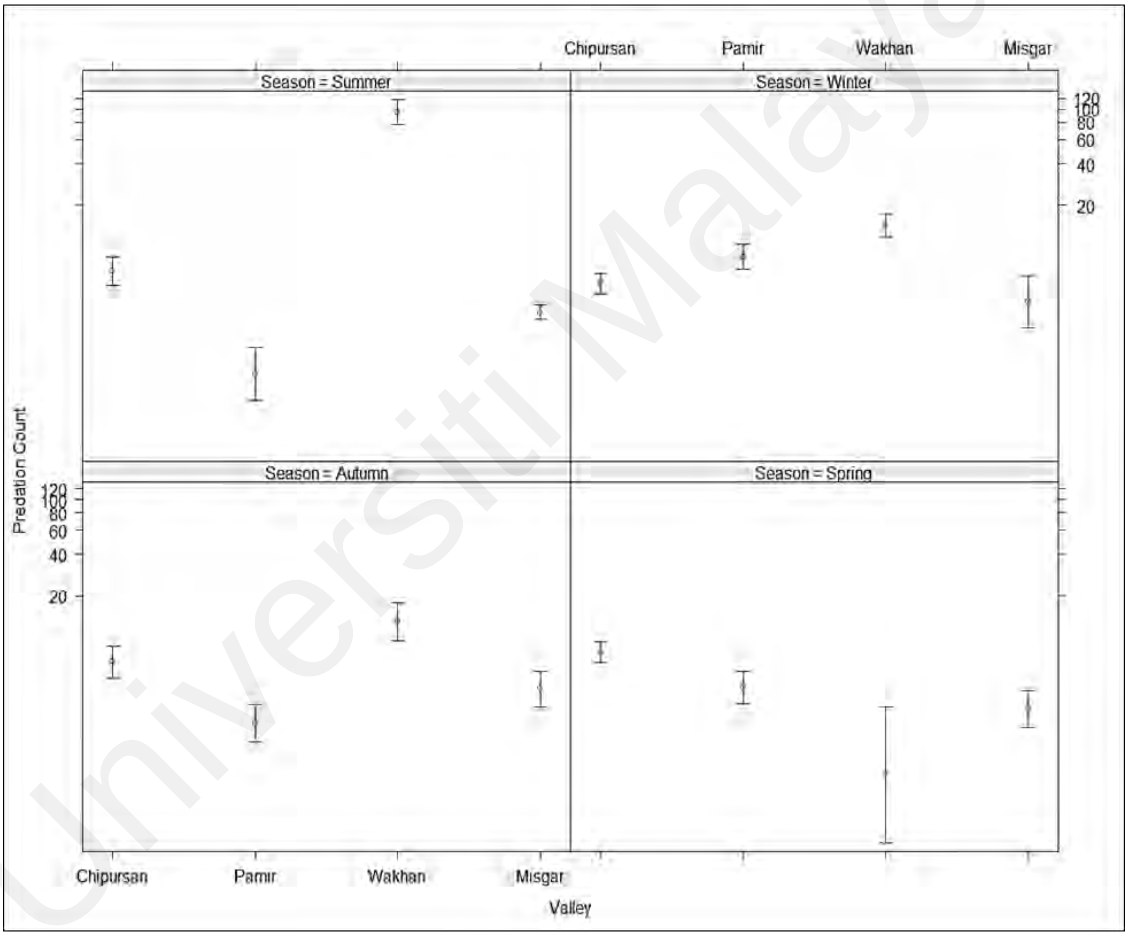

Figure 4.5: Interaction plot of seasons and valleys

4.2.5 Predators and prey preferences

The final model (Table 4.3) came up with prey age, sex, livestock owned, predator type, and abundance as the main effects. The distribution of prey sex in relation to predation count is presented in the center of the middle panel of Figure 4.3.

High predation count was observed in both sexes ($\overline{x} = 8.7 \pm 1.7$) while unique gender, i.e., male ($\overline{x} = 2.4 \pm 0.3$) and female ($\overline{x} = 3.1 \pm 1.1$) had the least predation. The distribution of prey age in relation to predation count is presented in the middle left panel of Figure 4.3. The least predation is observed with adult prey ($\overline{x} = 5.2 \pm 0.8$) while juvenile domestic animals had the maximum predation count ($\overline{x} = 8.8 \pm 1.9$).

The lower left panel in Figure 4.3, indicates that wolf predation is greater when wolf abundance is higher, and that snow leopard predation is lower when wolf abundance is high. The upper right panel of Figure 4.3 reads that wolf-induced livestock mortality is higher than the snow leopard. However, the predation rate increased with an increase in herd size (lower right panel of Figure 4.3) both for snow leopard and wolf across the three regions, through the variability of predation for snow leopard is noticeably higher than for the wolf.

4.3 Valuation of livestock, predation counts and public tolerance of predators (Paper III)

4.3.1 Social structure and livelihood system

A total of 182 informants and 278 data points focusing on the human-snow leopard conflict were used and the data collected is considered adequate to run analysis and draw conclusions. The average household size was 6.8 (SE = 0.7) while the average respondent age was 45 years (SE = 2.5). The difference in household size using Kruskal-Wallis (KW) test ($H = 2.0$, $DF = 2$, $p > 0.05$) and age groups ($H = 2.0$, $DF = 2$, $p > 0.05$) across the three study sites was not significant. Herders constituted 40%of the total respondents, farmers 23%, the general public 20%, wildlife guards 10%, and students/teachers 6%. Earning members per household ranged from 0 to 7 (mean = 3.8) while landholding per household varied from 0.05 to 3.8 hectares ($\overline{x} = 1.9$ hectares).

The majority of respondents had attended high school (42%), followed by the categories of illiterate (28%), college-educated (18%), and those having basic education (12%). The literacy rate was the highest in the Tajik Pamirs (100%), followed by the Pakistani Pamirs (73%), and the Afghan Pamirs (43%).

Informants reported holding some 10,068 animals in total (Table 4.4), with sheep constituting 55% (n = 5,526), goats 27% (n = 2,672), cattle 16% (n = 1,630), and other 2% (n = 241). Average herd size per household did not vary significantly among the three countries (H = 2, DF = 2, $p > 0.05$). Annual average livestock culling for domestic purposes was higher in the Tajik and Afghan Pamirs (4 animals) as compared to the Pakistani Pamirs (2 animals). Similarly, 1,831 animals (mean = 610) were marketed in one year (Table 4.4) with resulting revenues of US$187,777 (mean = US$62,592).

Table 4.4: Livestock holding, local consumption, and economic valuation of livestock owned by the respondents.

	Afghan Pamir	Pakistan Pamir	Tajik Pamir
Number of respondents	42	100	40
Total livestock owned	3,498	2,899	3,671
Average herd size	83	29	55
Total animals consumed locally per year	169	185	175
Consumption per household per year	4	2	4
Total animals marketed per year	963	393	475
Animals marketed/household/year	23	4	12
Total income generated in US$	76,105	45,943	65,729
Economic impact per household in US$	1,812	459	1,643

4.3.2 Livestock losses

This study revealed that snow leopards and wolves are the major causes of human-carnivore conflict in the Pamirs. Livestock losses to brown bears and lynx were very rare (< 1%).

Overall, 1,419 (315 per year and 1.7 per household per year) livestock were reportedly killed by snow leopards (47%) and wolves (53%) in the three study sites during the study period. Predation losses due to snow leopards were recorded as highest at 76% in the Pakistani Pamirs and 24% in the Afghan Pamirs. There were no reports of snow leopard predation from the Tajik Pamirs (Table 4.5). Wolf-induced mortality of livestock was the highest in the Afghan Pamirs (49%), followed by the Pakistani Pamirs (37%), and the Tajik Pamirs (14%). Mean mortality of livestock types induced by wolves varied significantly ($F = 3.8$, $P = 0.03$) across the study sites while snow leopard predation cases did not ($F = 1.4$, $p > 0.05$).

A total of 2,868 animals (637 per year) reportedly died in the Pamirs because of diseases during the study period of 4.5 years. Livestock losses per household per year were the highest in the Afghan Pamirs (7.0), followed by the Pakistani (2.7), and Tajik Pamirs (1.8). Sheep were found to be more susceptible to disease (45.3%) than goats (44.4%), cattle (10%), and others (0.4%). The average per-household loss (all study sites) estimated at 3.5 animals is considerably greater than the corresponding loss to predation (1.7 animals). Literature review reveals that wolf predation has been a major issue in the Tajik Pamirs (Izumiyama et al., 2009) and has been controlled lethally by the locals by paying hunters to kill them (Watanabe et al., 2010). Hence, no snow leopard predation was reported from the Tajik Pamirs.

Table 4.5: Livestock losses due to predators and diseases in the Pamirs during the period January 2008–June 2012

	Afghan Pamirs				Pakistani Pamirs				Tajik Pamirs			
	Total livestock	*Total killed*	*% Killed*	*Losses per HH*	*Total livestock*	*Total killed*	*% Killed*	*Losses per HH*	*Total livestock*	*Total killed*	*% Killed*	*Losses per HH*
Livestock												
Goat	598	169	32.1	0.89	1,490	450	57	1.00	584	15	15	0.08
Sheep	2,105	330	62.6	1.75	1,062	273	35	0.61	2,359	66	65	0.37
Cattle	634	2	0.4	0.01	282	32	4	0.07	714	2	2	0.01
Other	161	26	4.9	0.14	65	35	4	0.08	15	19	19	0.11
Total	3,498	527	100	2.79	2,899	790	100	1.76	3,672	102	100	0.57
Predator†												
Snow leopard		160	30.4	0.87		513	64.94	1.14		0	0	0
Wolf		367	69.6	1.99		277	35.06	0.62		102	100	0.57
Total		527	100	2.79		790	100	1.76		102	100	0.57
Disease‡		1,316	38	6.96		1,232	42.5	2.74		320	9	1.78

† Percentage of total livestock predation by snow leopard and wolf
‡ Percentage of total livestock killed by the disease

4.3.3 The economic value of livestock losses

Predation and diseases together constituted an economic loss of US$445,539 (US$99,009 per year) in the entire study area during the study period (Table 4.6). Predation-caused economic losses were estimated at US$156,654 (35%) whereas disease-caused losses accounted for US$288,885 (65%). Snow leopard-caused economic loss per year was estimated at US$14,801 (43%) whereas the figure for wolves was US$20,011 (57%). Predation-induced losses per household per year were the highest in the Afghan Pamirs (US$241), followed by the Pakistani (US$202), and Tajik Pamirs (US$113).

Table 4.6: Annual monetary losses (US$) incurred by Pamirians due to livestock depredation by predators and diseases.

	Afghan Pamir		Pakistan Pamir		Tajik Pamir		Total	
	Predation	**Disease**	**Predation**	**Disease**	**Predation**	**Disease**	**Predation**	**Disease**
Goat	5,915	15,470	42,750	69,445	1,560	10,400	50,225	95,315
Sheep	23,100	49,000	20,748	31,236	8,250	23,375	52,098	103,611
Cattle	526	44,447	10,656	28,305	626	10,329	11,808	83,081
Other	15,964	3,070	16,660	3,808	9,899	-	42,523	6,878
Total	45,505	111,987	90,814	132,794	20,335	44,104	156,654	288,885
Loss/year	10,112	24,886	20,181	29,510	4,519	9,801	89,208	64,197
Loss/hh	241	593	202	295	113	245	191	353

The average loss per household across the three sites was US$191 (Table 4.7). Similarly, disease-caused economic loss per household per year was the highest in the Afghan Pamirs (US$593) as compared with the Pakistani (US$295) and Tajik Pamirs (US$245). The average was US$353. Disease-induced livestock losses had been expected to affect the household economy more than predation-induced losses, but the mean economic loss due to either category did not vary much ($H = 2$, $DF = 2$, $p > 0.05$).

Table 4.7: Predator-specific monetary losses (US$) incurred by respondents in the study sites.

	Goat	Sheep	Cattle	Other	Total	Loss/ year	Loss/HH
Snow Leopard	29,500	21,422	7,992	7,692	66,606	14,801	81
Wolf	20,725	30,676	3,816	34,831	90,048	20,011	110
Total	50,225	52,098	11,808	42,523	156,654	34,812	191

4.3.4 Human attitudes toward predators

Nearly all respondents in Tajik Pamir, 95% in Afghan Pamir, and 90% in Pak Pamir considered wolves as more lethal to livestock than snow leopards. Consequently, 85% and 53% of respondents were in favor of reduced wolf and snow leopard populations, respectively. All the participants from Tajik and Afghan Pamir were found to have negative attitudes toward the wolf, whereas only 28% of the respondents from Pak Pamir were in favor of maintaining wolf populations. Public tolerance for snow leopards was comparatively better in the Tajik Pamirs where 82.5% of respondents were in favor of maintaining populations. Public tolerance of snow leopards in the Afghan and Pakistani Pamirs were 48% and 32%, respectively.

Education, number of earning family members, and family landholding were found to be good indicators of people's attitudes toward the snow leopard. For instance, teachers were in favor of preserving snow leopards 2.29 times more than people in other occupations. Similarly, an increase in the number of earning family members per household, and increases in family landholding resulted in 1.01 times (each) more positive attitude toward snow leopards. Furthermore, respondents who did spot snow leopards in pastures were 0.961 times less likely to support snow leopard populations compared with those who did not see them in pastures.

Similar factors influenced the public's attitude toward wolves in the study sites. Teachers' attitudes were 1.917 times more positive toward wolves than those of people in other occupations. Increases in family landholding and the number of earning family members resulted in 1.348 and 1.046 times more positive attitudes to maintaining wolf populations. Furthermore, public attitudes in the Afghan Pamirs were more negative toward wolves than in the other two countries (Table 4.8).

Table 4.8: Factors affecting attitudes toward snow leopards (*Panthera uncia*) and wolves (*Canis lupus*) in the study sites. (Parameters are estimated by the lasso regression model.)

	Intercept	Occupation: Teacher	Earning members	Land-holding	Snow leopard sighted	Education: Illiterate
Snow leopard						
Coefficient	-1.055	0.83	0.009	0.01	-0.031	-
Odds Ratio	0.348	2.293	1.01	1.01	0.961	-
SE	0.53	0.618	0.165	0.026	0.116	-
p-value	<0.000	0.016	0.043	0.046	0.023	-
Wolf						
Coefficient	-2.214	0.651	0.299	0.045	-	-1.213
Odds Ratio	0.109	1.917	1.348	1.046	-	0.297
SE	0.751	0.655	0.16	0.018	-	0.218
p-value	<0.000	0.001	0.019	0.044	-	0.008

4.4 Drivers of snow leopard poaching and trade (Paper IV)

A total of 101 poaching observations were recorded. The majority (87%) of the reported poaching incidences came from community surveys, followed by online observations (8%), departmental data (3%), and market surveys (2%), respectively. Data (n=101) was collected from 11 out of 14 federating units (districts) within the snow leopard range (Fig. 4.6).

Poaching incidences varied spatially (mean=9 ± 2.6 [95% Cl: 3 – 15]). The distribution of poaching incidences reported per 100 km² was higher in the Hunza district followed by Ghizer, Nagar, and Gilgit (Fig. 4.6).

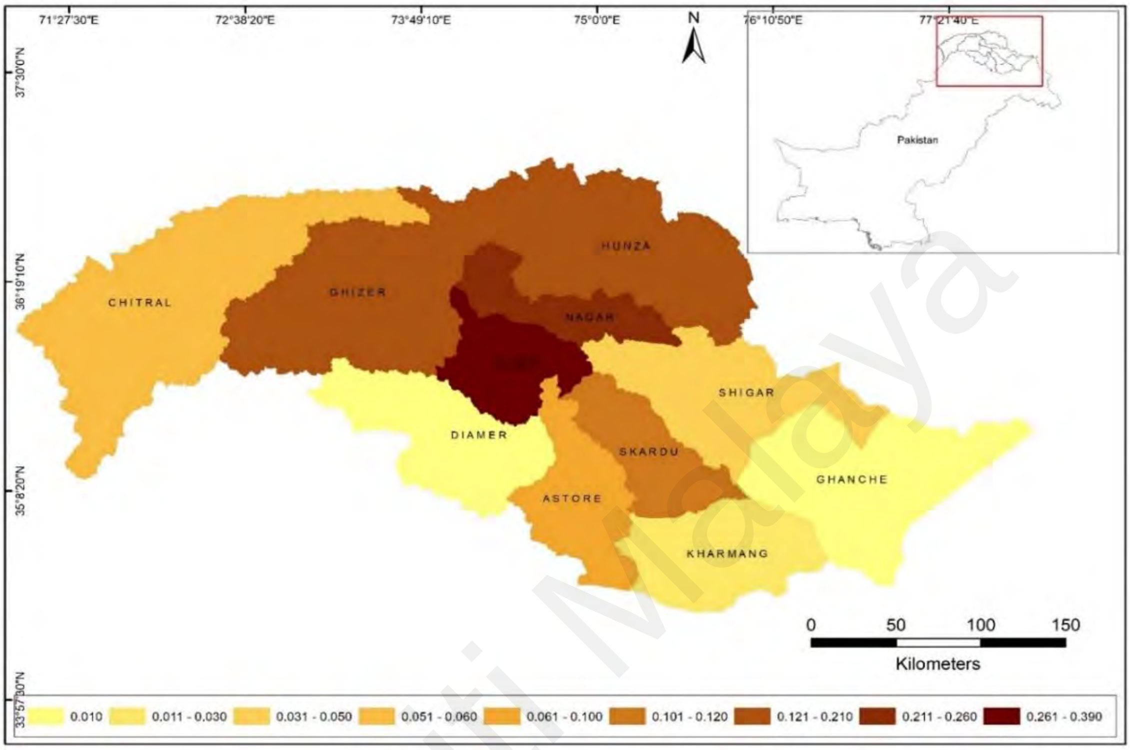

Figure 4.6: **Map of the study sites showing the intensity of snow leopard poaching per 100km² during the study period (2005-2017).**

Snow leopard poaching and trade rates also mixed temporally. Average poaching incidences per year were estimated as 7.8 ± 1.09 during the study period (2005-2017). Similarly, poaching was higher during the winter months with average reported cases of 4.5 ± 1.10 (Figure 4.7).

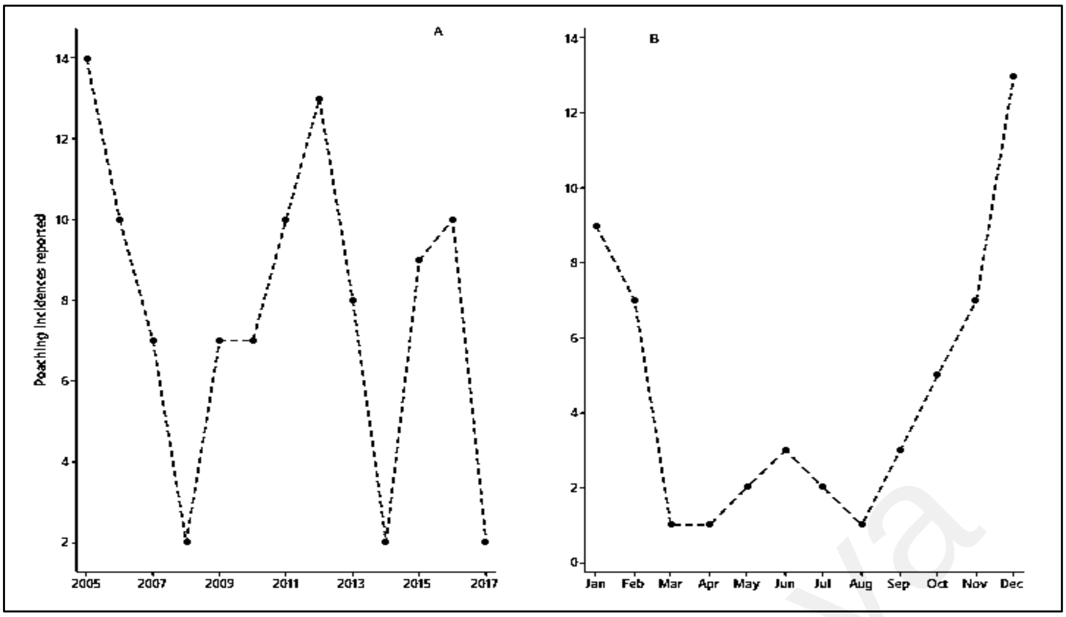

Figure 4.7: **Temporal distribution (A- Year-wise, B- month-wise) of poaching incidences recorded**

Poaching methods also varied (χ^2 [4, N = 101] = 138, $p < 0.05$). Shooting with the gun was most favored (66%) over poisoning (12%), snaring (12%), and live captures (4%), out of the total cases (n=101) reported. The rest (6%) of the cases (Figure 4.8) could not be confirmed. A significant variation (χ^2 [4, N = 101] = 152, $p < 0.05$) in the intention stimulating poaching was also noticed in this study. Factors fostering snow leopard killing included livestock defense (68%), trade (21%), stuffing for decor (5%), and self-defense (4%), respectively. Intentions behind poaching in the remaining 3% of the cases were not known (Figure 4.8).

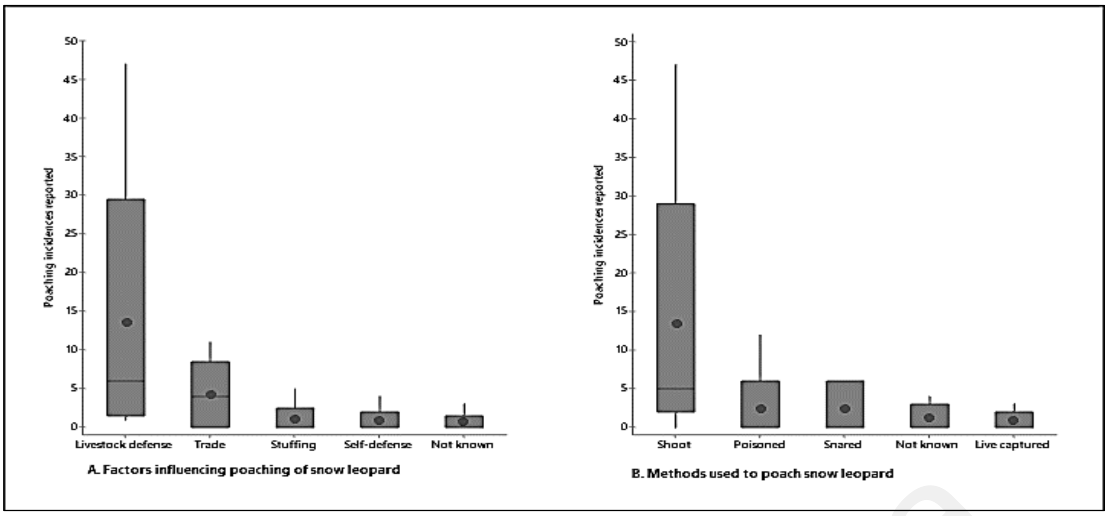

Figure 4.8: Poaching methods (B) and factors (A) influencing poaching of snow leopard

The majority of animals killed were adults (n=93), followed by subadults (n=6) and cubs (n=2). Similarly, out of the 101 poaching cases reported, 63 were male, 25 were female, and the status of the remaining 13 was unknown.

The base price (price offered at the poaching site) and end price (commercial markets in big cities) of the animals poached assorted significantly, t (21 = -2.8, $p < 0.05$). The average base price offered was 25,752 ± 3,824 PKR (245 ± 36 USD) and ranged from 1,000 PKR (10 USD) to 70,000 PKR (667 USD). Similarly, the average end price was calculated as 182,295 ± 54,583 PKR (1,736 ± 520 USD) and ranged from 13,500 PKR (129 USD) to 750,000 PKR (7,143 USD), respectively.

Data collected from the respective wildlife departments revealed that the strength of the field staff per 100km^2 was less than one personnel (Figure 4.9) and most of the staff lacked proper field gear and transport facilities.

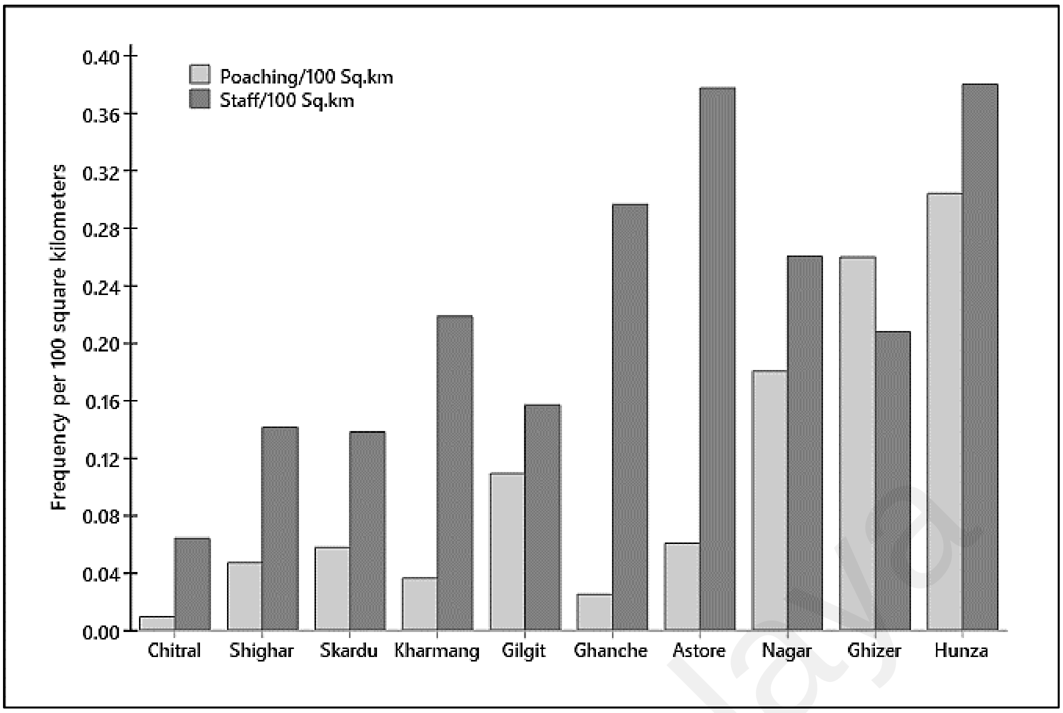

Figure 4.9: Comparison of the intensity of poaching and patrolling staff per 100 km in the study sites.

4.5 Valuation of the ecosystem services in a snow leopard landscape (Paper V)

4.5.1 The economic value of provisioning services

The findings of the study revealed that the mountain people collected a myriad of harvests from the 2 NPs. Table 4.9 shows the estimated annual economic worth of the provisioning services at the household level, in addition to the combined values of all households in the buffer zones of the 2 protected areas. Only QNP and KNP were compared for provisioning services mainly due to the lack of resources and time constraints. These two NPs represent two distinct ecosystems, the KNP being the cold desert and QNP being a more wetland ecosystem hence, worth comparing. The overall value of provisioning services was estimated to be approximately US$ 4.3 million per year for QNP, which translates into US$ 5673 per household per year, and US$ 1.8 million per year for KNP, equating to US$ 5384 per household per year. There was no significant difference in the mean value of provisioning services per household per year in QNP (mean = 630 6 264) and KNP (mean = 598 6 216), t (15) = 0.09, P = 0.92).

Table 4.9: Estimated annual economic value of provisioning services provided by QNP and KNP.

Type of provisioning service (PS)	Total annual value (US$)		Average value (US$/hh/yr)		Share in PS (%)		Dependent households (%)	
	QNP	*KNP*	*QNP*	*KNP*	*QNP*	*KNP*	*QNP (n = 1170)*	*KNP (n = 560)*
Crops	95,201	56,509	109	108	2.2	3.1	89	78
Fruits	65,751	69,468	154	247	1.5	3.9	63	58
Fodder	2,565,276	979,689	2,436	1,944	59.6	54.5	90	88
Medicinal plants	1,309	1,381	6	10	0.03	0.1	20	25
Fuel wood	505,440	177,660	432	540	11.7	9.9	94	59
Timber	11,839	5,667	405	405	0.3	0.3	75	60
Physical material	36,771	17,600	1,257	1,257	0.9	1.0	100	100
Domestic water consumption	966,643	462,667	826	826	22.5	25.7	100	100
Electricity	56,160	26,880	48	48	1.3	1.5	100	100
Aggregated value	4,304,389	1,797,520	5,673	5,384	100.0	100.0		

The provisioning services constituted about 92.87% (QNP) and 47.64% (KNP) of the aggregated value of the ecosystem services assessed in this study. Altogether, fodder, water, and fuelwood made up about 93% of the total provisioning services measured in this study for both NPs (Figure 4.10).

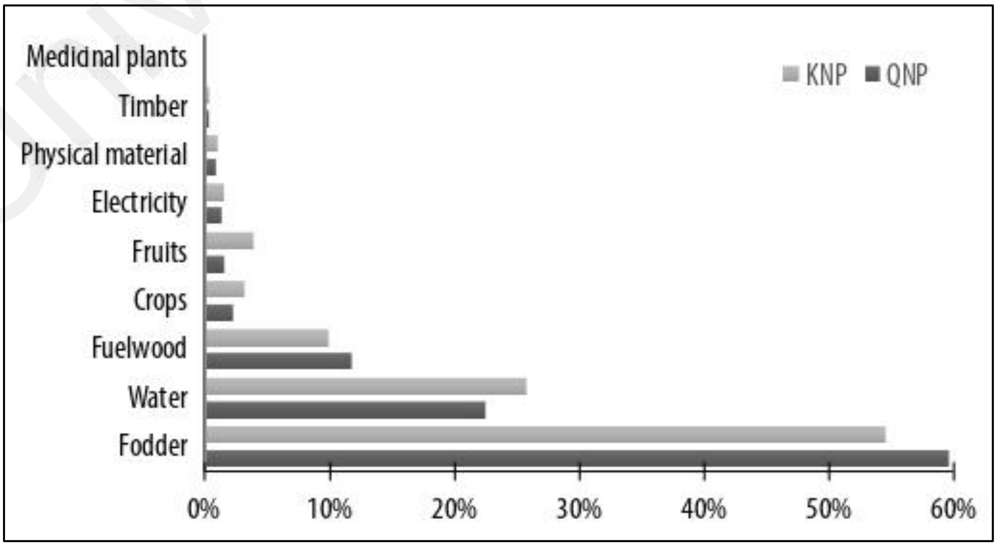

Figure 4.10: Relative contributions of each provisioning service type in QNP and KNP.

4.5.1.1 Agriculture (crops and fruits)

An average annual net return value of US$ 109 and US$ 154 per household per year for crops and fruits in QNP and US$ 108 and US$ 247 per household per year for KNP were estimated, respectively, after deducting average input costs, which were assumed to be 60 and 30% of the gross value of crops and fruits, respectively (Tables 4.9 & 4.10). Constituting about 63–89% (QNP) and 58–78% (KNP) of subsistence farming, the net annual value raised from harvests and fruits in QNP and KNP was estimated at US$ 160,951 and US$ 125,977, respectively. This accounted for 3.7 and 7% of the total value of provisioning services, respectively.

4.5.1.2 Fodder

Livestock rearing constitutes a major source of livelihood for mountain communities (Din et al., 2017; Khan et al., 2014), and up to 90% of households were engaged in pastoral practices for subsistence. The average herd size was calculated to be 32 animals in QNP and 26 animals in KNP (Khan et al., 2014). Goats and sheep made up the bulk (QNP = 70%; KNP = 75%) of the total livestock owned (QNP = 33,696; KNP = 13,250), followed by cattle, yak, and equines.

The livestock depends heavily on the rangelands and alpine pastures of the NPs and the buffer zones for their food requirements. The net total value of forage was estimated to be US$ 2.57 million and US$ 0.98 million per year for QNP and KNP, which translates into US$ 2436 and US$ 1944 per household per year, respectively. This represented about 59.6% (QNP) and 54.5% (KNP) of the total provisioning services considered in this study (Table 4.9).

4.5.1.3 Medicinal plants

Although both NPs are rich in medicinal plant diversity, most locals were unaware of these. Hence, a few households (20 in QNP and 25 in KNP) reported collecting medicinal plants, mostly for local use.

Thus, the value of the medicinal plants was not significant (US$ 6–10 per household per year) in the provisioning services measured in this study (Table 4.9).

4.5.1.4 Fuelwood, timber, and other physical material

The net annual value of fuelwood was estimated to be US$ 0.51 million and US$ 0.18 million per year and US$ 432 and US$ 540 per household per year for QNP and KNP, respectively. This constituted 11.7% (QNP) and 9.9% (KNP) of the total provisioning services considered in this study (Table 4.9).

Similarly, most local construction needs were met by growing poplar trees in plantations and a collection of Salix, birch, and juniper trees from local forest patches. The total worth of timber was calculated to be US$ 11,839 per year for QNP and US$ 5667 per year for KNP, which translates into US$ 405 per household per year for both NPs investigated. In addition, locals collected stone, sand, and gravel from the buffer area of the NPs for construction purposes. These had a net annual value of US$ 36,771 per year for QNP and US$ 17,600 per year for KNP (Table 4.9).

4.5.1.5 Domestic water benefits

All households in the buffer zones of QNP and KNP relied on snow or glacier meltwater for domestic use. This amounted to US$ 0.97 million per year for QNP and US$ 0.46 million for KNP, or about 22.45%(QNP) and 25.73% (KNP) of the net value of provisioning services (Table 4.9).

4.5.1.6 Hydropower

The buffer communities have access to cheap hydroelectricity produced locally through small hydropower plants. The monetary impact per household per year was calculated to be US$ 48 for both NPs, with a net worth of US$ 56,160 per year in QNP to US$ 26,880 in KNP.

4.5.2 The economic value of cultural services

4.5.2.1 Ecotourism

The aggregate gain from the tourism sector was estimated to be US$ 150,720 per year in QNP and US$ 1,162,384 in KNP (US$ 41–43 per tourist per year), which constituted about 3.25% (QNP) and 30.81% (KNP) of the total ecosystem services valued (Table 4.10).

4.5.2.2 Trophy hunting

A total of 21 ibex and 5 blue sheep were offered for trophy hunting in KNP during 2014–15, which accounted for net revenue of US$ 46,789, translating into US$ 84 per household per year. Similarly, 5 ibexes hunted in QNP generated a net income of US$ 2925, which equated to US$ 2.50 per household per year (Table 4.10).

4.5.3 The economic value of regulatory services

4.5.3.1 Carbon sequestration

The total value of carbon sequestered by rangelands, herbs and shrubs, and cultivated areas in QNP and KNP was estimated to be US$ 176,813 and US$ 766,108 per year.

This translates into US$ 151 and US$ 1368 per household per year, respectively (Table 4.10). In aggregate, this accounted for 3.81% (QNP) and 20.31% (KNP) of all ecosystem services measured (Table 4.10).

4.5.4 Aggregated economic values

The overall economic benefits from the provisioning services considered in this study were approximately US$ 4.6 million per year for QNP and US$ 3.8 million per year for KNP (Table 4.10). This translates into US$ 5,955 per household per year in QNP (1,200 households) and US$ 8,912 per household per year in KNP (560 households). Furthermore, the spatial distribution of the value was higher in QNP (US$ 44/ha) than in KNP (US$ 5/ha).

The economic benefits generated from provisioning services were highest in both QNP (93%) and KNP (48%), followed by cultural services (QNP = 3%; KNP = 32%) and regulatory services (QNP = 4%; KNP = 20%).

Table 4.10: Aggregate economic value of ecosystem services provided by the QNP and KNP.

	Total value (US$)		**Average value (US$/hh/yr)**		**Share in total ESs assessed (%)**	
Ecosystem services	**QNP**	**KNP**	**QNP**	**KNP**	**QNP**	**KNP**
Provisioning services	4,304,389	1,797,520	5,673	5,384	92.87	47.64
Cultural services						
- *Ecotourism*	150,720	1,162,384	129	2,076	3.25	30.81
- *Trophy hunting*	2,925	46,789	3	84	0.06	1.24
Regulatory services						
- *Carbon sequestration*	176,813	766,108	151	1,368	3.81	20.31
Total economic value (TEV)	4,634,848	3,772,801	5,955	8,912	100.00	100.00

CHAPTER 5: DISCUSSION

5.0 Discussion

A lack of understanding of the ecology, threats, and conservation needs of the free-ranging large carnivores is contributing to the decline of their populations worldwide (Winterbach et al., 2013). The snow leopard is one of the threatened apex predators found across 12 range countries of South and Central Asia in sympatry with other carnivores, such as the grey wolf and wild sheep and goats (Hameed et al., 2020). The current applied study provides important and up-to-date informative data that shall enhance the understanding of snow leopard ecology (published as Paper I), its conflict with humans (published as Papers II and III), poaching and trade (published as Paper IV), and socio-ecological attributes of the snow leopard ecosystems (published as Paper V) in one of the least explored and hard to reach transborder regions of Pamir Mountain Range.

5.1 Determinants of snow leopard occupancy and management implications

This study was the first-ever attempt to understand the distribution and factors inducing the site use and detection probability of snow leopards at the landscape level in the Pamir. The results of this study reinstate that the habitat characteristics such as cragginess and water sources best explain the occurrence of snow leopards in the study areas. These findings are in line with the studies conducted in other parts of the snow leopard range (Bai et al., 2018; Liu et al., 2013; McCarthy et al., 2005; Wolf and Ale, 2009) supporting that potential habitat features of snow leopard remain constant across its range. Moreover, anthropogenic activities and precipitation were found to have a negative impact on the occupancy of snow leopards. Other studies (Bai et al., 2018; Li et al., 2016) on snow leopards have also come up with similar findings.

Available knowledge about the snow leopard's distribution pattern is limited (Robinson & Weckworth, 2016) and hardly 30% (3.26 million square kilometers) of the range has been explored, so far (McCarthy et al., 2016). Remote landscapes and the secretive nature of the species in tandem with the bureaucratic and geopolitical barriers (Hunter et al., 2016) are some of the factors restraining ecological research across the snow leopard range. This study confirmed the occurrence of the snow leopard in a myriad of protected area networks in the Pamir bordering China and Afghanistan, and thus added to the limited body of knowledge on snow leopard ecology.

Snow leopard occupancy varied within the study sites, and occupancy estimates were highest in KNP followed by the Misgar and Chipursan (MC) Valleys, QNP, and BNP. The suitability of the habitat, diversity of wild and domestic prey (Khan et al., 2016), and improved surveillance in place, may have resulted in higher occupancy values in the national park. The MC valleys are adjoining to the KNP and harbor similar geographies such as rugged and broken rocky outcrops and scrub patches, favored by snow leopards (Fox & Chundawat, 2016) while, BNP and QNP are mainly characterized by high-altitude wetland ecosystems.

The valleys of MC were recently established as Community Managed Conservation Areas (CMCAs), a lower IUCN PA category (VI) than the national park (Dudley et al., 2013); primarily to foster trophy-hunting of the ibex. The dynamics of the human-snow leopard conflict assessed in this study (published as Papers II & III) discovered a high intensity of conflict in the valleys and concluded that the exiting PA status is insufficient to safeguard the subsistence of snow leopard. Resultantly, it is recommended that the CMCAs should be de-notified and annexed with the KNP by expanding the boundary of the park to ensure the survival of snow leopards in this landscape. The spillover effect resulting from the proposed management measures will likely enhance the dispersal of snow leopards in the adjacent national parks of QNP and BNP, as well.

A significant portion of the Pamir Mountain Range falls in the 20 model landscapes identified under the GSLEP to achieve the global goal of “securing 20 by 2020” (Snow Leopard Working Secretariat, 2013). The findings of this study may be incorporated in the zonation of the landscapes into the priority conservation areas and the multiple-use areas while formulating the landscape management plans.

This study was conducted in the Pamir trans-border region and the findings confirm that this landscape constitutes promising habitat for snow leopards. Since wildlife species do not distinguish international boundaries (McCarthy et al., 2007), it is a prerequisite to undertake similar studies in the adjacent landscapes in Afghanistan, China, and Tajikistan to produce a holistic species occupancy and habitat suitability map for the Pamirs. This will foster materializing regional cooperation for the conservation and provide logic for the establishment of transboundary PAs as was realized in the international workshop organized in China in 2006 (Moheb & Paley, 2016).

5.2 Spatiotemporal pattern of livestock depredation in the Pamir

A study of the dynamics of the human-snow leopard-wolf conflict through questionnaire surveys of the remote agropastoral communities residing in the Afghan, Tajik, and Pakistan Pamir Mountain ranges revealed that both snow leopard and wolf are often reported across the three regions and subsequently, have a negative effect on the rural economy of the region. Additionally, there is substantial seasonal and temporal disparity in livestock depredation by wolves and snow leopards across the study sites. Livestock is considered a currency in this region and variation in the predation patterns can be ascribed to the livestock rearing system, availability of pastures, and abundance of wildlife (Ostrowski et al., 2007). The coexistence of wildlife and livestock, especially large carnivores are crucial in maintaining fragile high-altitude ecosystems intact.

This can be accomplished by integrating livestock management into conservation planning and instigation of predation compensation and mitigation measures in pastoral settings like Pamir (Tyrrell et al., 2017).

5.2.1 Predation trend at the spatial scale

At the spatial scale, the predation rate was higher in the Wakhan valley. Being the transhumance herders, livestock is an important financial resource for the Wakhis and with the passage of time, grazing in the summer rangelands has increased significantly in the Wakhan corridor (Mock et al., 2007). Barter systems prevail, goods collected in winter are repaid in livestock in summer, and without keeping a large number of animals, the pastoral communities cannot break the debate cycle (Mock et al., 2007). People keeping a large herd of livestock (>200) are called "*boi*", which is considered a sign of prestige. However, rearing a large herd of livestock requires sufficient manpower and money and the lack of these resources, results in slack management of animals, making them susceptible to attack by predators. When herders lose their animals, they react and kill snow leopards and wolves in retribution (Li & Lu, 2014; Namgail et al., 2007). For instance, about 10 snow leopards were reportedly executed in Wakhan in a period of five years, due to the predation on livestock (UNEP & FAO, 2003). Besides, spatial drift in livestock predation by wolf and snow leopard can also be subjected to the density of predators, habitat suitability (Wielgus & Peebles, 2014), the abundance of wild prey, and their competition with livestock for forage and livestock management pattern in the study sites (Johansson et al., 2015). Wakhan corridor has been a stronghold of snow leopards (Mishra & Fitzherbert, 2004) and this elusive cat has instigated human-wildlife conflict in the region by being involved in the surplus killing of livestock (UNEP & FAO, 2003). Simms et al. (2011) have also reported high snow leopard capture rates from Wakhan Valley.

Similarly, camera trapping studies in Pakistan Pamir reflected Chipursan-Misgar valleys as a suitable habitat for snow leopards (Snow Leopard Foundation, unpublished data). The snow leopard predation on livestock in the Tajik Pamir was not noticed in this study, which could be due to the limited data available from the valley, though recent studies on snow leopards in the Tajik Pamir confirm the presence of snow leopards (Saidov et al., 2016).

5.2.2 Temporal predation pattern

This study marked that predation cases in the three transborder regions were higher in the winter season. The cold desert mountain ecosystem and harsh weather conditions in tandem with the livestock-rearing system explain this notion. The temperature dropped down to -20°C in the Pamir during the winter months (Ostrowski et al., 2007). Heavy snowfall conceals the vegetation cover and wild prey such as marmots hibernate, paving way for snow leopards and sympatric predators to come close to predator-prone winter corrals (UNEP & FAO, 2003). Out of ten snow leopard prosecutions reported (UNEP & FAO, 2003), five were killed inside the livestock pens in Wakhan. Similarly, a snow leopard was captured by the villagers in Misgar valley in 2017, after being involved in back-to-back predation incidences and the killing of about 30 animals (SLF unpublished data, 2017).

The study also revealed that valley-season interaction explains variation in the predation trend and Wakhan come up with higher predation reports in the summer. This pattern can be subjected to the transhumance system in place and can be overcome by improving the livestock management system. Khan et al. (2018) suggests considering the impact of climate change, which causes an upwards shift in the snow and tree line and brings predators and livestock into closer proximity.

Livestock is housed in the open corrals and at night opportunistic predators like snow leopard easily enter these pens, which results in the excessive killing of animals. The findings of this study show that livestock predation incidences are higher at night and evening, which reflects the behavior of snow leopards and wolves, and a similar pattern is reported in other studies (Johansson et al., 2015) across their range.

5.2.3 Prey Preferences by the Predators

Sheep and goat mortality due to predation by snow leopards and the wolf were higher (91%) as compared to large animals such as yak and cattle (9%), which is consistent with similar studies (Anwar et al., 2011; Khan et al., 2014) undertaken in the snow leopard region. The proportionally higher predation rate in the case of sheep and goats may be due to the fact that these animals are comparatively easier to catch and prey upon than the yak and cattle (bulls and cows). Moreover, yaks and cattle have comparatively larger body weights, for instance, an adult yak can weigh up to 180 kg and they have long pointed horns to defend themselves from predators. Studies on the snow leopard diet undertaken in the Himalayas (Shrestha et al., 2018) have also come up with similar findings. Snow Leopards consume about 1.5 kg of meat per day and a total of about 20-20 adult ungulates per year (Schaller et al., 1988). An adult sheep or goat thus meets the dietary needs of a snow leopard for about three weeks. Another scenario is the rampant increase in the livestock population owing to the increase in the human population and resultantly decrease in the biomass of wild ungulates (less than 5% of the livestock biomass) in Central Asia as observed by Johansson et al. (2015). The increased population of domestic ruminants with comparatively limited predator avoidance skills results in higher mortalities due to predators.

In other cases, livestock constituted 66-75% of the snow leopard and wolf diet in the Karakoram (Bocci et al., 2017), while in the Himalayas (Chetri et al., 2017) domestic animals were less frequently (24-27%) consumed than their relational availability. This underpins that prey ingestion by large carnivores differs geographically and calls for site-specific conservation and management measures (Chetri et al., 2019).

In contrast to other studies (Khan et al., 2014; Li et al., 2013) losses of mature livestock were lower as compared to young animals in this study. Moreover, mixed herds were more affected than single-sex herds. This is logical as juvenile animals' predator avoidance skills are comparatively least developed and are more prone to predator attack.

5.3 Predation intensity, valuation of losses, and public tolerance of predators

This study examined the intensity of livestock depredation by snow leopards and wolves across the three geopolitical regions, the economic impact of livestock mortality due to diseases and predators, and subsequent public attitude and perception of the predators. Factors influencing public tolerance of the snow leopard and wolf were also assessed in detail.

5.3.1 Predation intensity and valuation of livestock losses

This study demonstrated that livestock mortality per household per year due to the snow leopards and wolves was 2.8 animals in the Afghan Pamirs, followed by 1.76 in the Pakistani Pamirs, and 0.6 in the Tajik Pamirs. Predator-induced livestock mortality has been reported to cause losses of 1–12 heads per household, on average (Hussain, 2000; Jackson & Wangchuk 2001; Li et al., 2013; Mishra, 1997; Oli et al., 1994; Schaller et al., 1987) across South and Central Asia, and 1–2% in the Wakhan belt (Ostrowski, 2007; Habib; 2008).

The findings of this study also depict that predation caused livestock mortality (1.78 animals per household per year, on average) and institute major threats to livestock and eventually to the rural economy (US$191 per household per year) in the Pamir. However, the mortality of livestock due to diseases, which is estimated at an average of 3.5 animals per household per year with an economic impact of US$352 surpasses the former. This is mostly overlooked in studies aimed to consider the dynamics of the human-livestock-carnivore interface. Available studies on this topic (Dar et al., 2009; Habib, 2008; Li et al., 2013; Ostrowski, 2007) support this notion. The government-supported animal husbandry and health facilities are scarce in the region and the pastoral communities cannot afford expensive vaccines and medicines to control the most prevalent and contagious diseases or to cure diseased livestock.

The disease and predation caused economic impact was higher in Afghan Pamir followed by the Pakistani and Tajik Pamirs. This variation reflects the remoteness of these landscapes and the lack of suitable socioecological measures (Fitzherbert & Mishra, 2003) to manage the issue. The agro-pastoralist communities of the Pamir heavily depend on livestock rearing (Schaller, 1998) as a major source of family income and market/cull surplus animals for day-to-day family monetary needs (Ostrowski, 2007). Moreover, livestock slaughter is a social compulsion on the occasion of family bereavements and weddings. The slaughtered animals are also offered to spiritual leaders "Pirs" (Mock et al., 2007). The estimate of the income generated from yearly livestock consumption in the Pamir is about US$187,777 or about US$1,313 per household per year.

These numbers are vital for the assessment of the economic pressure faced by the remote communities living below the poverty line (Ehlers & Kreutzmann, 2000; Hurni & Breu, 2003) and the loss of animals due to predators and the diseases further impair the living of the families and create hatred toward carnivores.

5.3.2 Public tolerance of snow leopards and wolf

The majority of the informants alleged snow leopards and wolves proved fatal for livestock and subsequently, desired to reduce their populations. Wolf was the least tolerated carnivore in the Afghan and Tajik Pamirs, while the snow leopard was less endured in Pakistan, Pamir. Factors influencing public attitude towards large carnivores are logical because livestock and subsistence farming constitute the major portion of family income in the Pamir and any threat to the scarce livelihood means is not welcomed. The education level in these remote valleys is very low. Education plays an important role in equipping people with conservation-friendly attitudes and practices. Educational activities aimed to develop public support for wildlife and its conservation is important in circumstances where the economic return for livestock losses by carnivores is not possible (Sillero-Zubiri & Laurenson, 2001). For example, informal education activities in Africa have significantly reduced the number of cheetahs removed by farmers per year (Marker et al., 2003). Other studies (Holmern et al., 2007) acclaim conservation education to increase public acceptance of predators. In this study, the educated people, as well as the comparatively well-off families, displayed positive attitudes towards the large carnivores. The findings of this study also suggest that poverty is one of the key factors that negatively influence predator conservation in Pamir. Thus, the conservation of large carnivores in the study sites requires concrete conservation actions to counterbalance predator-induced economic losses and instruct a sense of stewardship for carnivores.

5.4 Drivers of snow leopard poaching and trade

5.4.1 The intensity of snow leopard poaching and trade

This study revealed that poaching and trade continue to be one of the major threats to snow leopards in Pakistan, as much as across other range countries (Maheshwari & Niraj, 2018).

About 8 snow leopards were reportedly poached and traded per year, which constitutes 2-4% of the available guestimated total snow leopard population (200-420) in the country (Din et al., 2016). It is believed that the snow leopard population may start declining if the annual mortality rate is >21% (Chapron & Legendre, 2002). Besides, only a population of >15 females could endure a poaching rate of 1 individual every 2 years (Li & Lu, 2014). Application of the theorem to our findings reflects that 2-4% annual population loss would seemingly not affect the snow leopard population in the country. However, documentation of the poaching and trade in iconic species, such as snow leopards, is highly difficult due to the secretive nature of the business, fear of reporting incidences, and lucrative monetary benefits associated with the illegal wildlife trade. Secondly, reliable estimates of the snow leopard population are not available for the country (Ale & Mishra, 2018). Therefore, it is difficult to ascertain what is the exact contribution of poaching to the annual mortality of snow leopards in the country.

Contrary to the results of the current study, the TRAFFIC report (Nowell, 2016) based on an expert survey estimated 23-53 snow leopards being poached annually in Pakistan, which constitutes 12-13% of the estimated population in the country. Previous studies conducted in the global range of snow leopards (Nowell, 2016) and some neighbouring countries (Li & Lu, 2014; Maheshwari et al., 2016) relied on internet searches, market, and expert surveys. In this study, the communities living alongside snow leopards have been included in the data collection to enhance the accessibility and reliability of the data. Studies aimed to investigate sensitive issues such as poaching and trade in iconic species have management implications and must be planned with utmost care to ensure meticulous interpretation of the outcomes.

5.4.2 Spatial and temporal distribution of snow leopard poaching and trade

Spatial distribution and intensity of the poaching of snow leopards measured in this study can be subjected to access and availability of data, socio-ecological drivers such as the abundance of snow leopards, the status of prey, effectiveness of surveillance system, and intensity of human-carnivore conflict (published as Paper III/ Din et al., 2019), respectively. At a temporal scale, poaching incidences increased in the winter months. This is the time when snow leopards descend to lower altitudes following their wild and domestic prey and adapt to the comparatively smaller landscape triggering mass livestock predation incidences (published as Paper II/ Din et al., 2017). Moreover, the mating season starts in winter (December-March), which is characterized by vocalization and marking (Fox & Chundawat, 2016). Thus, the climate and behavioral response of snow leopards make them prone to poachers and susceptible to poaching in the winter months.

5.4.3 Factors influencing poaching and trade in snow leopards

Just like other parts of the snow leopard range (Nowell, 2016; Theile, 2003), the retaliatory killing for predation on livestock remains the major driving force behind snow leopard poaching in Pakistan followed by trade, for home décor, and perceived self-defence. Human-snow leopard conflict has been a major socio-ecological issue in Pakistan resulting in a loss of up to two (2) animals per household, per year, with an economic impact of more than 200 USD per household (published as Paper II/ Din et al., 2017). Direct killing is, thus, driven by: (a) the protection of livestock, which constitutes a major source of income for the communities in the snow leopard range, and (b) trade in fur or other body parts.

The latter, most of the time ends up in the marketing of fur or even the whole carcass (Theile, 2003), although retaliatory killing and poaching for trade are difficult to differentiate (Li & Lu, 2014).

Motivation in the remaining cases was for decorative pieces and other luxury items. EIA (2012) and Li & Lu (2014) have reported a shift in snow leopard poaching towards luxury products.

5.4.4 Methods used for poaching snow leopards

The findings of this study suggest that the frequently used method of poaching snow leopards is shooting in Pakistan, which is supported by other available studies (Nowell, 2016). While, poisoning and the use of snare are second and third among the common methods, respectively. However, where the intention of killing was trade, foot traps were preferred over shooting (Theile, 2003). In Pakistan, shooting and hunting guns are not banned, one needs a license from the wildlife department and people usually carry guns to the high pastures, which makes it easier to use instead of other means of poaching. Secondly, snares need more technical skills and can be easily detected by field staff of government departments. Therefore, it is necessary to consider stricter regulations for shooting guns, while devising conservation measures for snow leopards in the country.

5.4.5 Potential trade routes and markets

Snow leopard pelts and other body parts were reportedly transported to big cities such as Peshawar, Islamabad, Rawalpindi, and even Lahore and Karachi (Khan, 2002a) for onward shipment to the Middle East and other countries (Khan, 2002b). Similarly, poached animals or parts were also reportedly transported to China. Since Pakistan shares a long open border with Afghanistan, pelts, and trophies of snow leopards and Marco Polo sheep were reportedly smuggled to Pakistan as was reported in previous studies (Theile, 2003).

5.4.6 Efficacy of the available laws

Snow leopards are protected animals in Pakistan under the CITES and provincial wildlife laws. However, a detailed analysis of the updated Wildlife Acts of the range provinces revealed that one can shoot snow leopards and any other carnivore in self-defence or defending livestock from a reasonable distance. Moreover, the maximum monetary penalty proposed for killing a snow leopard is around 275 USD (45,000 PKR) or three years imprisonment or both. The monetary penalty is less than the monetary value of the snow leopard pelt in the local market. It is reckoned that the maximum average market price for a snow leopard was 1,736 USD (182,295 PKR) and the minimum average price received was 129 USD (13,500 PKR) in 29 reported cases.

Law enforcement and strict regulations alone may not produce the required outcome for controlling snow leopard poaching when multiple socio-ecological factors like the rarity of the species, high incentives for poaching, and higher demand for the parts of the animal are operating (Carter et al., 2014). Despite the operational constraints such as limited staff strength; i.e., <1 personnel/100km^2, lack of appropriate equipment, gear and transport facilities in tandem with complex and ever-changing combination of smuggling routes and concealments used by the traffickers to evade detection by enforcement agencies, the provincial wildlife departments are doing well. In August 2020, two poachers were caught red-handed and were fined 5 million PKR (>30,000 USD) each, along with imprisonment for one year in Hopper Valley of northern Pakistan (https://www.dawn.com/news/1572824).

5.5 Worth of ecosystem services in the mountain ecosystems

This study estimates that the annual monetary value of the ecosystem services measured in QNP and KNP is US$ 4.6 million and US$ 3.8 million, which equates to US$ 5,955 and US$ 8,912 per household per year.

Thus, both these national parks are of enormous importance for the sustenance and subsistence of the mountain communities living in the remote valleys.

Although this study takes into account only 3 types of ecosystem service, the perceived economic effect per household per year in the PAs is about 10 (QNP) to 15 times (KNP) higher than the mean annual household income of US$ 600 (World Bank, 2011). It is thus foreseen that dependency on natural resources will result in increased degradation of the ecosystems. Appreciation of these ecosystem services in the preparation of management agendas and policies is crucial for the sustenance of the people and the resources. The economic impact generated from the provisioning services itself was comparatively higher (QNP = US$ 5,673 and KNP = US$ 5,384) than those described from the rest of the snow leopard landscapes. For example, provisioning services are worth an estimated US$ 4,125 in the Himalayan Landscape in Pakistan, US$ 3,964 in the Hemis–Spiti Landscape of India (Murali et al., 2017), and US$ 818 in the Koshi-Tappu Wildlife Reserve, Nepal (Sharma et al., 2015). This difference may result from the type of services studied, resource use patterns, and the dearth of substitute livelihood bases. An appraisal of the provisioning ecosystem services (PES) measured across the mountain ecosystems is vital to developing a holistic understanding of direct assistance from nature.

5.5.1 Provisioning ecosystem services

In this study, fuelwood, fodder, and local water consumption together instituted 90–94% of all PS measured. The rangelands of the national parks and their buffer zones support around 47,000 livestock (QNP = 33,696 & KNP =13,250), in addition to wild ungulates, such as ibex, Marco Polo sheep, and blue sheep (Khan, et al., 2016). As there is no reliable info available on the carrying capacity, resilience, and climate change impact on the rangelands (Khan, et al., 2016) of the NPs, these numbers are distressing and necessitate tangible management measures.

The hasty growth in population (human and livestock) in the neighborhood of the NPs has increased the reliance of the people on ecosystem services. Subsequently, the resources are rapidly draining out (Khan et al., 2013). The area of KNP (703,881 ha) is larger than that of QNP (105,808 ha), but the number of households depending on the natural resources in KNP (n = 560) is much lower than in QNP (n = 1,200). Hence, QNP is more vulnerable to human-induced deterioration than KNP. All the households in both KNP and QNP used spring and stream water sources. Both NPs have glaciers and high-altitude lakes, which account for 41–59% of the total area and institute major freshwater sources and supply for the locals dwelling in the buffer zones of the PAs and beyond. Water is also used to run hydropower, which is essential to reduce communities' reliance on high-altitude forests to meet the energy needs of the households; thus, water forms an important ecosystem service (Fu et al., 2014). In spite of the high potential for hydropower generation, this important resource is under-utilized.

5.5.2 Regulatory and cultural ecosystem services

The roles of regulatory (carbon-sequestration) and cultural services were also evaluated in this study. In KNP, regulatory services established about 20% of all the services measured in this study.

The effect of cultural services was substantial in KNP. A total of 28,260 tourists visited KNP in 2015, making a total income of US$ 1.16 million per year and US$ 1,661 per household per year. However, despite its immense potential, QNP is less developed than KNP, and income made from tourism remains on the edge. Together with trophy hunting of ungulates, cultural services accounted for 32% of the total services appraised in this study. Proper planning, management, and regulation of tourism by involving locals could boost the tourism business.

Despite criticism of its ethical and moral inferences, trophy hunting of wild ungulates as a conservation tool was introduced in northern Pakistan in the 1990s and has since, proved to be an effective measure for conservation-linked livelihood improvement (Nawaz et al., 2016; Shackleton, 2001; Zafar et al., 2014).

Out of the income produced from trophy hunting, 80% goes straight to the communities, which has collected up to US$ 4.05 million (US$ 1.4 million in GB and US$ 2.65 million in KP) during the period 1998 to 2015 (Nawaz et al., 2016). Furthermore, a trickledown effect of trophy hunting has to be determined. For instance, in the Karakoram–Pamir, humans and wildlife species, such as snow leopards, sympatric carnivores, and ungulates, share high-elevation ecosystems. Predators, like wolves and snow leopards, often kill domestic animals, causing monetary losses of more than US$ 200 per household per year (published as Paper II/ Din et al., 2017; published as paper III/ Din et al., 2019; Khan et al., 2014). In such a situation, the trophy hunting package as a conservation measure has facilitated enhancing public acceptance of carnivores and has provided a significant cash injection into the local economy with reckoning wildlife conservation benefits in the longer run (Nawaz et al., 2016).

CHAPTER 6: CONCLUSION

This is an applied and management-oriented study on the ecology and conservation issues and management implications of the snow leopard − a threatened, comparatively less understood apex predator found across the twelve countries of South and Central Asia. The global range of snow leopard falls in Pamir, Hindu Kush, Karakoram, Himalaya, Tian Shan, Kunlun, and Altai Mountain Ranges and this is the first-ever study pitched in the remote and unexplored transborder region of the Pamir and, thus, adds to the existing knowledge about the majestic cat.

Specifically, this current study identified key factors affecting the relative abundance and occurrence patterns of snow leopards and enlisted the main drivers of human-carnivore conflict besides investigating the illegal poaching and subsequent trade in snow leopards. Lastly, a comprehensive overview of the ecosystem services provided by the snow leopard ecosystems is evaluated to highlight and realize the importance of the snow leopard range for the mountain society sharing the ecosystems with carnivores. In this section, the main findings of the study are summarized along with the limitations and recommendations for future research.

The sign-based occupancy surveys provide a cost-effective approach to estimating site use of snow leopard and merit replication. The findings of the study also underpin that expansion and effective management of protected areas (PAs) along with the promotion of transboundary efforts in the Pamir is a prerequisite to secure the regional and national goals of snow leopard conservation endorsed by the 12 range countries by adopting the Global Snow Leopard and Ecosystem Program (GSLEP) agenda of "Securing 20 by 2020". The understanding of occupancy and abundance can further be improved by conducting surveys using camera traps and genetic sampling and repeating the surveys over different seasons.

Being remote and rugged terrain, the Pamir landscape provides limited livelihood opportunities to the local communities. The majority of the communities are pastoralists and mainly depend on livestock for their living. The snow leopard and sympatric carnivores such as the wolf prey on the livestock which often results in retaliatory killings of the predators. The conflict can be minimized by initiating predation mitigation (i.e., predator-proof corrals, grazing management), and compensation measures (i.e., livestock insurance schemes). The findings of this study revealed that disease-caused mortality of livestock was significantly higher than predation-caused losses. Minimizing livestock mortality due to diseases through periodic vaccination and deworming will not reduce livestock losses and improve local livelihood but also halt the transmission of diseases from livestock to wildlife. Other livelihood-linked conservation measures such as the improvement of rangelands through reseeding and water conservation and the value addition of local handicrafts will enhance public tolerance of predators in the region.

Snow leopard faces threats of poaching and persecution not only in revenge for livestock depredation but also for illegal trade to gain adequate revenue. Loopholes in the existing Wildlife Laws and Acts coupled with weak surveillance systems and lack of transboundary cooperation mechanisms further worsen the situation. This can be improved by updating the existing laws and strategies and developing transboundary cooperation mechanisms including the establishment of a transboundary PA network in the region. At the provincial and national levels, the menace of illegal wildlife trade can be checked by improving the wildlife surveillance systems through the allocation of more funds, induction of field staff, and equipping them with the necessary skills and gear.

Results of the current study also suggest that the livelihood and sustenance of mountain communities are dependent on ecosystem services, especially on the provisioning of ecosystem services for food, water, pastures, fodder, medicines, timber, hydropower, and important minerals. Sustainable harvesting of wild ungulates and tourism also play a key role in the rural economy in the study sites. The ecosystem services, thus, need to be realized while formulating conservation and management plans in these landscapes. The promotion of community-based ecotourism will help boost conservation efforts and generate much-needed revenues for the local people. Lastly, this study also necessitates considering the tradeoff between economic development and nature conservation while initiating pure developmental projects in these fragile landscapes.

The field studies focusing on wildlife species, especially large carnivores require ample resources, both financial and human, and involve longer commitment to fieldwork. The importance and vital findings from this research have been affirmed, however admittedly, there were limitations mostly imposed by the lack of resources. One shortcoming was not being able to expand the studies other than the investigation of the dynamics of the human-carnivore conflict in the transborder regions of Afghanistan and Tajikistan. Subsequently, undertaking similar studies across the transborder region of the Pamir is recommended to have a holistic overview of the snow leopard distribution and conservation issues across these landscapes.

Other important aspects that can be looked at in future endeavors are studies focusing on population estimates, the interaction between livestock and wild ungulates, and the assessment of the resilience and carrying capacity of rangelands and pastures grazed by wild ungulates and livestock.

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